

The Effect of Parameter Laser Markin and Immersion Time on Laser Marking Quality and Corrosion Rate of Stainless Steel S304LL Grade 2B in Seawater

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Abstract

Corrosion is the term for damage to metallic materials brought on by the metal's contact with its surroundings. This procedure uses high-power laser radiation to create permanent markings while also altering the material's surface structure. But a material's vulnerability to corrosion can also be impacted by laser marking, especially when 304L stainless steel is exposed to saltwater. This study aims to identify the laser marking parameters, the impact of immersion time on laser marking quality, and the rate of corrosion of 304L stainless steel in saltwater. This study employed a 90-day immersion period. A laser marking method was used to mark the surface of 304L stainless steel. Quality testing was made possible by analyzing the material's weight loss following the laser branding procedure. A laser marking method was used to mark the surface of 304L stainless steel. The quality of the laser marking was evaluated by measuring the weight loss of the material following the immersion procedure. The degree of corrosion on the material's surface is indicated by this weight loss. According to the research results, when the stainless steel surface has corroded, the ideal parameters-Power 10%, Frequency 10 kHz, Speed 500 mm/s, and immersion duration-can impact the quality of laser marking. For example, after 90 days of immersion in seawater, the corrosion rate for 304L stainless steel was 0.000003160 mpy.

Keywords

Weight Loss, Fiber Laser Marking, Stainless Steel 304L, Sea Water, Immersion Time

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1. INTRODUCTION

Stainless Steel 304L is widely used in various industries, such as automotive, aerospace, construction, and others. Because of its strength, corrosion resistance, and ability to withstand different environments. The Export of stainless steel slabs grew from 302919 tons in 2017 to 459502 tons during January-September 2018, while stainless steel HRC surged from 324108 tons to 877990 tons in the same period (Boillot and Peultier, 2014; Pauliuk et al., 2013; Rossi et al., 2024). Stainless steel 304L is one type of stainless steel that has good mechanical strength and corrosion resistance. Numerous businesses, particularly the shipping and maritime sectors, make extensive use of this material (Radhamani et al., 2019; Reclaru et al., 2025). However, using stainless steel 304L in seawater-containing situations might cause corrosion problems that shorten the material's lifespan and reduce its performance (Shokri and Fard, 2022).

Damage to metal materials from a reaction between the metal and its surroundings, which produces metal oxides,

metal sulphides, or other reaction products generally referred to as rusting, is called corrosion (El Maghfiroh et al., 2019; Tian et al., 2022). Therefore, the problem of rusting needs to be addressed. The improvement of material properties, which can be achieved by mixing metals with other metals that have higher qualities, is one way to combat corrosion. For instance (Qian et al., 2015). Because it includes at least 18% chromium and 8% nickel, stainless steel, as it is often called, is a corrosion-resistant steel variety. Because it includes at least 18% chromium and 8% nickel, stainless steel, as it is often called, is a corrosion-resistant steel variety. Because it includes at least 18% chromium and 8% nickel, stainless steel, as it is often called, is a corrosion-resistant steel variety. Because it includes at least 18% chromium and 8% nickel, stainless steel, as it is often called, is a corrosion-resistant steel variety. The corrosion-resistant properties of stainless steel do not automatically make it immune to corrosion, because in reality, stainless steel can experience grain boundary corrosion, crevice corrosion, and stress corrosion cracking. Although (Kothari, 2017).

Fiber Laser Marking is a technology that can be used

to mark metal surfaces with high speed, high precision, and without damaging the surface (Korakana et al., 2020). This process uses a laser light focused on the surface of the workpiece, thereby leaving a permanent mark on the metal surface (Cioboata et al., 2021). However, some studies indicate that the fiber laser marking process can affect the corrosion resistance of 304L stainless steel, as the fiber laser marking process generates high temperatures that can damage the surface of the stainless steel (Lazov, 2015; Łęcka et al., 2016). One way to test corrosion resistance is by measuring the corrosion rate, which is the speed of mass or thickness reduction of the material due to chemical reactions with the surrounding environment (Mekonnen, 2026). In a seawater environment, stainless steel 304L can be subjected to electrochemical corrosion caused by the presence of oxygen, chloride, and moisture. This corrosion can damage the passive protective layer on the surface of the material and reduce its corrosion resistance (Dong et al., 2013). Additionally, when the surface of 304L stainless steel is exposed to heat from the laser marking process, changes in the material's microstructure can occur, which may affect its corrosion properties (Pacquentin et al., 2015; Švantner et al., 2016).

The process of using intense laser energy to alter the surface structure of materials and create permanent marks. However, laser marking can also affect the corrosion quality of the material, especially when stainless steel 304L is exposed to seawater. The process of using intense laser energy to alter the surface structure of materials and create permanent marks. However, laser marking can also affect the corrosion quality of the material, especially when stainless steel 304 is exposed to seawater. This is supported by the existence of a company that produces spoons made of 304L stainless steel with a branding process using fiber laser marking, which causes corrosion on the part of the spoon that has been marked. In a seawater environment, stainless steel 304L can be subjected to electrochemical corrosion caused by the presence of oxygen, chloride, and moisture. This corrosion can damage the passive protective layer on the surface of the material and reduce its corrosion resistance (Liu et al., 2021). Additionally, when the surface of 304L stainless steel is exposed to heat from the laser marking process, changes in the material's microstructure can occur, which may affect its corrosion properties (Yoo et al., 2023).

The process of using intense laser energy to alter the surface structure of materials and create permanent marks. However, laser marking can also affect the corrosion quality of the material, especially when stainless steel 304 is exposed to seawater (Yang et al., 2023; Yoo et al., 2025). This is supported by the existence of a company that produces spoons made of 304L stainless steel with a branding process using fiber laser marking, which causes corrosion on the part of the spoon that has been marked.

This research aims to investigate the effect of immersion time on the quality of laser marking and the corrosion rate

of stainless steel 304L in seawater media. With the problem limitations used; 1. The material used, 2. The effect of Fibre Laser Marking on corrosion, 3. Using seawater as a corrosion medium, 4. The corrosion test is conducted using the immersion method based on weight loss. 5. Duration of immersion. It is hoped that the results of this research can provide a better understanding of the interaction between laser marking, immersion time, and the corrosion rate of stainless steel 304L in an industrial environment.

2. MATERIAL AND METHODS

This research was conducted with the aim of determining the effect of soaking time on the quality of laser marking and the corrosion rate of stainless steel 304L in seawater media.

2.1 The Stainless Steel with Laser Marking

In this study, Stainless Steel will be cut into a square shape, after which the surface of the specimen will be cleaned by polishing. Then, the specimen will be laser marked using the MAX M5 Box 20W laser marking tool with parameters speed 400, frequency 20, power 60, space 0.05. As shown in the image 2.1 below It is known that the higher the power, frequency, and speed of the laser, the greater the damage received on the surface of the material. The surface damage of the material can be seen in the SEM test in Figure 3.

2.2 Salinity Testing

In this study, the immersion medium used seawater taken from Makarti Village. Testing the salinity level in seawater is necessary to determine the salt content in the water that will later be used as a soaking medium. The salinity test uses a device in the form of a C-100 A 5 in 1 salinometer. The result showed that the salinity content in seawater is 32.8 ppt (Parts Per Thousand), which means there are 32.8 grams of dissolved salt in one kilogram of seawater.

This salinity level plays an important role in accelerating the corrosion process of the laser-marked 304L stainless steel specimens. The high concentration of dissolved salt increases the availability of chloride ions (Cl^-) in the immersion medium, which act as a catalyst that speeds up the electrochemical reaction between iron and oxygen on the metal surface (El Maghfiroh et al., 2019). As salinity increases, the electrical conductivity of the seawater also increases, facilitating electron transfer between the anodic and cathodic sites on the specimen surface and thereby accelerating the overall corrosion rate. This effect becomes more pronounced in areas where the laser marking process has disturbed or removed the passive oxide layer, since chloride ions can more easily penetrate the exposed metal surface and react with the iron beneath it, forming soluble iron chloride compounds such as FeCl_2 and FeCl_3 . Therefore, the 32.8 ppt salinity value recorded in this study confirms that the seawater used as the immersion medium possesses



Figure 1. Sample Stainless Steel 304L Before Corrosion



Figure 2. Sample Stainless Steel 304L After Corrosion

sufficient ionic strength to represent an aggressive corrosive environment consistent with natural marine conditions.

2.3 Scanning Electron Microscopy

This SEM testing is conducted to observe the surface of the specimen that has undergone laser marking, as shown in the image below. After the surface of the stainless steel 304L has been laser marked, the surface of the specimen will erode due to melting and evaporation caused by the generated heat.

2.4 Calculation of Weight Loss

In this study, the corrosion rate calculation was performed using the weight loss method. Before calculating the corrosion rate, data on the weight loss of the specimen and the surface area of the specimen are first collected. This testing standard uses ASTM G31 (Testing, 2021). It can be seen from Table 1. above that after being soaked for 2160 hours, it was found that each specimen had experienced weight loss. This is due to the corrosion that has occurred on Stainless Steel 304L that has been laser marked and submerged in

seawater. Because laser marking can damage the protective layer that protects stainless steel from corrosion.

2.5 Calculation of Corrosion Rate

After obtaining the data on weight loss and surface area of the specimens, the next step is to determine the corrosion rate occurring on 304L stainless steel resulting from fiber laser marking with seawater immersion media.

$$CR = \frac{K.W}{A.T.\rho} \quad (1)$$

3. RESULTS AND DISCUSSION

In Figures 3.(a) and (b), the control samples at 500× magnification show that some parts of the specimen are damaged due to the heat from the laser marking process. and this damage is even more apparent at 1000× magnification. with some areas clearly showing damage caused by the laser marking process.

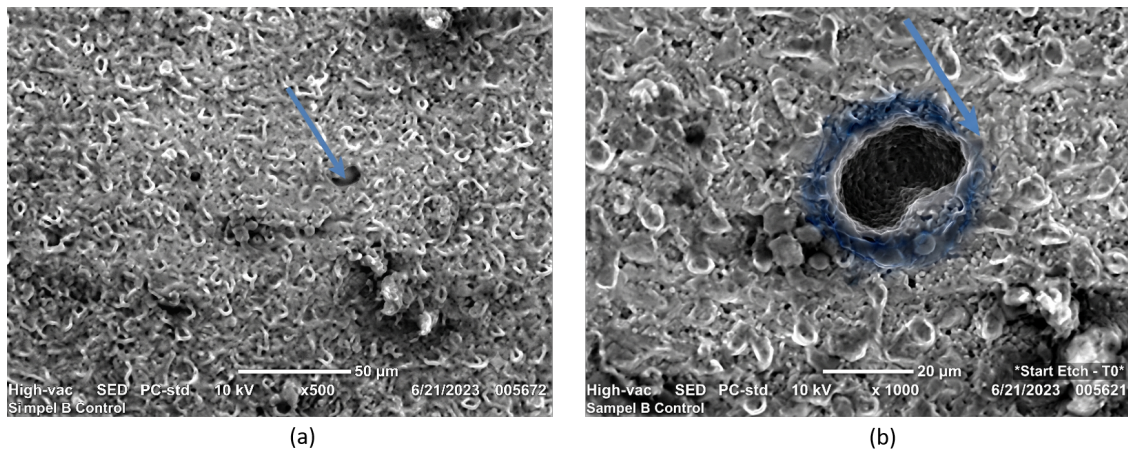


Figure 3. Observation Using SEM on the Magnification (a) 500 $\times$ and (b) 1000 $\times$.

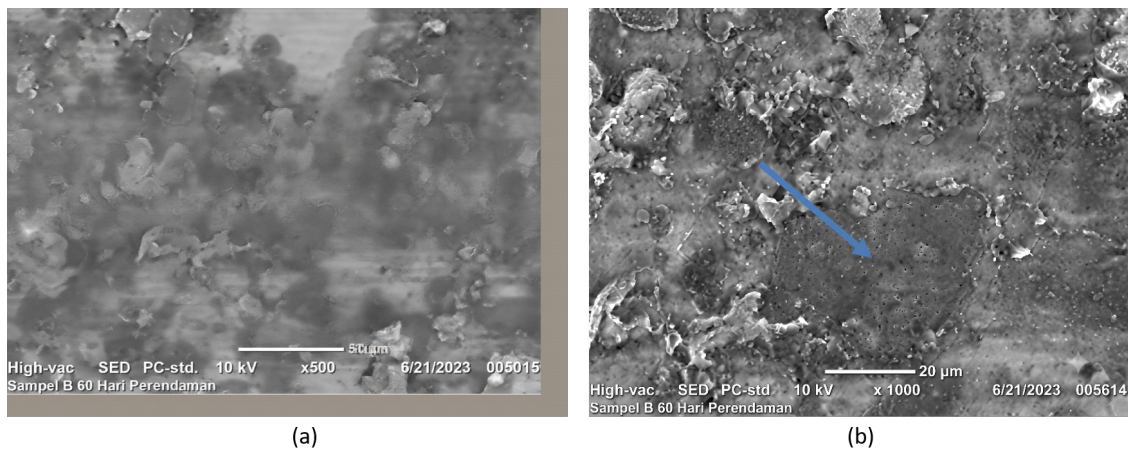


Figure 4. Immersion for 60 Days (a) Magnification 500 $\times$ and (b) 1000 $\times$

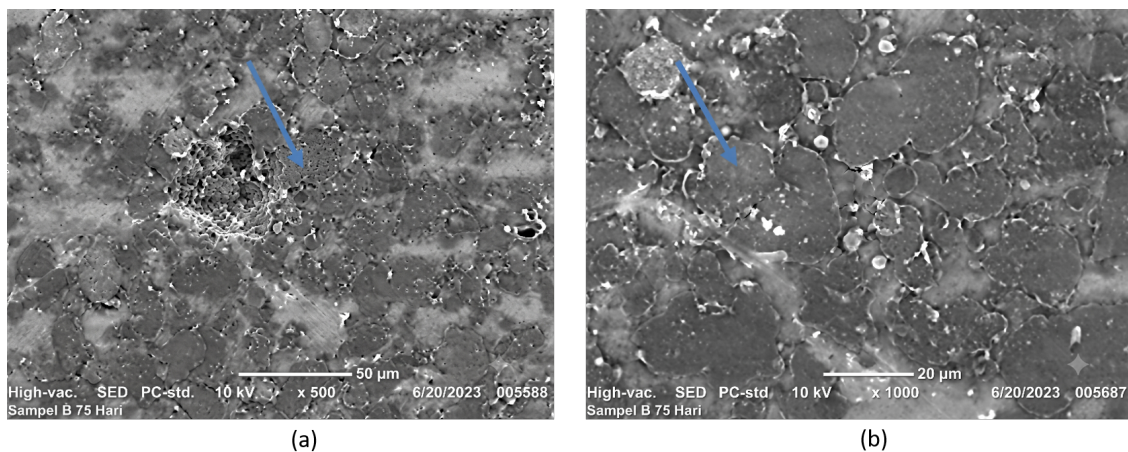


Figure 5. Immersion for 90 Days Magnification (a) 500 $\times$ and (b) 1000 $\times$

In Figures 4.(a) and (b), the samples that have been soaked for 60 days can be clearly seen to have undergone

significant changes compared to Figures 3a and 3b. It can be seen in the 500 $\times$ magnification that parts of the sample

Table 1. Weight Loss Data After Immersion 2160 Hours and Corrosion Rate

Initial Weight (gr)	Final Weight (gr)	Weight Loss (W) (gr)	AverageWeight Loss (W) (gr)	Time (T) (hour)	Area (A) (cm ²)	Corrosion Rate (mpy)	Average Corrosion Rate (mpy)
37.0547	37.0509	0.0038			24.143	0.000004864	
34.8743	34.8726	0.0017			22.667	0.000002318	
35.8765	35.8741	0.0024			23.452	0.000003163	
35.0373	35.0361	0.0012			22.653	0.000001637	
34.9101	34.9089	0.0012			22.786	0.000001627	
36.0856	36.083	0.0026			22.973	0.000003497	
37.3979	37.3958	0.0021			23.995	0.000002705	
35.3969	35.395	0.0019			23.044	0.000002548	
38.6832	38.6798	0.0034			25.108	0.000004185	
37.7721	37.7693	0.0028			24.57	0.000003522	
33.3026	33.3012	0.0014			21.586	0.000002004	
37.2247	37.2226	0.0021			23.961	0.000002708	
35.1536	35.1508	0.0028	0.0024	2160	23.159	0.000003736	0.00000316
36.5295	36.5267	0.0028			23.979	0.000003608	
36.7839	36.7816	0.0023			23.756	0.000002992	
37.3241	37.3208	0.0033			24.355	0.000004187	
41.373	41.3709	0.0021			26.861	0.000002416	
36.6875	36.6845	0.003			23.74	0.000003905	
43.1533	43.1479	0.0054			28.162	0.000005926	
35.8028	35.801	0.0018			21.911	0.000002539	
35.2724	35.2701	0.0023			22.922	0.000003101	
35.4878	35.4852	0.0026			23.169	0.000003468	
35.7368	35.7335	0.0033			23.329	0.000004371	
36.6773	36.676	0.0013			23.663	0.000001698	
35.6078	35.6059	0.0019			22.953	0.000002558	
e 34.6173	34.6152	0.0021			22.607	0.000002871	

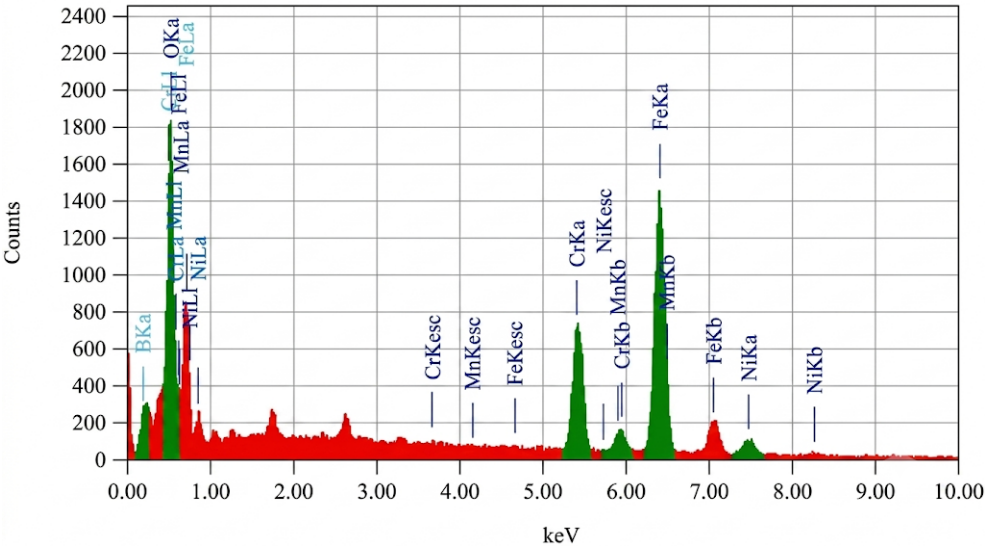


Figure 6. Graphic EDS Test on Control Sample

surface have been corroded. as well as in the 1000× magnification marked by black spots on the specimen surface. In Figures 5.(a) and (b). the surface condition of the sample that has been immersed for 90 days is shown.

It can be seen that corrosion has formed on the surface of the sample. and the areas affected by corrosion are much more extensive. This can be observed by the increased black spots on the surface of the specimen compared to figures 4a and 4b. where only a few are visible. The surface of stainless steel that has undergone corrosion with the formation of clumps due to the reaction of Cl⁻ ions and metal ions

present in stainless steel The surface of stainless steel that has undergone corrosion with the formation of clumps due to the reaction of Cl⁻ ions and metal ions present in stainless steel (Filatov et al., 2023; Švantner et al., 2016). Black spots in the SEM testing of stainless steel are the surface of the specimen that has been corroded (Liu et al., 2021). It can be seen in Figure 4.(a) that the oxygen content in the control sample is only around 1800 counts. where this oxygen content is the oxygen content before the sample was immersed.

In Figure 4.(b). it can be seen that after the sample

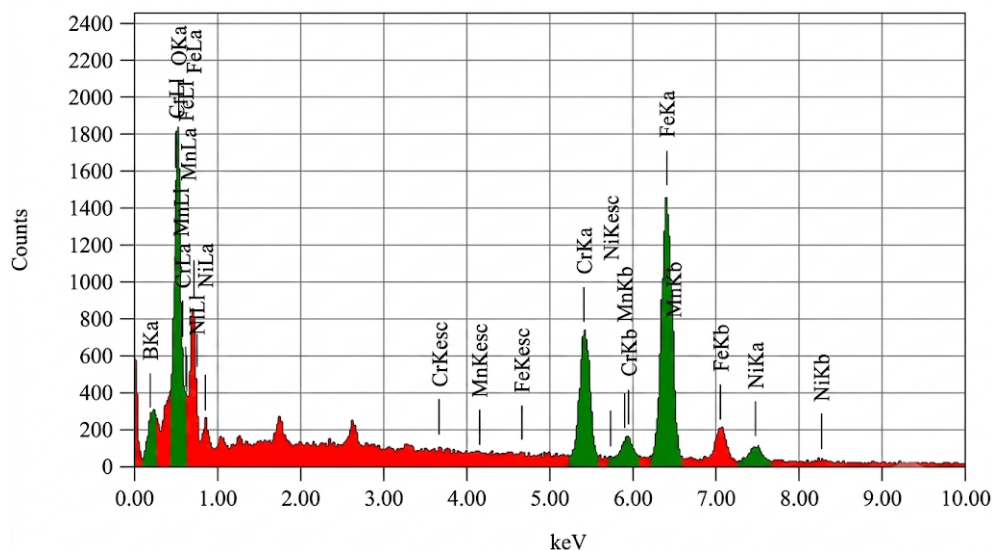


Figure 7. Graphic EDS Test on Immersion for 60 Days

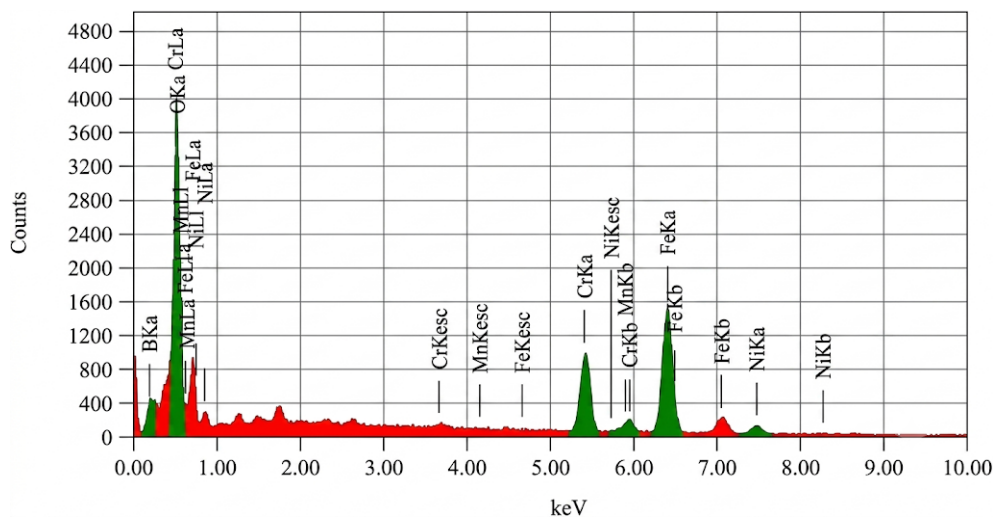


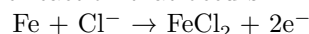
Figure 8. Graphic EDS Immersion 90 Days

was soaked for 60 days. the oxygen content increased from 1800 counts to 3900 counts. indicating an increase in oxygen levels. This suggests that oxidation of the iron has occurred. resulting in the formation of iron oxide as a product of corrosion on stainless steel. That an increase in oxygen levels on the surface of stainless steel will cause oxidation of iron. resulting in the formation of iron oxide as a product of corrosion on stainless steel (Yoo et al., 2023).

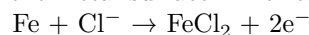
The percentage of iron oxidation rises in tandem with the oxygen levels. increasing the probability that the iron surface will be exposed to oxygen. When the oxygen level is high. the amount of oxygen available to react with iron will be greater. The oxidation process can occur more quickly As previously discussed in the salinity testing section, the high chloride concentration accelerates the oxidation of iron on

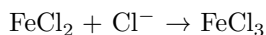
the specimen surface. where it serves as a catalyst to speed up the reaction between iron and oxygen (El Maghfiroh et al., 2019).

This is what causes the surface of 304L stainless steel that has been laser marked to form spots with disturbed or removed passive oxide layers. Chloride ions (Cl^-) in seawater diffuse through the disturbed passive oxide layer. The reaction that occurs:

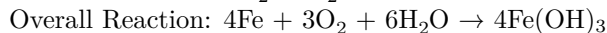
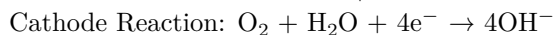
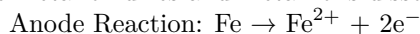


Chloride ions that enter react with the metal beneath the passive oxide layer to form metal chloride compounds that are soluble in water. such as FeCl_2 and FeCl_3 . These compounds dissolve in seawater and form a corrosion layer on the metal surface. The reaction that occurs:





Corrosion on stainless steel 304L involves an electrochemical reaction between the metal and ions in seawater. The oxidized surface (anode) releases electrons (oxidation), while the unoxidized metal (cathode) receives electrons (reduction). This causes corrosion on the metal surface, where the metal oxidizes and metal ions dissolve in seawater.



The corrosion process on stainless steel 304L submerged in seawater will continue to progress over time. The metal surface continues to oxidize, producing $\text{Fe}(\text{OH})_3$ compounds and expanding the corrosion area.

4. CONCLUSIONS

From the research results, it is known that the effect of soaking time on laser marking quality can influence the quality of laser marking where the surface of stainless steel has experienced corrosion and the corrosion rate of stainless steel 304L in seawater media for 90 days is 0.000003160 mpy.

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