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Preliminary communication

INFLUENCE OF CORROSION ON MECHANICAL CHARACTERISTICS OF STEEL SAMPLE (42CrMo4)

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ABSTRACT

Specific environmental conditions, such as marine environments, often influence steel applications in marine industries. These conditions are commonly simulated using a NaCl solution in order to simplify the study and eliminate the complexities of seawater's chemical and biological variability. In this study, 42CrMo4 steel samples, a widely utilized material in components subjected to static and dynamic stresses found in vehicles, engines, and machinery, were selected for analysis due to their susceptibility to various forms of corrosion. The corrosion behavior of the samples was monitored using mass loss and corrosion rate. The results were then correlated with changes in mechanical properties, including tensile strength and Brinell hardness. The study provides insight into how corrosion impacts the degradation of mechanical properties.

Keywords: steel sample, corrosion behavior, mechanical properties

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1. INTRODUCTION

The corrosion behaviour of various materials is of great importance, particularly for metallic materials, with different types of steel being the most commonly used. Different environmental conditions can induce corrosion. The influence of different fluids and gases that cause corrosion is well studied [1-3]. The process of corrosion influences the degradation of mechanical properties, so monitoring the level of material degradation is important to predict the materials' lifetime and reliability in engineering conditions. In order to assess the degradation level caused by corrosion, many different methods have been developed [4-6].

These methods are based on different approaches and can be divided into seven groups [4-6]:

1. Weight Loss Coupons
2. Electrical Resistance Monitoring
3. Electrochemical Methods
4. Hydrogen Monitoring
5. CEION
6. Non-Destructive Testing (NDT) Techniques
7. Analytical Techniques

WEIGHT LOSS COUPONS: The first technique for determining how corrosive a material is to its surroundings is weight loss coupon monitoring, which entails exposing a specimen (coupon) of the material to the environment for a predetermined amount of time and then measuring the weight loss that results. The coupons may take the shape of discs, rods, plates, or any other practical form.

ELECTRICAL RESISTANCE (ER) MONITORING: One of the most used methods of corrosion monitoring is the ER method, which measures a metal element's resistance change as it corrodes in a process environment. Corrosion causes the element's cross-sectional area to shrink, which raises the electrical resistance. The element is often a wire, strip, or tube, and a change in resistance is proportional to an increase in corrosion if the corrosion is approximately uniform. Subsequent observations can be used to estimate the overall deterioration over time. An average corrosion rate can be calculated using a straightforward calculation.

ELECTROCHEMICAL METHODS: There are several electrochemical techniques for corrosion monitoring, which is not surprising given that corrosion is an electrochemical process. Galvanic monitoring, commonly referred to as zero resistance amperometry, and linear polarization resistance monitoring are the two electrochemical methods that are most frequently employed. The primary distinction between electrochemical and ER methods is that the former provides information on the rate of material loss, while the latter provides information on the total amount of material lost.

HYDROGEN MONITORING: Since the discovery of hydrogen indicates that corrosion is occurring or has occurred, hydrogen monitoring is a crucial component of corrosion monitoring. The production of hydrogen is a major concern, especially when plants are exposed to wet sour gas (H_2S) or acidic environments. In these circumstances, hydrogen may be immediately absorbed into the plant's structure, leading to scorching, embitterment, stress corrosion, cracking, and other issues caused by hydrogen. There are hydrogen monitoring probes that can be placed within the plant to measure its hydrogen content or, on the other hand, mounted on the outside of the plant in a saddle mode to detect hydrogen diffusion.

CEION: The resolution of the new ratiometric metal loss measurement tool CEION is at least 100 times higher than that of the current ER-based instruments. It is perfect for keeping an eye on systems that produce and process oil and gas. A technology that can function without maintenance in between scheduled shutdowns and drive an inhibitor pump's real-time control loop. Additionally, CEIONTM is the preferred technology for sub-surface and sub-sea applications where quick reaction is still crucial, but access and dependability are crucial. A particular collection of sensor designs has been created specifically for CEION's use in assessing sand erosion in producing systems.

NON-DESTRUCTIVE TESTING (NDT) TECHNIQUES: There is a wide variety of NDT methods that supplement the "instrumentation" methods that were previously discussed. These include eddy current measurement, radiography, thermography, ultrasonics, and many more. These methods are typically found in the field of plant inspection.

ANALYTICAL TECHNIQUES: The chemistry of the process fluid is examined using a variety of analytical techniques. Typically, this entails extracting fluid samples for examination in a lab. This section includes areas of interest like temperature, conductivity, pH, oxygen, iron and chloride counts, and flow measurements.

In this paper, the influence of the marine environment using a usual approach of testing in NaCl solution was studied [7]. Corrosion behaviour was monitored by measuring mass loss and mass loss rate, as well as changes in selected materials' properties during immersion in NaCl solution. Monitored material mechanical properties were: tensile strength (R_m), yield point ($R_{p0.2}$), and Brinell hardness. The time of immersion was from 0 to 120 days.

2. MATERIAL

The material that was tested in this research is low alloy steel 42CrMo4, processed by classical casting - as cast. The chemical composition is given in Table 1. The steel was delivered as hot rolled plates with dimensions of 10 mm × 1000 mm × 2000 mm. All 42CrMo4 low alloy steel samples were not heat treated further for testing.

References in the text are placed in square brackets; separate multiple references with a comma without a space, for example [3,4] or [3-9].

Table 1. Chemical composition 42CrMo4 low alloy steel

	42CrMo4										
Element (wt. %)	C	Cr	Mo	Mn	Si	Ni	Cu	Al	S	P	Fe
	0.40	0.93	0.20	0.65	0.29	0.003	0.04	0.04	0.003	0.009	Bal.

3. METHODS

The corrosion behaviour of structural steel 42CrMo4 was investigated by immersion in a 3.5% NaCl solution according to standard ISO 11130:2017 (E) [7]. Before and after each interval of the corrosion immersion, the mass of the samples was measured using an analytical balance with an accuracy of ± 0.1 mg. Mass loss and corrosion rates are measured and calculated using standard procedures.

The degree or level of corrosion was measured as the mass loss of the steel samples before and after the corrosion tests. The samples were weighed, and the mass loss was calculated using Equation (1) [8,9].

$$W (g) = Mi-Mf \quad (1)$$

Where Mi and Mf are the masses (in grams) of the sample before and after corrosion experiments, respectively.

The initial total surface area of the specimen (making corrections for the areas associated with mounting holes) and the mass lost during the test are determined. The average corrosion rate (according to ASTM Standard [7]) may then be obtained using equation (2).

$$CR = (K \times W)/(A \times T \times D) \quad (2)$$

Where CR is corrosion rate in mm/year, K is a constant equal to 8.76 × 104 mm/year, T is time of exposure in hours, A is the area in cm^2, W is the mass loss in grams, and D is the density of steel in g/cm^3.

Mechanical properties were monitored using standard laboratory procedures: MEST EN 6892-1:2018 [10] and SRPS EN ISO 6506-1:2016 [11].

4. RESULTS AND DISCUSSION

Mass loss and mass loss rate were monitored for corrosion behaviour description. In Figure 1, the obtained results for mass loss and mass loss rate are presented.

It can be observed in Figure 1 that the mass loss and corrosion rate increase with the time of immersion, almost as a linear correlation. The results pointed out degradation of the sample, and the results of this degradation on the mechanical properties behaviour are given in Figure 2.

Changes in mechanical properties during the immersion time of 120 days were not significant. Yield point ($R_{p0.2}$) is during testing between 502 and 511 MPa, which is a small increase due to the starting value (479 MPa) (Figure 2). Similar behaviour is observed for tensile strength (R_m), as values vary from 691 to 708 MPa compared to the starting 676 MPa. Brinell hardness showed values from 210 to 217, compared to a starting value below 200. Mechanical characteristics monitored, tensile and yield strength did not exhibit significant changes during testing, as well as Brinell hardness (Figure 2).

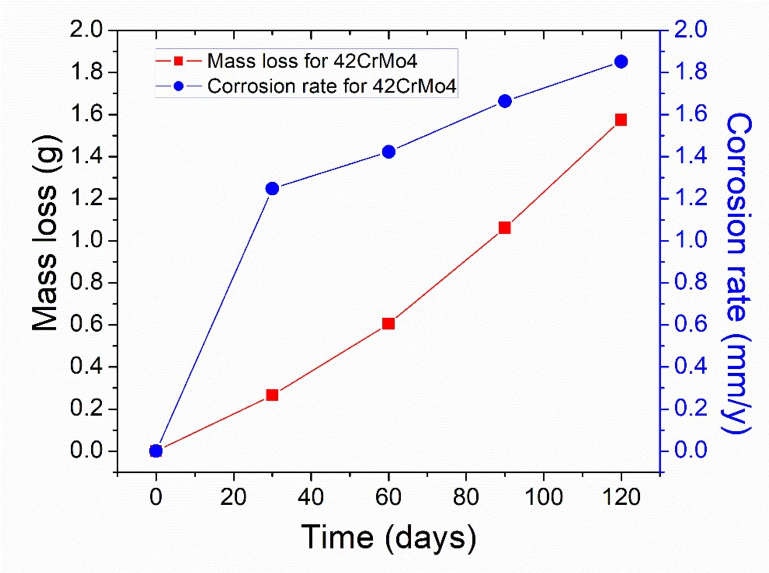

Figure 1. Mass loss and corrosion rate for 42CrMo4

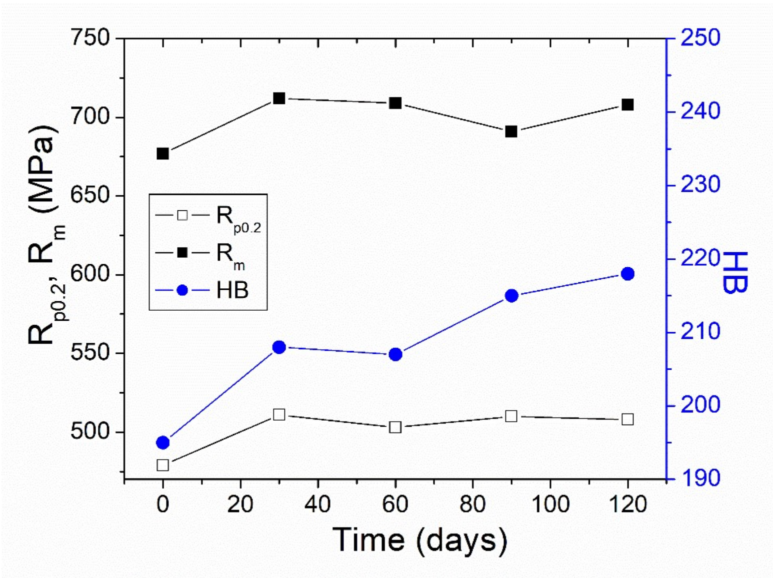

Figure 2. Mechanical properties (yield point ($R_{p0.2}$), tensile strength (R_m) and Brinell hardness) versus time of immersion

However, the influence of immersion and corrosion process on yield strength is mild, decreasing, as well as for tensile strength. Brinell hardness was mildly increased compared to starting values (Fig.2). These results can be explained using chemical analysis in order to discuss the formed oxides and their influence on mechanical properties. Also, the time of immersion could be extended to get better insight into mechanical behaviour during corrosion testing related to longer times of immersion. The diagrams presented in Figure 3 illustrate the correlation between mass loss, mass loss rate, tensile strength (R_m), yield point ($R_{p0.2}$), and Brinell hardness as a function of immersion time.

The cumulative graphs presented in Fig. 3 can be useful for monitoring mass loss and mass loss rate changes to easily and quickly predict the expected changes in mechanical properties, as well as for different immersion times. The combination of easily measured parameters (mass loss and mass loss rate) can be combined with other relevant parameters significant for corrosion monitoring (surface level of degradation, for example).

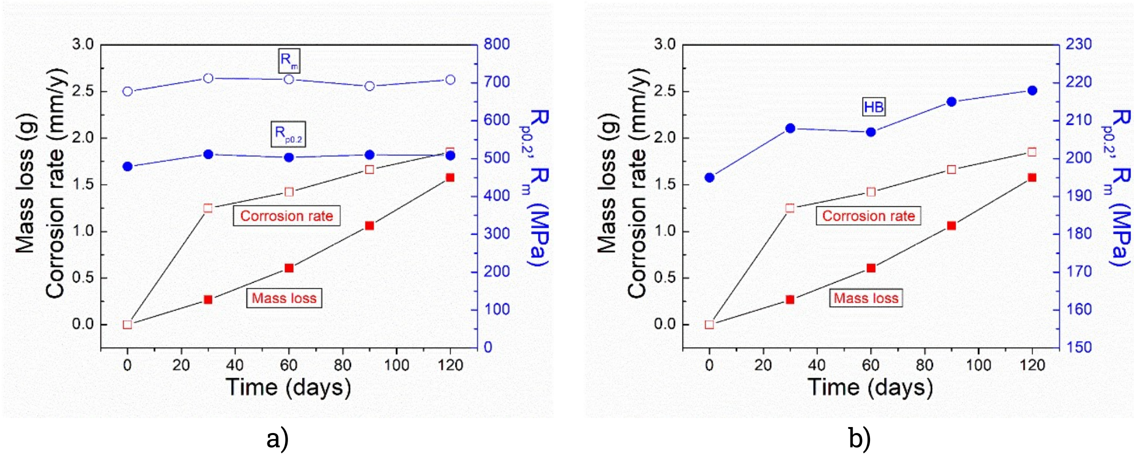

Figure 3. Mass loss, mass loss rate and tensile strength (R_m), yield point ($R_{p0.2}$) (a) and Brinell hardness (b) as a function of immersion time

5. CONCLUSION

The corrosion behaviour of the steel sample in NaCl solution was monitored using mass loss and mass loss rate, as well as monitoring of changes in selected material mechanical properties: tensile strength (R_m), yield point ($R_{p0.2}$) and Brinell hardness. The total time of immersion was 120 days.

The results obtained give good insight into the sample behaviour during different periods of immersion. This relationship between mass loss and mass loss rate (corrosion rate), which can be easily measured and monitored, can be related to the degradation of material properties and can be used for modelling appropriate and reliable models for mechanical properties degradation due to corrosion. These models could lead to models for the prediction of the lifetime of a sample/material based on different parameter changes.

Obtained results for mechanical properties changes pointed out that for the time of immersion of 120 days, there were no significant changes. However, longer immersion times are expected to have a more significant influence on the degradation of mechanical properties. Further experiments will take into account longer immersion times and their influence on mechanical characteristics.

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Conflicts of Interest

The authors declare no conflict of interest.

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