Effect of Nickel Chrome and Diamond-Like Carbon Coating HQ 805 Steel on Corrosion Rate

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Abstract. HQ (High Quality) machinery steel series 805 equivalent to AISI 4340 is a low alloy steel group with very high strength and toughness. These steels are often used for the manufacture of shafts, gears, and various machining components. However, HQ 805 steel is also very sensitive to damage caused by corrosion and can cause continuous damage to the material. A common problem faced by advanced industries today is metal corrosion. Corrosion is a decrease in the quality of metal due to electrochemical reactions with its environment, causing damage resulting in both economic and safety losses. Corrosion losses result in increased maintenance costs, decreased production capacity, production stops completely (shutdown), causes product contamination, environmental pollution, health and safety problems, and other intangible losses. In general, the most common corrosion is caused by air and water. One way to prevent corrosion is by coating, namely coating the metal with a material, so that the metal is protected from corrosion and currently many use surface treatment processes, by providing a thin film on the steel surface. HQ 805 by way of Diamond-Like Carbon (DLC) and Ni-Cr Electroplating. DLC can increase surface hardness and reduce corrosion rates while Ni-Cr electroplating is a type of surface treatment that can improve mechanical properties and can reduce corrosion rates.

The method of coating the surface of HQ 805 steel with Ni-Cr electroplating was carried out in two stages. The first stage is nickel (Ni) plating for 15 minutes (constant), the second stage is chrome (Cr) plating for various variations of coating time 7.5; 12.5; 17.5; 22.5; 27.5 minutes. DLC coating was carried out at constant pressure, coating time and temperature, namely 1.4 mbar, 4 hours and 4000C. The bilayer layers made are Ni-Cr & DLC and DLC & Ni-Cr. Characterization of the results include: testing the corrosion rate. The lowest corrosion rate for the Ni-Cr layer is 0.5375 mpy. The corrosion rate on the bilayer layer was 0.2777 mpy achieved on the Ni-Cr(22.5) & DLC layer. Optimum results from all tests were obtained on the Ni-Cr(22.5) & DLC bilayer coating.

Keywords: Machinery Steel HQ 805, Ni-Cr electroplating, DLC, corrosion rate

ICIESC 2023, October 24, Medan, Indonesia

DOI 10.4108/eai.24-10-2023.2342279

1 Introduction

The properties of this material need to be studied for its fatigue resistance before use, because the determination of the structure must be based on the fatigue limit of the material. The method used to improve the surface mechanical properties of materials is carried out by materials engineering, both for conductive and non-conductive materials [1]. By applying a thin layer to the material's surface, a process known as surface treatment, material engineering techniques can enhance a material's mechanical characteristics. The process of improving a material's desirable surface quality is known as surface treatment. HQ (high quality) 805 machine steel, which is comparable to AISI 4340, JIS SNCM 477, and DIN 34CrNiMo6 SH+V, is one kind of machine steel. HQ 805 machined steel is not the same as regular steel because it has undergone a "post-heat treatment" procedure. This is a continuation of the development of the HQ 7 series, specifically for the HQ 8 series, with the addition of vacuum peeling and degassing technology to homogenize the structure and remove surface flaws. Additionally, the series HQ 8 has been [2].

The nickel-chromium-molybdenum alloy steel known as HQ 805 is frequently used to make components with a high level of wear resistance [3]. But HQ 805 steel is also prone to corrosion and fatigue, which can result in ongoing material degradation. In order to solve this issue, a surface treatment procedure is used, which involves applying a thin coating, or thin film, to the material's surface in order to raise its surface hardness while preserving its interior flexibility [4]. By producing high hardness, low coefficient of friction, resistance to peeling (retention), improved anti-aging, abrasive, and abrasive qualities, surface coating with the Ni-Cr and DLC (Diamond-Like Carbon) electroplating technique is intended to slow down the pace of product corrosion [5]. The substrate is covered in order to finally.

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On a steel substrate, amorphous diamond-like carbon was effectively deposited employing two sources of solid carbon and gas in addition to a single ion beam. Another way to think of DLC is as a structure made of graphite (sp2 carbon) and diamond (sp3 carbon). DLC offers enhanced hardness, good adhesion, low chemical inertness, and grain density, all of which contribute to improved fatigue and corrosion resistance when applied as a surface coating. The gas that can be utilized to produce sp3/sp2 bonds in the DLC layer is CH4, C2H2, C2H4, or C6H6, according to plasma chemical vapor deposition (PCVD) [7].

This description served as the basis for a surface coating experiment in which the substrate/raw material surface was electroplated with Ni-Cr and DLC. Next, apply two layers of coating to the HQ 805 machine steel: a layer of Ni-Cr coating followed by a layer of DLC coating and a layer of Ni-Cr coating. This description served as the basis for a surface coating experiment in which the substrate/raw material surface was electroplated with Ni-Cr and DLC. Next, apply two layers of coating to the HQ 805 machine steel: a layer of Ni-Cr coating followed by a layer of DLC coating and a layer of Ni-Cr coating [8].

An electrolyte solution and an electron source are the two electrodes required for the electroplating reaction. A direct current (DC) source that is linked to the electrode can produce electrons; however, the electrode often receives electrons from both the cathode and the anode. The cations in the electronic solution migrate toward the cathode, adhere to its surface, and absorb electrons from the cathode as a result of the cathode receiving electrons from the outer circuit. Afterward, the cations are reduced to form a precipitate that covers the cotode [9].

$$M^{n+} + ne^{-} \rightarrow M^{o} \tag{1}$$

The following reactions could happen if the anode is soluble [10];

$$M^{o} \rightarrow M^{n+} + ne^{-} \tag{2}$$

Metal oxidation, electrolyte dissolution, and the creation of positive ions are the reactions that take place at the anode. Through the outside circuit, electrons will go in the direction of the cathode during this period. The negative ions that travel in the direction of the cathode are balanced by the positive ions that have produced and entered the electrolyte.

The electrolyte concentration stays constant in an equilibrium state, and as residue accumulates on the cathode, the anode gradually loses capacity. Redox reactions have a writing format.;

$$\begin{array}{ll} \text{Anoda} & : \; M^{o} \rightarrow M^{n+} + ne^{-} \\ \text{Katoda} & : \; \underline{M^{n+} + ne^{-} \rightarrow M^{o}} \end{array}$$

$$M^{o} + M^{n+} \rightarrow M^{n+} + M^{o} \tag{3}$$

Using plasma to accelerate the material's chemical reactions is known as the plasma CVD method. Hydrocarbon gases (such as methane, acetylene, benzene, etc.) are broken down in a vacuum during the plasma CVD process to produce hydrogen and carbon ions. These ions are then accelerated and given the opportunity to collide to form a layer on the surface substrate. generated by applying a negative voltage, resulting in a thin layer of DLC [11].

DLC coating has been used on machine components, molds, and automobile parts because of its high hardness, low friction coefficient, and outstanding wear resistance. It is vital to choose the right DLC coating depending on the usage circumstances because the wear and friction qualities of DLC coatings are dependent on the production process and the conditions of use.

An uneven mixture of diamond atoms establishing sp2 bonds (coal structure tin) and diamond atoms forming sp3 bonds (diamond structure) makes up the amorphous DLC layer. In contrast, the final DLC layer comprises between 15% and 50% atm% hydrogen atoms since the CVD process uses hydrocarbon gas as the starting material. A DLC coating made entirely of carbon can be produced by the PVD technique by utilizing solid carbon as a vaporization source [12].

The atoms that will be deposited or coated on the part's surface using plasma technology will be subjected to an energetic ion bombardment from noble gas atomic ions (spray gas), such as Xe, Ar, He, Ne, and Kr. Because of the ions' momentum transfer from the spray gas.

DLC layers are often created in a vacuum chamber and can be made of solid carbon or gaseous hydrocarbons like benzene, acetylene, and methane. A CVD technique application is plasma glow discharge. The more active medium employed in the glow discharge plasma method is plasma created during the glow discharge procedure. The process is known as chemical vapor deposition that is activated by plasma (PACVD) [13]. An RF or DC oscillator with a high voltage is the source of the plasma generation process. This technique allows for a lower deposition temperature between 200 and 300^0 C. Under vacuum (10-2 - 10-3 torr), the atoms to be coated (often from a gas) are inserted into a plasma reaction tube (discharge tube) during the process.

2 Method

Prototyping tests, Ni-Cr electroplating surface coating procedures, mechanical testing, and corrosion testing are among the procedures that are typically included in the research stage. After reaching the best test results at specific intervals. The substrate surface coating technique was then applied utilizing a two-layer procedure consisting of DLC (Diamond-Like Carbon) and Ni-Cr electroplating. A two-layer coating procedure between DLC and Ni-Cr electroplating is the following step. Next, carry out the test once more.

Table 1. Electroplating solution for nickel (Ni & Cr)

No.	Name of solution	Amount of solution
1.	*Nickel sulphate* ($NiSO_4$)	200 grams/l
2.	*Nickel chlorite* ($NiCl_2$)	50 grams/l
3.	*Boric acid* (H_3BO_3)	40 grams/l
4.	*Brightener I* (HBF_4)	3 ml/l
5.	*Brightener M* (SO_3NH_2)	2 ml/l
6.	*Wedding agend*	2 ml/l
7.	*Chrome acid* (H_2CrO_3)	250 grams/l
8.	*Chatalyst* (H_2SO_4)	2,5 grams/l

The corrosion rate test uses the three-electrode cell principle at the UGM Yogyakarta Engineering Materials Laboratory, as shown in Figure 1. The instrument used is the VersaSTAT 4 Potentiostat Galvanostat which is equipped with VersaStudio corrosion measurement software using an electrolytic solution using 0.9% NaCl solution.**.**

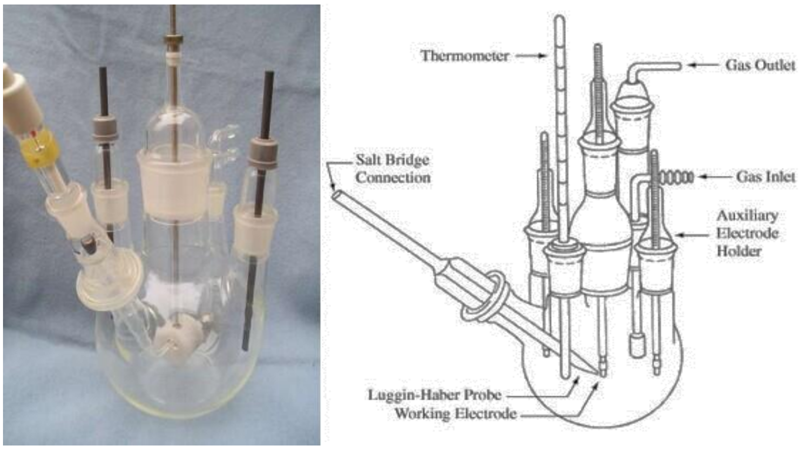

Fig. 1. Three-electrode cell corrosion test equipment

3 Result and Discussion

Corrosive medium, namely a 0.9% NaCl solution, is used in corrosion rate testing. Potentiodynamics is used to calculate the surface corrosion rate. Testing for corrosion rate was done on HQ 805 steel without any coating procedure and after Ni-Cr electroplating for different coating times: 7.5, 12.5, 17.5, 22.5, and 27.5 minutes. After wards, DLC was applied for four hours at a pressure of 1.4 mbar. Comparing the corrosion rate values of each Ni-Cr and DLC coating is the aim of this corrosion rate test [14].

A number of characteristics, including Icorr (corrosion current density), ρ (material density), and Ew (material equivalent weight), affect the corrosion rate value. The average atomic weight of the corresponding weight is.

For any test parameter, the corrosion rate can be computed in the same manner. The equivalent weight value derived from the EW value in Table 2 is the equivalent weight of HQ 805 steel material.

Table 2. Data relevant to each element for the comparable weight of HQ 805 steel.

Element	mass percentage (%)	Valence electrons	atomic mass
C	0,0036	4	12,011
Si	0,0022	4	28,085
Cr	0,014	1	51,996
Mn	0,00713	2	54,938
Fe	0,9548	2	55,845
Ni	0,013	2	58,693

Mo	0,0016	2	95,96
S	0,0003	6	32,066

Demonstrates the outcomes of corrosion tests conducted with the dynamic potential method and the results of corrosion rate computations associated with variations in the Ni-Cr electrocoating's length. After the Ni-Cr electroplating process, the corrosion rate on HQ 805 steel can be lowered based on test results. As the Ni-Cr coating period increased, the corrosion rate decreased in all coating variations [15].

The thickness of the substrate surface layer can be increased by prolonging the electroplating process. This layer has the potential to generate a chromium oxide (Cr2O3) passivation layer. Test results and rising surface hardness both support this. The life and fatigue resistance of the coating made from Ni-Cr electroplating are significantly influenced by the rate of corrosion [16].

Table 3. Results of the corrosion test on the layer of Ni-Cr electroplating

Coating time t (menit)	*Raw material* 0	7,5	12,5	17,5	22,5	27,5
I_{corr} (µA/cm^2)	34,631	3,85	3,789	2,001	1,205	2,309
E_{corr} (mV)	-582,338	-513,946	-420,807	-358,728	-131,896	-497,011
Corrosion rate (mpy)	15,4497	1,7175	1,6903	0,892	0,5375	1,030
Corrosion rate (mm/thn)	0,393	0,0436	0,0429	0,0227	0,0136	0,0262

Figure 2 shows the corrosion rate due to Ni-Cr electroplating for different variations in coating time.The corrosion rate for HQ 805 steel material is 15.4497 mpy. All coatings have a coating time of 7.5; 12.5; 17.5; 22.5; 27.5 minutes, resulting in a lower corrosion rate compared to the raw material. Increasing the Ni-Cr coating time causes the curve to increasingly shift towards the anode. The plot curve moves upward indicating a higher Nobel Prize potential [17]. Material coated with Ni-Cr will have a higher anodic corrosion potential value than uncoated material. Coating time of 22.5 minutes produces the best corrosion rate of 0.5375 mpy.

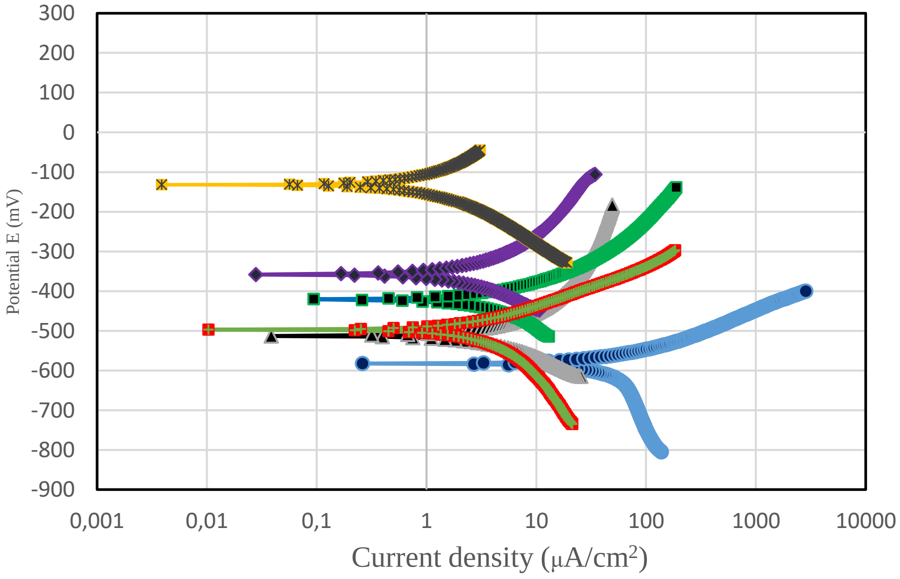

Fig. 2. Corrosion test results using potentiodynamics for different treatment conditions

The results of the corrosion rate testing using DLC electroplating and Ni-Cr(22.5) are shown in Figure 3 The least corrosion-prone electroplating layers are Ni-Cr(22.5) & DLC. The corrosion rates of 0.2776 mpy and 1.0573 mpy were obtained for each layer of Ni-Cr(22.5) & DLC and DLC & NiCr(22.5). The highest hardness test results on the Ni-Cr(22.5) & DLC layer demonstrate this. In this instance, where the Cr ions are denser and have Cr2O3 oxide compounds that can slow the rate of corrosion, the tougher the surface layer, the more difficult it is to be attacked by corrosion. In contrast, the rate of corrosion for the DLC & Ni-Cr(22.5) coating is faster than that of Ni-Cr(22.5) & DLC [18]. This is due to the inability of the Ni-Cr and DLC layers to form a strong bond, which makes the Ni-Cr electroplating layer.

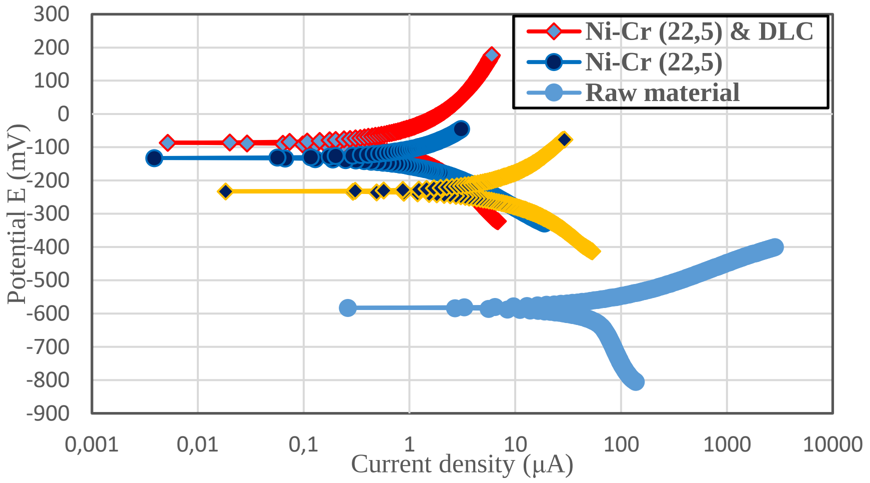

Fig. 3. Comparison of corrosion tests using potentiodynamics (Tafel plot) for different coating conditions

Table 4. Results of comparing the rate of corrosion of HQ 805 steel in a corrosive solution containing 0.9% NaCl before and after it was coated with Ni-Cr and DLC

Specimen code	Coating time (Minute)	Current meeting Corrosion, I_{corr} ($\mu A/cm^2$)	Corrosion rate		*Relative corrosion resistance*
			mpy	$\frac{mm}{yr}$	
Raw material	0	34,631	15,4497	0,393	Fair
Ni-Cr	7,5	3,85	1,7175	0,0436	Excelent
Ni-Cr	12,5	3,789	1,6903	0,0429	Excelent
Ni-Cr	17,5	2,001	0,892	0,0227	Outstanding
NiCr	22,5	1,205	0,5375	0,0136	Outstanding

Ni-Cr	27,5	2,309	1,030	0,0262	Excelent
DLC & Ni-Cr	22,5	2,37	1,0573	0,0268	Excelent
Ni-Cr & DLC	22,5	0,6224	0,2776	0,007069	Outstanding

Table 4 shows the results of a comparison of relative corrosion resistance in mpy and metric. The smallest corrosion rate from all tests was obtained on the Ni-Cr(22.5) & DLC electroplating layer with a corrosion rate value of 0.2776 mpy, which is relative corrosion resistance outstanding, which was initially a fair relative corrosion resistance raw material based on testing in a solution of 0.9 % NaCl, with a corrosion rate of 15.4497 mpy.

4 Conclusion

The Ni-Cr coating has been proven to increase the surface hardness of HQ 805 steel. As the coating time increases, the hardness value also increases. The maximum hardness value obtained was 577 VHN with a coating time of 22.5 minutes. This shows a significant increase in hardness, where the hardness value of the raw material before being coated with Ni-Cr is 328 VHN. The lowest corrosion rate in the bilayer layer was obtained in the Ni-Cr(22.5) & DLC coating, the corrosion rate was faster for the DLC & Ni-Cr(22.5) coating. The respective corrosion rates are 0.2776 mpy and 1.0573 mpy.

Acknowledgement

The Authors would like to thank the Institute of Research and Community Service Universitas Negeri Medan for funding this research under contract no. 0021/UN33.8/PPKM/PD/2023.

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