



Original Research

## Analysis of High Temperature Oxidation Characteristic of Chrome-Plated, Nickel-Plated and Non-Plated Mild Steels

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### Abstract

Metals are the best engineering materials owing to their superior conductivity, mechanical properties, and formability. However, they can be highly affected by environmental elements like oxygen, chlorine, etc. This reaction of metals with the environmental elements will indeed alter their electrical, chemical, and mechanical properties. To protect against corrosion, various protection methods such as electroplating have been established. The presence of anodic or cathodic films on the substrate surface protects steel from corrosion damage at ambient atmospheric temperature. This work focuses on the effect of temperature on the oxidative (corrosion) rate of non-plated, nickel-plated, and chrome-plated ASTM A283GC mild steel samples. A temperature range of 200–800 °C and a total heating time of 120 min were considered in this experiment. A temperature-regulated muffle furnace with a maximum heating capacity of 1000 °C has been used. Weight changes were determined every 30 minutes of heating using a digital weight balance with a precision of 0.001 g. The obtained experimental results of non-plated, nickel-plated, and chrome-plated mild steel samples were analyzed and compared with each other. The effect of oxidation on the surface hardness has also been studied with the help of a Vickers hardness testing machine. Changes in the physical nature of the samples caused by oxidation were also observed and pictured.

**Keywords:** metals, corrosion, temperature, surface hardness, electroplating

## 1. Introduction

Corrosion is surface degradation of metals which damages its properties and performance. It is a major operating problem that takes place in gas turbines, diesels engines, furnaces and other machinery components that come in contact with hot gas containing oxygen and other contaminants (Frankel, 1998). The metal atoms that are exposed to the corrosive environment are the ones that will encounter the damage along with the atoms surrounding them to undergo chemical reaction which will result corroded surface. Some of the reacting elements that can cause corrosion may go deep into the substrate through porous surface film to a limited thickness beneath the surface and react with the subsurface atoms of the substrate. This surface deterioration of metals may depend on the type of the metal substrate and the reacting elements (Maurice & Marcus, 2018). The exposure of metals to corrosive environment results to an appreciable mass loss, which increases with increasing duration of exposure (Apostolopoulos & Papadakis, 2008).

Some metals, like aluminium by nature have higher corrosion resistance. But huge volumes of metals notably iron and steel, used in designs and structures are damaged by various forms corrosion, including dry and wet corrosion (Lu, 2010). Because of this developed nations are yearly investing billions of dollars to protect metals from oxidative damage by developing and applying various prevention methods such as (Aliofkhazraei, 2014; Hou et al., 2017). Protection methods are applied to



increase the working life of the metals and are assumed to play a great role at an ambient atmospheric temperature in dry as well as wet season (McMahon, 2019).

The average pace at which a certain material will degrade owing to corrosion in a given environment is the definition of a substance's corrosion rate. This rate is influenced by the material's characteristics as well as the environment it is subjected to. Corrosion rate might be facilitated or speed up by environmental conditions such as temperature and humidity. Different materials have different resistance and susceptibility to corrosion. The rate of oxidation of metals may depend on the type of metals (Andrade & Alonso, 2001).

Corrosion can be influenced by various parameters including: strength and concentration of the reactants as well as temperature. For a given type of metal, the rate of corrosion is assumed to increase with concentration of the reactants and temperature. These protective coating however are assumed to play a greater protection role at an ambient atmospheric temperature in dry as well as wet season. At higher working temperature, it is deemed that these coatings may also play a role in protecting the substrate surface from corrosion. But the ability of the coating in protecting corrosion at a higher working temperature is not assumed to be the same with that of the lower working temperature. The methods will reduce to some extent the corrosion rate, if not like that of lower temperature case (North & MacLeod, 1987; Young, 2008).

For various coating applications, a wide range of coating techniques and materials are available with the shared objective of shielding a component or structure from mechanical or chemical harm. One of the dominant coating techniques is electroplating. Electroplating is the process of applying a metallic coating to an article by passing an electric current through an electrolyte in contact with the metal to be plated, thereby forming a surface having properties different from the substrate. The process is considered as one of the largely used electro deposition processes and is essentially used to electroplate any electrically conductive surface and nonconductive surfaces, such as plastic by making conductive layer through coating with metallic-loaded paints or silver-reduced spray. Both the cathode and the anode components are immersed in a solution called electrolyte containing one or more dissolved metal salts as well as other ions that permit the flow of electricity. The electrodes are immersed in the electrolyte with the anode connected to the positive leg of the power supply and the cathode to the negative leg. As the current is increased from zero, a point is reached where metal plating begins to occur on the cathode (Fotovvati et al., 2019; Kanani, 2004; Ojo & Dharmadasa, 2018). A desired metal's cations are reduced in solution by the electroplating method, which uses an electrical signal from an external power source to create a metallic coating (Chen et al., 2013). An electrolyte is a compound which forms ions in solution. Electrolytes include water solutions of acids, bases, or metal salts, certain pure liquids, and molten salts. Gases may act as electrolytes under conditions of high temperature or low pressure. In addition to metal salts, electrolytes usually contain a number of additives for various purposes for example: to increase electrolyte conductivity, to increase bath stability, to activate the surface, to improve leveling or metal distribution, or to optimize the chemical, physical, or technology properties of the coating (Samui & Sivaraman, 2010; Zhang et al., 2016).

A study done by Wang et al. (2015) analyzed the coating of copper surfaces with a single-phase  $\text{Ni}_2\text{Al}_3$  by electrodepositing nickel, followed by slurry pack aluminizing at 800 °C for 12 hours. The oxidation resistance of the coating was identified by examining the fluctuations in mass gain vs. time. After slow oxidation of the coated copper for 250 hours at 1000 °C, there was no exfoliation of the protective  $\text{Al}_2\text{O}_3$  scale, and the mass gain was 10.108 mg/cm<sup>2</sup>. This study follows the same characterizing technique to analyze the oxidation property.

Hardness testing is usually performed to evaluate the mechanical characteristics of thin surface. This test procedure uses a single-point contacts, a diamond pyramid for measuring micro-hardness, and typically a diamond cone for measuring scratch resistance by causing plastic deformation on the substrate and coating's surface (Burnett & Rickerby, 1987). The relationship between relative indentation depth and the hardness of a coated system during indentation has been extensively investigated that the penetration should be less than 10% of the coating thickness to obtain coating hardness independent of the substrate (Burnett & Rickerby, 1987).

The high-temperature oxidation behavior of iron and steel alloys has been a subject of extensive research (Chen & Yeun, 2003). Studies have explored the kinetics and mechanisms of oxidation, shedding light on the formation of oxide scales and their impact on the material's performance at elevated temperatures (Chen & Yeun, 2003; Ma et al., 2023). Nickel, recognized for its intrinsic corrosion resistance, is often alloyed with iron to improve the oxidation resistance of steels in aggressive environments (Klapper et al., 2017). Furthermore, nickel-plated surfaces have been investigated for

their ability to provide an additional layer of protection against high-temperature oxidation (Weinstein et al., 2021).

Chromium, another essential alloying element, exhibits remarkable resistance to oxidation, forming a stable and adherent chromium oxide layer on the surface (Mehtani et al., 2021). Chrome-plated mild steels have demonstrated enhanced resistance to high-temperature oxidation, making them valuable in applications where prolonged exposure to elevated temperatures is a concern (Akhtar et al., 2023). Research efforts have been directed towards understanding the nuances of chromium's role in mitigating oxidation and its effectiveness in diverse environmental conditions (Lunk, 2015).

The following work was performed to study the high temperature oxidation characteristics of nickel-plated, chrome-plated and non-plated mild steel.

## 2. Materials and methods

### 2.1. Materials

This study utilized ASTM A283GC mild steel, nickel, and chromium samples, along with an electroplating device under specific operational conditions. The electrolyte, hardness furnace, tester, and spark emission spectroscopy were obtained from the Dejen Aviation Engineering Industry (Ethiopia).

### 2.2. Methods

The samples utilized in this experiment were prepared, electroplated, and examined at the Dejen Aviation Engineering Industry (Ethiopia). The mild steel substrates were also collected from the same industry, ensuring uniform thickness and coating thickness for all samples. Each sample had dimensions of 4 mm × 25 mm × 25 mm. In this study, the oxidation behavior of chrome-plated, nickel-plated, and non-plated mild steel was investigated at elevated temperatures. The oxidation tests were conducted at 200, 400, 600, and 800 °C using a muffle furnace with a maximum heating capacity of 1000 °C. The increase in weight, considered as a reference for oxidation behavior, was measured during the experiment using a precision weight balance with an accuracy of 0.001 g. The weight of each sample was recorded every 30 minutes, and the resulting increase in weight ( $\Delta w$ ) was documented and analyzed.

#### 2.2.1. Elemental analysis

The elemental analysis of the initial sample (ASTM A283GC mild steel) used in the oxidation study was conducted using spark emission spectroscopy at the Dejen Aviation Complex (Ethiopia). The obtained results have been tabulated in Table 1.

**Table 1.** Chemical composition of mild steel.

Element	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	W	Fe
Composition in wt.%	<0.05	0.02	0.29	0.02	0.013	0.043	0.012	0.032	0.051	0.10	99.03

As presented in the web page Mild Steel (2023), the chemical compositions of mild steel in the standard value are listed as follows: carbon (0.16–0.18%), silicon (0.40% max.), manganese (0.70–0.90%), sulfur (0.040% max.), and phosphorus (0.040% max.).

The three elements are phosphorus and sulfur, and the major element is iron (Fe). The percentage composition of the test sample of mild steel is given in Table 1. As can be observed from the Table, the composition of the steel is generally different from the standard value. The standard value of carbon is 0.16–0.18%. The practical chemical composition analysis of mild steel shows that C is < 0.05% or dead steel, and other elements are reduced, like phosphorus (0.02%), manganese (0.02%), and silicon (0.013%).

#### 2.2.2. Samples preparation method

The first step is to prepare mild steel samples of size 4 mm × 25 mm × 25 mm using a cutting machine. The second step involves cleaning the samples to remove dust, oil, and grease by degreasing and using other removal methods like polishing. After cleaning, the mass of each steel sample was determined using a weight measurement balance. A total of 12 samples were prepared for the experi-

ment. Subsequently, mild steel was chrome-plated and nickel-plated. Parameters of the plating process are listed in Tables 2 and 3. The experiments were carried out at the Dejen Aviation Engineering Industry in Ethiopia. Initial weight of chrome-plated, nickel-plated and non-plated samples is listed in Table 4.

Following the plating process, the samples were subjected to high-temperature oxidation to investigate their behavior. The change in weight of the samples was then measured. Additionally, the microstructure of the samples was observed, and a hardness test was performed.

**Table 2.** Parameters of the chrome plating process.

S/N	Chemical name / Parameter	Molecular formula	Concentration and specification
1	Anyhydride chromic acid	CrO <sub>3</sub>	<ul style="list-style-type: none"> <li>• Composition of solution 140–180 g/dm<sup>3</sup>,</li> <li>• Red dark flakes (plates form).</li> </ul>
2	Sulphuric acid	H <sub>2</sub> SO <sub>4</sub>	<ul style="list-style-type: none"> <li>• Composition of solution 1.5–2.2 g/dm<sup>3</sup>,</li> <li>• Specific gravity 1.84,</li> <li>• Density 1840 g/m<sup>3</sup>.</li> </ul>
3	Parameters	PH	3.8-4.2
4		Bath cathodic current density	10-25 A/dm <sup>2</sup>
5		Temperature	55-68 °C
6		Voltage	4-12 V
7		Preheating time	T

**Table 3.** Parameters of the nickel plating process.

S/N	Chemical name /Parameter	Molecular formula	Value
1	Sodium hydrated	NaOH	46.212
2	Nickel sulfate	NiSO <sub>4</sub> .H <sub>2</sub> O	89 g/dm <sup>3</sup>
3	Boric acid	H <sub>3</sub> BO <sub>3</sub>	45 g/dm <sup>3</sup>
4	Wetting agent	-	0.3 % vol./dm <sup>3</sup>
5	Total solution volume	-	70 dm <sup>3</sup>
6	Plating bath temperature	-	50 °C
7	PH	-	4.5–5.0
8	Bath cathodic current density	-	7–40 mA/cm <sup>2</sup>

**Table 4.** Initial weight of chrome-plated, nickel-plated and non-plated samples.

Samples	Weight of chrome-plated sample, g	Weight of nickel-plated sample, g	Non-plated sample weight, g
Sample 1	19.400	19.000	17.623
Sample 2	19.223	19.222	17.524
Sample 3	19.348	19.129	17.591
Sample 4	19.185	18.890	17.278

### 2.3. Oxidation process

The oxidation properties of the samples were measured based on the work by a Wang et al. (2015). In this study, we measured the initial thickness of the samples and studied the change in weight that occurred in non-plated, chrome-plated, and nickel-plated mild steel due to oxidation when heat-treated at 200 °C, 400 °C, 600 °C, and 800 °C at discrete intervals of time.

The tests were conducted at the Dejen Aviation Engineering Industry using micro test, a versatile and sophisticated thickness tester capable of measuring almost all electroplated metals on ferrous, non-ferrous, and non-metallic substrates. It can measure multiple coatings and provide individual readings. Table 5 displays the initial thickness of the samples.

**Table 5.** Thickness of plating.

Chrome-plated sheet	Thickness of plating, μm	Nickel-plated sheet	Thickness of plating, μm
Sample 1	12.5	Sample 1	11
Sample 2	12	Sample 2	9.5
Sample 3	9	Sample 3	9
Sample 4	11.5	Sample 4	10

## 2.4. Hardness measurement

The Vickers hardness test is a widely used method to determine the hardness of materials. To perform the test, first, ensure that the Vickers hardness tester is properly calibrated and in good working condition. The procedure of the hardness measurement was as follows:

- 1) Place the specimen on a flat and stable surface and select the appropriate scale based on the material's hardness.
- 2) Gently lower the indenter onto the material's surface to make initial contact, then zero the scale using the zero-adjustment dial.
- 3) Apply the initial minor load, followed by the main or major load specific to the scale being used.
- 4) Allow the major load to dwell for about 15 seconds, then release it while keeping the minor load applied.
- 5) Read the hardness value directly from the Vickers hardness tester's scale.
- 6) Take multiple measurements at different locations on the material for accuracy, and calculate the average hardness value.
- 7) Follow the manufacturer's instructions for your specific Vickers hardness tester model to ensure accurate and reliable results.

## 3. Result and Discussion

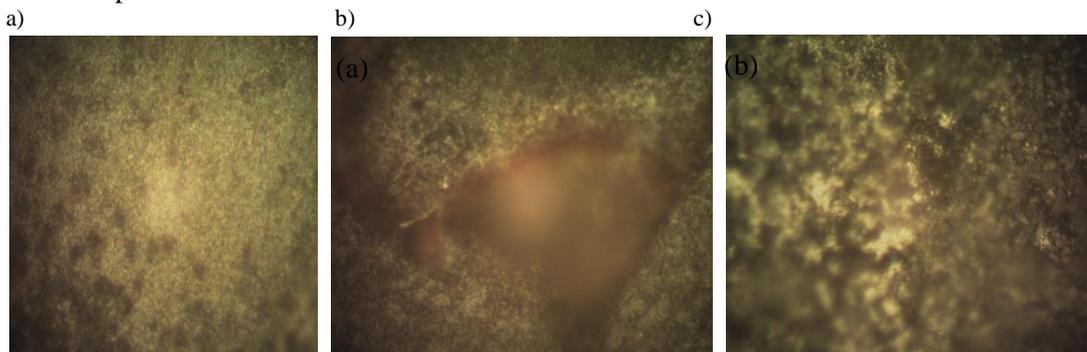
### 3.1. Microstructure

The original non-plated mild steel sample has been polished to achieve its mirror finish using various grades of polishing papers. Subsequently, the polished sample was examined using inter-phased optical microstructure analysis (Fig. 1), revealing the absence of phases other than ferrite.

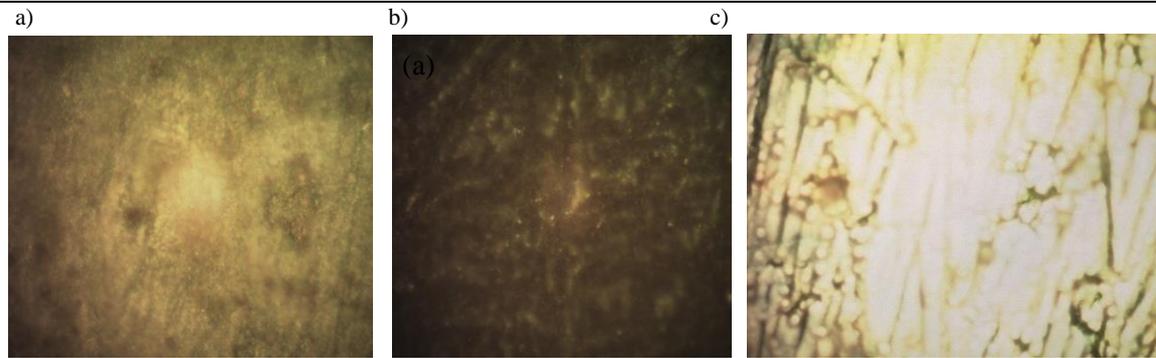


**Fig. 1.** Microstructure of mild steel.

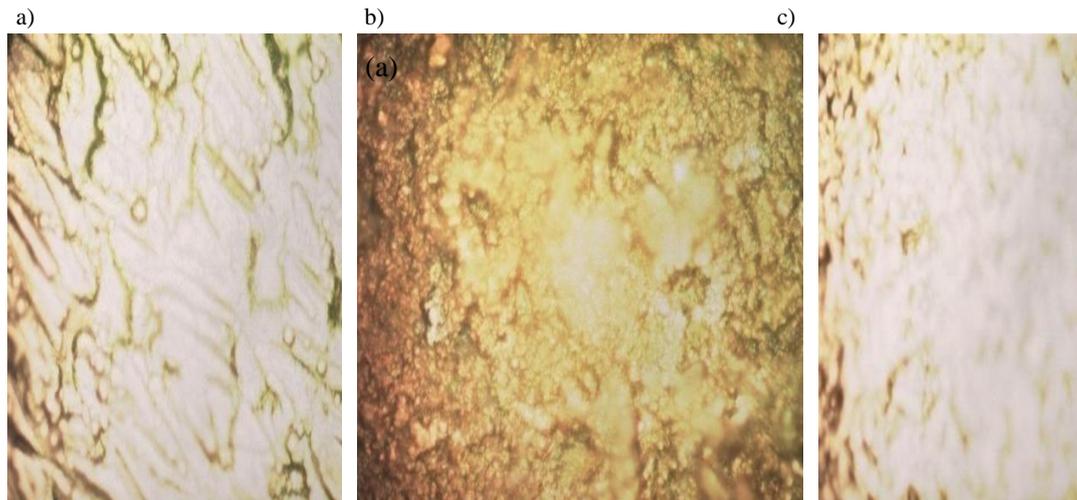
An attempt was also made to observe the changes in their physical states, such as color changes that may appear after the samples were heated to various temperatures for a total time of 120 minutes. Camera pictures were taken in both post-heating and pre-heating conditions. As can be seen in Figs. 2–5, a radical change in color was observed on the non-plated mild steel surface at temperatures beyond 600 °C and above. The color changed from grey (before heating) to dark brown (after heating). Notably, at 800 °C, the oxide layer of the mild steel sample was observed to flake off easily even by touch. However, this flaking-off problem was not observed in the nickel-plated and chrome-plated mild steel samples.



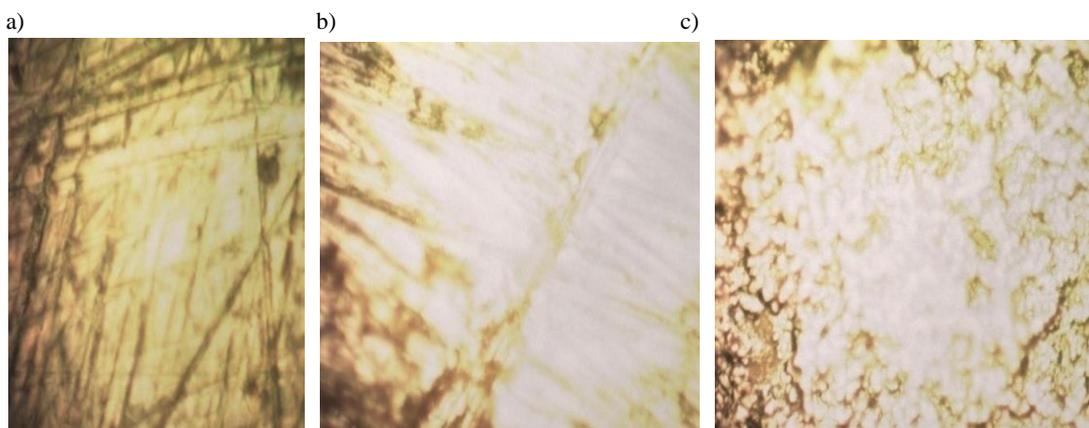
**Fig. 2.** Surface morphology of a) nickel-plated and b) chrome-plated and c) non-plated mild steel, oxidized at 800 °C for 120 min in unpolished condition.



**Fig. 3.** Surface morphology of a) nickel-plated, b) chrome-plated and c) non-plated mild steel, oxidized at 600 °C for 120 min in unpolished condition.



**Fig. 4.** Surface morphology of a) nickel-plated, b) chrome-plated and c) non-plated mild steel, oxidized at 400 °C for 120 min in unpolished condition.



**Fig. 5.** Surface morphology of a) nickel-plated, b) chrome-plated and c) non-plated mild steel, oxidized at 200 °C for 120 min in unpolished condition.

### 3.2. Effect of change in weight in high temperature oxidation

Various temperatures, i.e., 200 °C, 400 °C, 600 °C, and 800 °C, have been selected for conducting oxidation studies on non-plated, chrome-plated, and nickel-plated mild steel samples. A total time of 120 minutes was considered for all three samples, including both plated and non-plated ones. Weight measurements were conducted every 30 minutes, and the variations of oxidation with respect to temperature and time are presented graphically for the three mentioned samples.

For the hot temperature corrosion studies, four samples from each type (non-plated, nickel-plated, and chrome-plated) were considered, and these samples were prepared to have similar surface areas. Before heating, the original weight of each sample was measured using a 0.1 mg precision balance.

All the mentioned samples were heated at various holding temperatures (200 °C, 400 °C, 600 °C, 800 °C) for a total heating time of 120 minutes. To determine the weight changes, the heating was interrupted every 30 minutes, during which the hot sample was gently removed from the muffle furnace using stainless steel tongs. The hot samples were allowed to cool to ambient atmospheric temperature before measuring their weight. The weight measurements of the samples are presented in Table 5.

**Table 5.** Experimental results for high temperature oxidation.

Materials	T, °C	w <sub>0</sub> , g	w <sub>1</sub> , g	ΔW <sub>1</sub> , %	w <sub>2</sub> , g	ΔW <sub>2</sub> , %	w <sub>3</sub> , g	ΔW <sub>3</sub> , %	w <sub>4</sub> , g	ΔW <sub>4</sub> , %
Non-plated mild steel	200	17.6256	17.6258	0.0008	17.6261	0.0023	17.6266	0.0036	17.6273	0.0075
Chrome-plated		19.3987	17.3987	0	19.3991	0.00206	19.3993	0.00309	19.3995	0.0041
Nickel-plated		18.9986	18.9986	0	18.9993	0.0037	18.9998	0.0063	19.0001	0.0079
Non-plated mild steel	400	17.5241	17.5243	0.001	17.5252	0.0063	17.5260	0.0108	17.5261	0.011
Chrome-plated		19.2229	19.2230	0.00052	19.2235	0.00312	19.2236	0.0036	19.2238	0.0047
Nickel-plated		19.2224	19.2226	0.00104	19.2233	0.00468	19.2237	0.00676	19.2241	0.00884
Non-plated mild steel	600	17.5907	17.6008	0.057	17.6025	0.067	17.6038	0.0745	17.6054	0.08356
Chrome-plated		19.3470	19.3477	0.0036	19.3483	0.00672	19.3491	0.0108	19.3497	0.0139
Nickel-plated		19.1285	19.1290	0.0026	19.1299	0.00732	19.1307	0.0115	19.1313	0.0146
Non-plated mild steel	800	17.2780	19.3920	0.659	17.4183	0.812	17.4308	0.8843	17.4405	0.9405
Chrome-plated		19.1853	19.1877	0.0125	19.1881	0.0146	19.1884	0.016	19.1887	0.0177
Nickel-plated		18.8897	18.9068	0.0905	18.9139	0.127	18.9199	0.1598	18.9240	0.1799

Weight increase ΔW<sub>1</sub>–ΔW<sub>4</sub> has been determined according to Eqs. (1)–(4):

$$\Delta W_1 = \frac{W_1 - W_0}{W_0} \times 100\% \quad (1)$$

$$\Delta W_2 = \frac{W_2 - W_0}{W_0} \times 100\% \quad (2)$$

$$\Delta W_3 = \frac{W_3 - W_0}{W_0} \times 100\% \quad (3)$$

$$\Delta W_4 = \frac{W_4 - W_0}{W_0} \times 100\% \quad (4)$$

where: w<sub>0</sub> is weight of non-plated sheet, w<sub>1</sub> is weight of sample after heating for 30 minutes, w<sub>2</sub> is weight of sample after heating for 60 minutes, w<sub>3</sub> is weight of sample after heating for 90 minutes and w<sub>4</sub> is weight of sample after heating for 120 minutes.

### 3.3. Oxidation behavior of non-plated mild steel

As shown in Figs. 6a)–6d) for the non-plated steel sample under constant given temperatures, oxidation increases with time. This increase in oxidation is manifested by an increase in the weight of the sample. The effect of temperature on weight change is presented graphically in Fig. 7. It is evident from this graph that temperature has a significant influence on corrosion. Upon comparison, it is observed that for any given time, higher temperatures result in greater weight change (oxidation) of the non-plated steel sample.

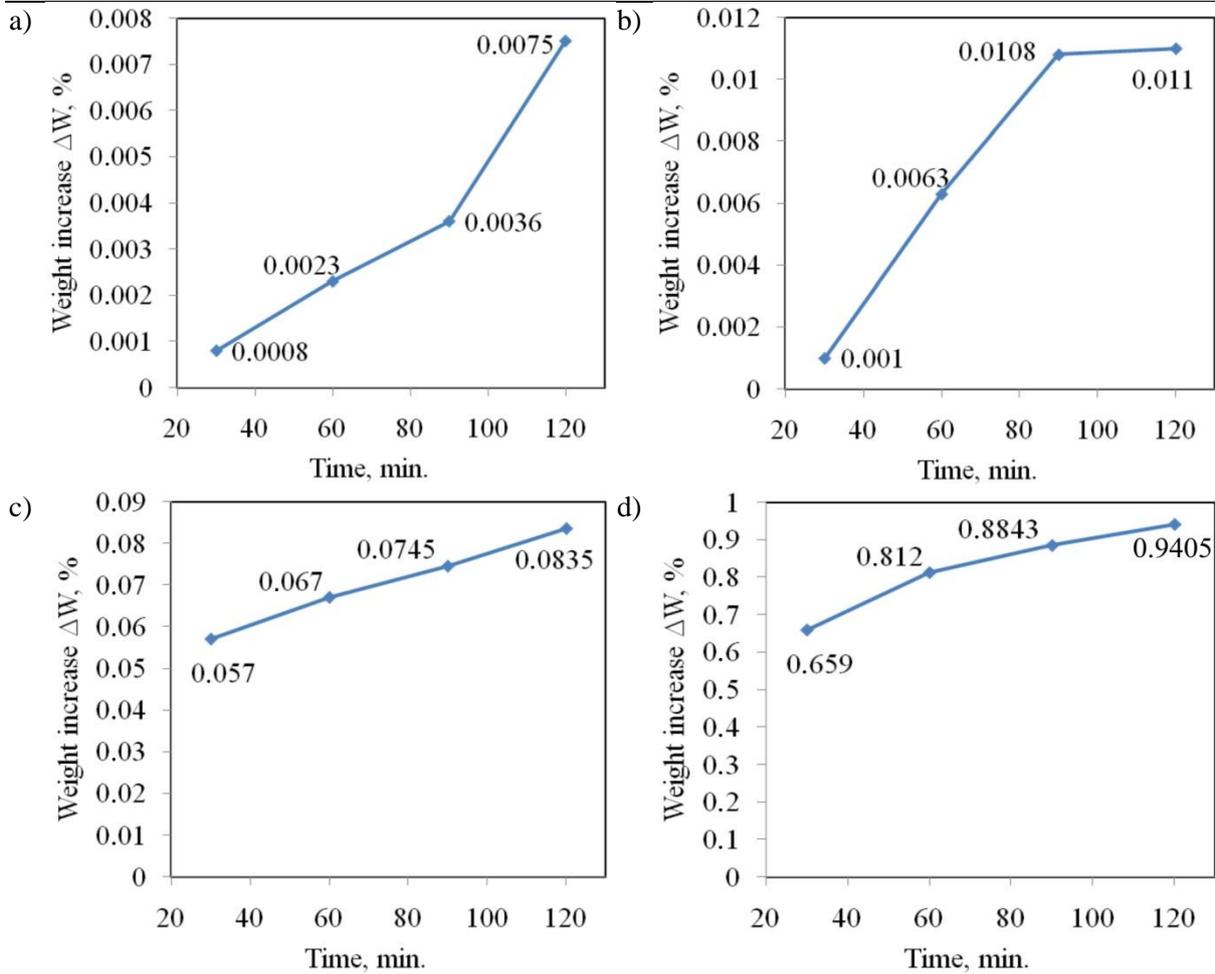


Fig. 6. Variation of oxidation with time for non-plated mild steel: a) T = 200 °C, b) T = 400 °C, c) T = 600 °C and d) T = 800 °C.

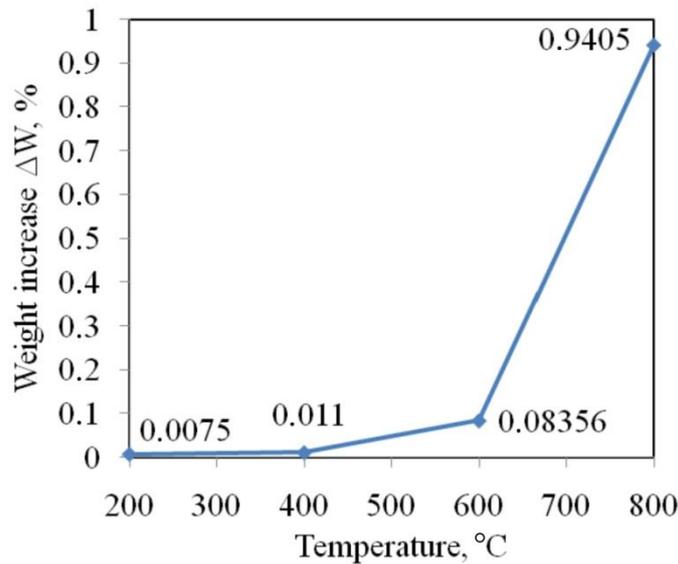
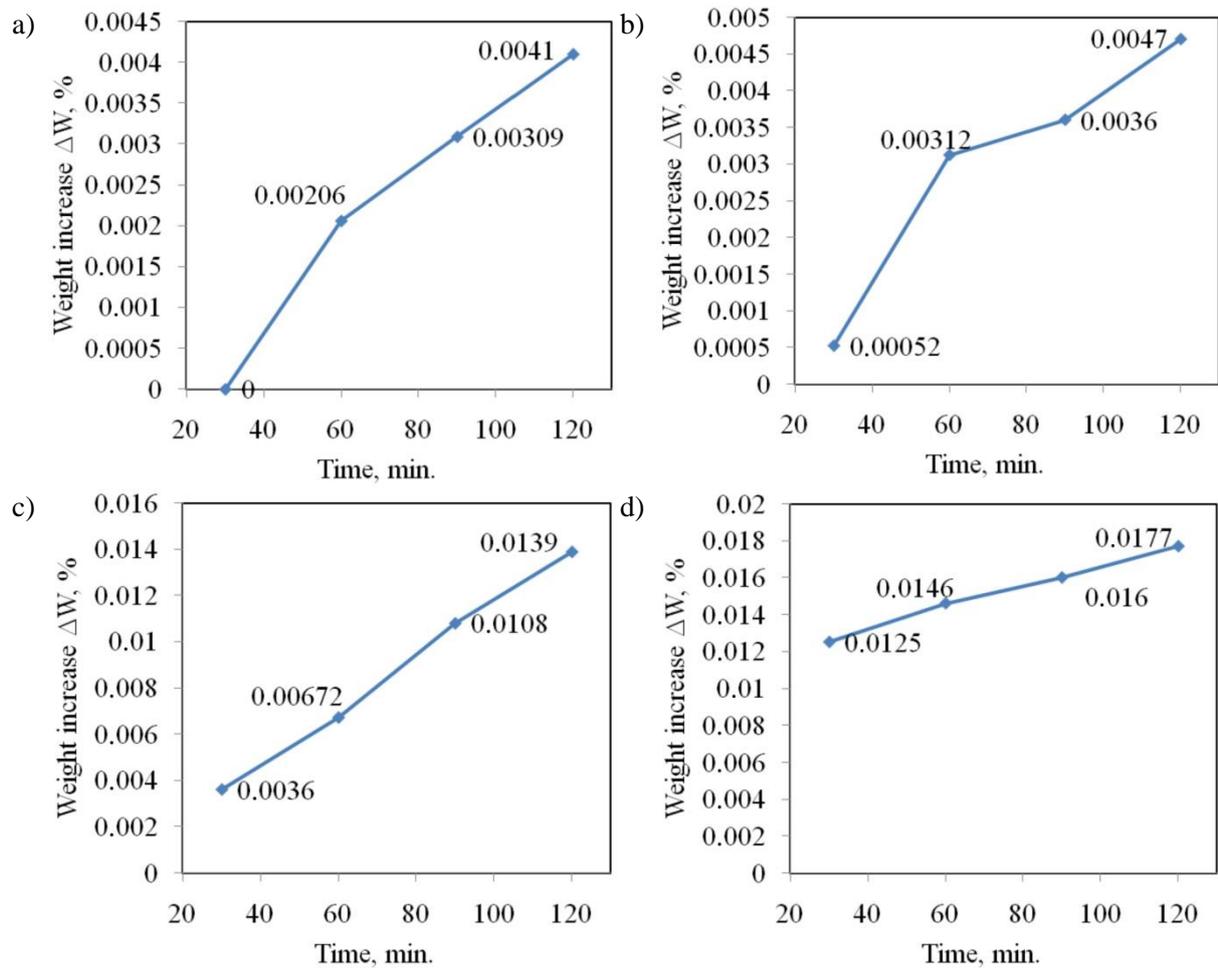


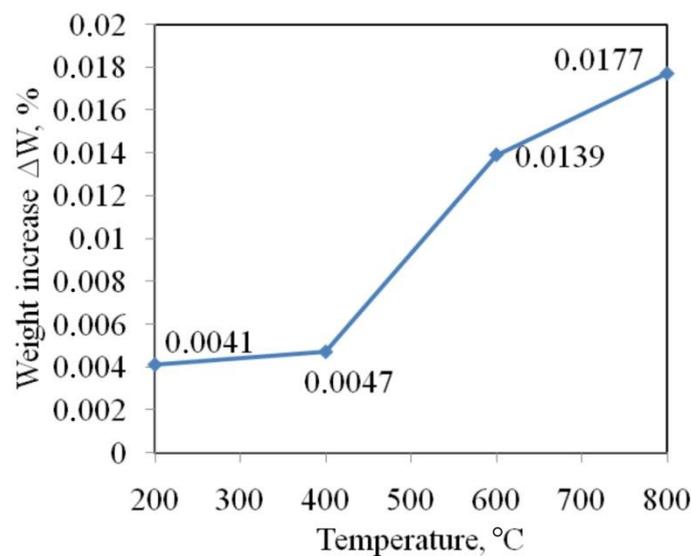
Fig. 7. Variation of oxidation with temperature for non-plated steel (time t = 120 min.).

### 3.3.1. Oxidation behavior of chrome-plated mild steel

Effect of time and temperature on oxidation behaviour of chrome-plated mild steel sample is shown graphically in Figs. 8a)-8d). The experimental result indicates that oxidation behaviour of chrome-plated mild steel increases with time. The experimental result also testifies the strong dependence of oxidation rate on temperature. Moreover, the rate of oxidation increases with temperature Fig. 9.



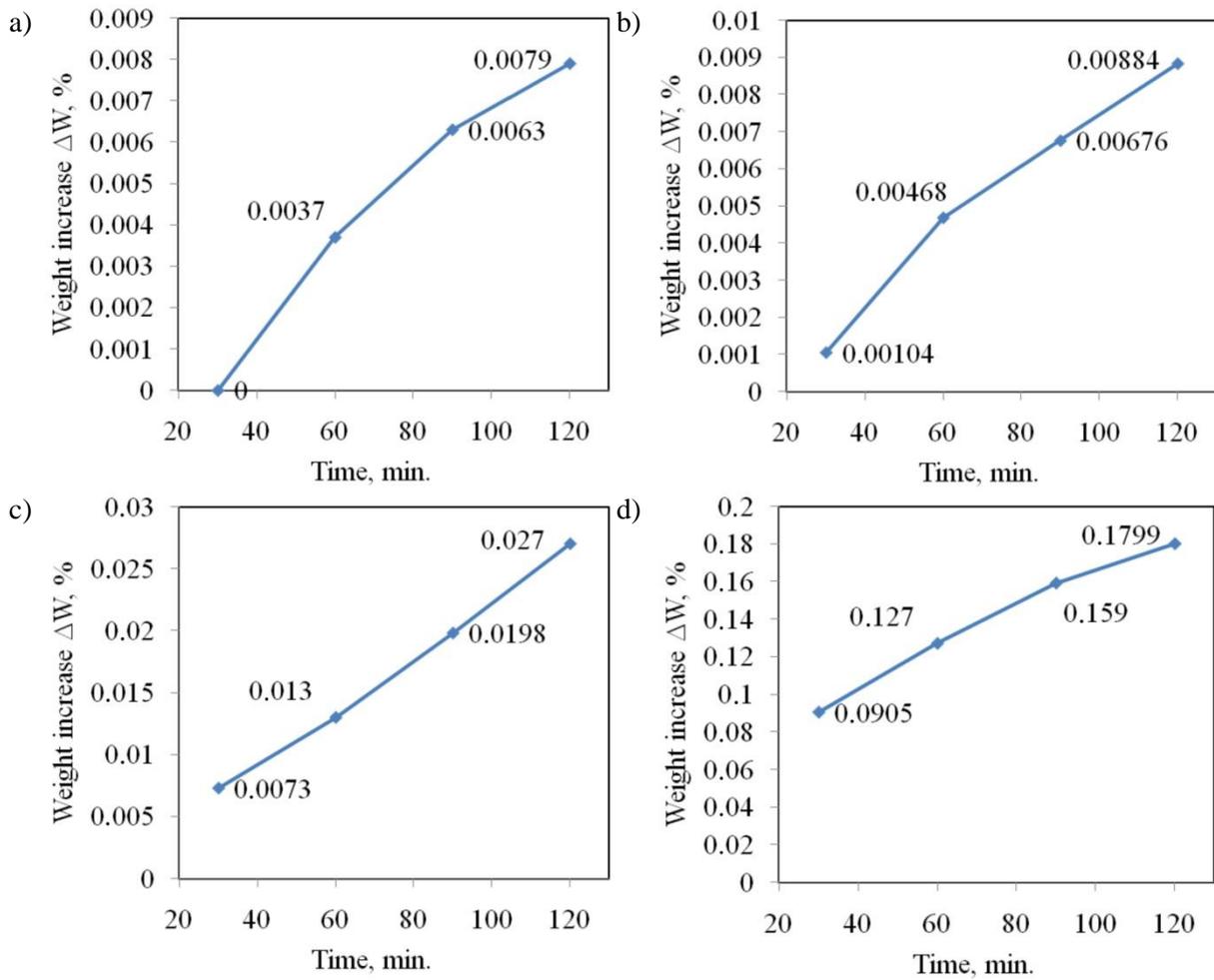
**Fig. 8.** Variation of oxidation with time for chrome-plated steel: a) T = 200 °C, b) T = 400 °C, c) T = 600 °C and d) T = 800 °C.



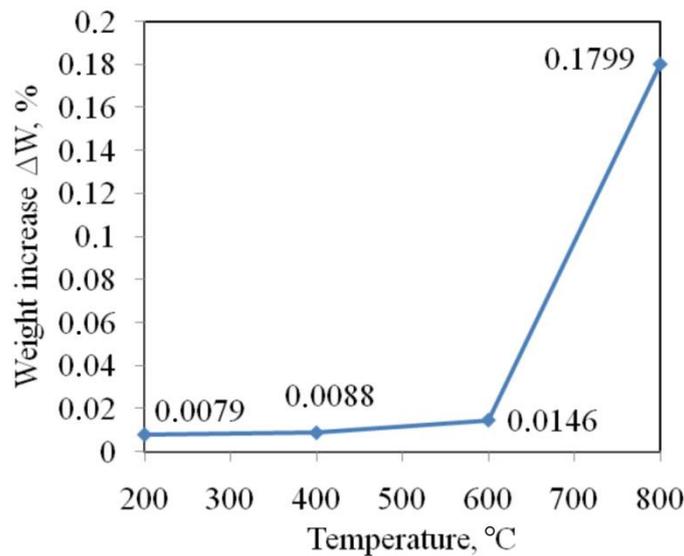
**Fig. 9.** Variation of oxidation with temperature for chrome-plated steel (time t = 120 min.).

### 3.3.2. Oxidation behavior of nickel-plated mild steel

The experimental results of the high-temperature oxidation study of nickel-plated mild steel are presented graphically in Figs. 10a)-10d). The oxidation behavior in nickel-plated mild steel is analogous to that of chrome-plated mild steel. The graphical results demonstrate that the oxidation behavior of nickel-plated steel increases with both time and temperature, as shown in Fig. 11.



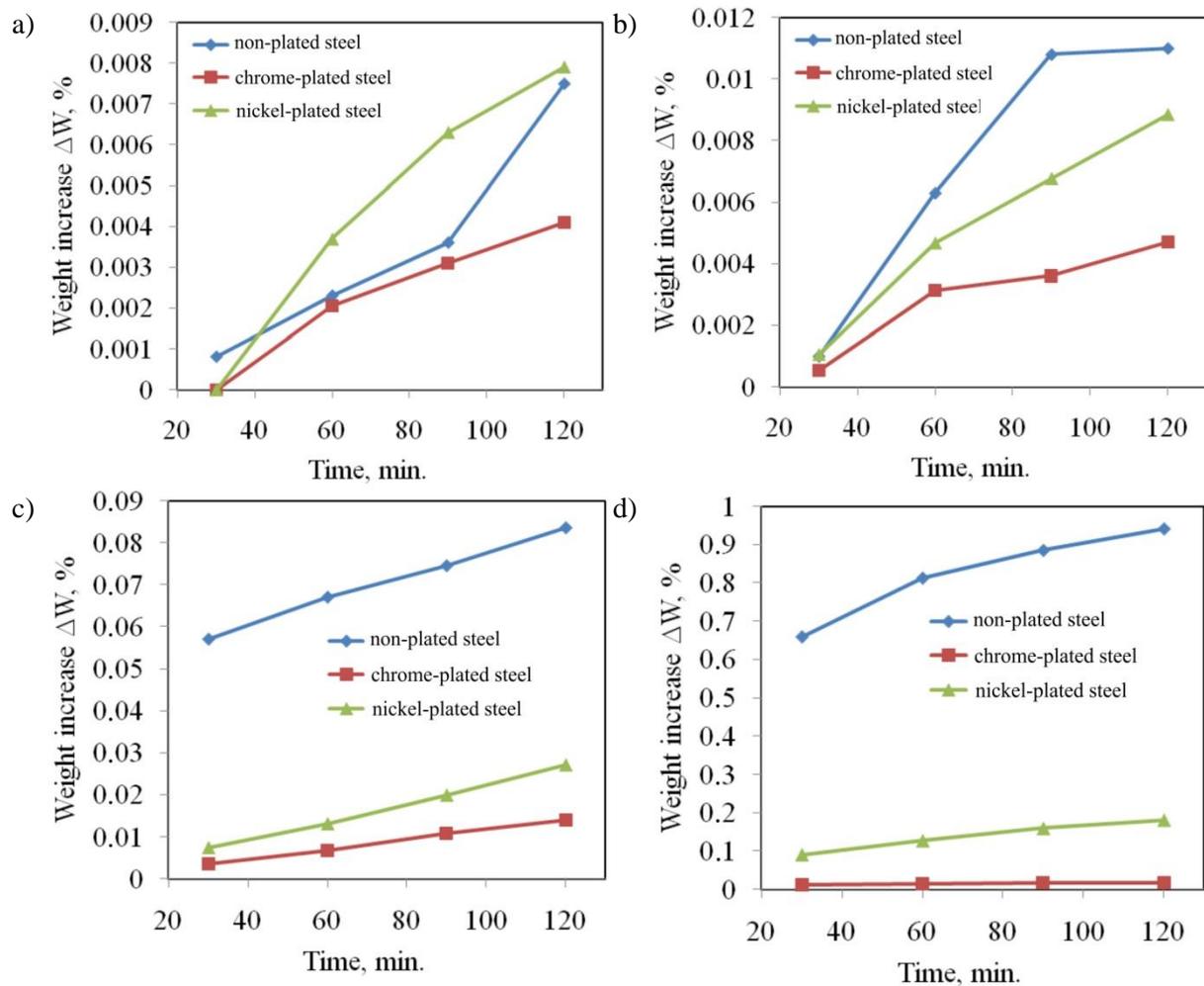
**Fig. 10.** Variation of oxidation with time for nickel-plated steel: a) T = 200 °C, b) T = 400 °C , c) T = 600 °C and d) T = 800 °C.



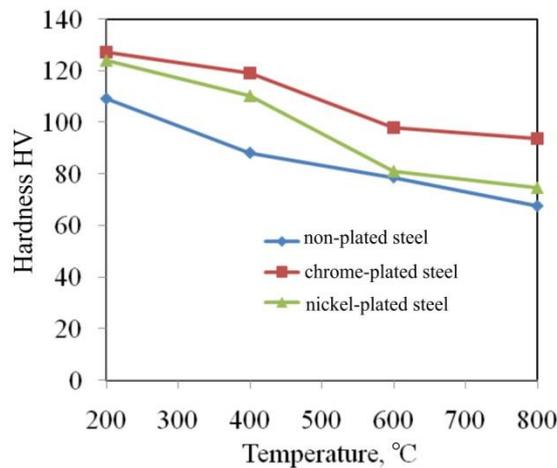
**Fig. 11.** Variation of oxidation with temperature for nickel-plated steel (time t = 120 min.).

**3.3.3. Comparison of oxidation behavior of samples**

The oxidation behaviors of the three samples, heated at the same temperature and for the same duration, have been compared with each other. The oxidation versus time relationship for all three samples (non-plated, chrome-plated, and nickel-plated samples) at a given temperature has been plotted in one graph, as shown in Figs. 12a)-12d).



**Fig. 12.** Variation of oxidation behavior of non-plated and plated mild steel with time: a) T= 200 °C, b) T= 400 °C, c) T= 600 °C and d) T= 800 °C,



**Fig. 13.** Variation of oxidation behavior of non-plated and plated mild steel with temperature (time t = 120 min.).

As shown in Fig. 13, at any given temperature, the weight change (due to oxidation) of non-plated mild steel is higher than that of chromium or nickel-plated mild steel. This indicates that nickel-plated or chrome-plated mild steels exhibit higher corrosion resistance than non-plated mild steel. When comparing the performance of Ni and Cr in terms of corrosion resistance across various temperatures, it is observed that chrome-plated mild steel has higher corrosion resistance (lower corrosion rate) than nickel-plated mild steel.

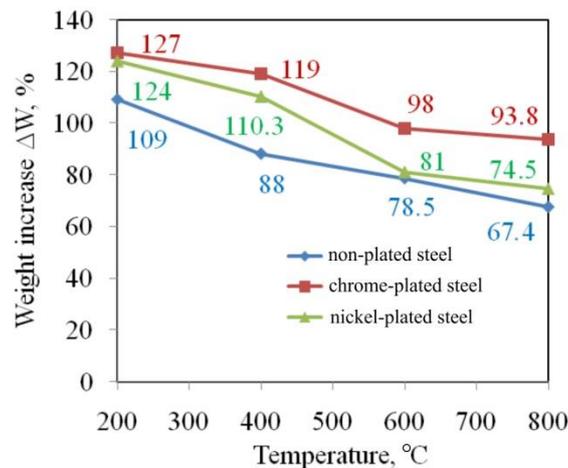
### 3.4. Hardness

The hardness values of non-plated, chrome-plated and nickel-plated samples, heated for a total time of 120 minutes, were determined using a Vickers hardness tester. The aim of this test was to understand whether the formed oxide layers improve the hardness values of the surface or not. The hardness of the non-plated and unheated original mild steel sample is 133.4 HV.

The hardness of the heated mild steel sample was observed to be lower (Table 6 and Fig. 14) than that of the unheated one. When the results were correlated with temperature, it was found that the hardness of non-plated mild steel samples decreases with increasing temperature. The same trend was observed for the chrome-plated and nickel-plated mild steel samples.

**Table 6.** Variation of hardness with temperature of heating for non-plated, chrome-plated and nickel-plated mild steel.

T, °C	Non-plated mild steel	Chrome-plated mild steel	Nickel-plated mild steel	Total heating time
200	109	127	124	120 min
400	88	119	110.3	
600	78.5	98	81	
800	67.4	93.8	74.5	



**Fig. 14.** Variation of hardness with temperature for non-plated, nickel-plated and chrome-plated mild steel (time  $t = 120$  min.).

The same trend was observed for chrome-plated and nickel-plated mild steel samples. The surface hardness results of chrome-plated and nickel-plated samples are also affected by the heating temperature. As the holding temperature increases, the hardness of these plated samples becomes less and less. However, the rate of reduction in hardness of nickel-plated mild steel is observed to be higher than that of chrome-plated or non-plated mild steel.

## 4. Conclusions

In conclusion, the study shows that as the temperature increases, the three ASTM A283GC mild steel samples (non-plated, nickel-plated, and chrome-plated) experience higher rates of oxidation. Non-plated mild steel is the most vulnerable to corrosion, while chrome-plated mild steel demonstrates the best resistance to hot corrosion at all tested temperatures. The surface hardness of all samples decreases with increasing temperature and oxidation. Additionally, oxide scale easily peels off from the non-plated mild steel surface at 800 °C, but this issue is not observed in the plated samples. These findings emphasize the importance of temperature and plating in determining the corrosion behavior of mild steel. The study contributes valuable insights for selecting appropriate materials in applications requiring corrosion resistance in high-temperature environments.

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## **Analiza Charakterystyki Utleniania Wysokotemperaturowego Chromowanych, Niklowanych i Nieplaterowanych Stali Miękkich**

### **Streszczenie**

Metale są najlepszymi materiałami konstrukcyjnymi ze względu na ich doskonałą przewodność właściwą, właściwości mechaniczne i odkształcalność. Jednakże wpływ czynników środowiskowych takich jak tlen i chlor może zmienić ich właściwości elektryczne, chemiczne i mechaniczne. W celu ochrony metali przed korozją opracowano różne metody ochrony, m.in. w procesie galwanizacji. Obecność filmów anodowych lub katodowych na powierzchni podłoża chroni stal przed uszkodzeniami korozyjnymi w temperaturze otoczenia. Niniejszy artykuł skupia się na wpływie temperatury na szybkość utleniania (korozji) próbek stali miękkiej nieplaterowanej, platerowanej niklem i chromowanej. W badaniach uwzględniono zakres temperatury 200-800 °C i całkowity czas ogrzewania 120 minut. Zastosowano piec muflowy z regulowaną temperaturą o maksymalnej wydajności grzewczej 1000 °C. Zmiany masy mierzono co 30 minut w trakcie nagrzewania przy użyciu cyfrowej wagi z dokładnością do 0,001 g. Uzyskane wyniki eksperymentalne próbek ze stali miękkiej ASTM A283GC nieplaterowanej, platerowanej niklem i chromowanej poddano analizie i porównano ze sobą. Badano także wpływ utleniania na twardość powierzchni za pomocą twardościomierza Vickersa. Zaobserwowane zmiany w zachowaniu próbek spowodowane utlenianiem zostały sfotografowane.

**Słowa kluczowe:** metale, korozja, temperatura, twardość powierzchni, powlekanie galwaniczne

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