Testing of black chromium coating on low carbon steel

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Abstract. The problem lies in the colour resistance of the black chromium electroplating results that are not yet known for its effective test methods. The purpose of this research is to find an effective method for testing colour resistance. The methods used include preparing the specimen from motorcycle rim, black chromium electroplating, heating the specimens in Muffle furnace for different temperatures, cooling the specimen to room temperature, measure and calculate the colour state in order to decide the fading level, corroding the specimen in several acidity solutions from chloric acid, calculate the corrosion rate and analysis of the results. The results of the study in the form of (1) measurements with Colourflex showed that heating the low carbon steel rim for 2 hours at 200°C the colour remained dark black, at 250, 300, 350, and 400°C the colours faded 20, 40, 45, and 60% respectively. (2) corrosion test shows that at pH 3, 4, 5, and 6 the corrosion rate is 0.166, 0.136, 0.122 and 0.107 mm/year which the colour begins to fade at pH 4 and increase for more acid.

1. Introduction
Chromium electroplating has been widely used for the purpose of wear resistance of a component, corrosion resistance, and a decorative product. Electroplating with the aim of hardening is generally done by coating in stages with copper coating as a base layer, followed by Nickel coating, and finally coated with chromium. For decorative products made from low carbon steel, it is done by initial coating with Nickel to get a better coating resistant to use, then chromium coating is carried out under certain conditions at the current density and duration of the process with a certain solution, in order to obtain black chromium staining.

Previous experiments had obtained preliminary results indicating shiny and fading colours for certain electroplating conditions. It is not yet known how good the results of the colouring of black chromium and how much colour durability requires testing with certain methods.

The colour resistance of black chromium electroplating has been carried out with various methods including heating test and corrosion test. The real object used is a motorcycle rim made from low carbon steel that has been coated with nickel, then followed by electroplating black chromium at optimum conditions. Colour fading test is done by heating the specimen in an electric furnace for 2 hours for a certain temperature, then measuring its fading with Colourflex. Corrosion test is done by immersion specimen in a solution at a certain acidity and duration of time.

Low carbon steel is used for motorcycle rims because it has a higher strength compared to aluminium rim material, but has the disadvantage of being rusty unless it is coated with nickel or nickel and then chromium.
The development of market aesthetic in white rim nickel coating results tend to decrease and switch to black rims that are increasingly attracting users/teenagers. Low carbon steel is a metal with the main element Fe in group VIII in the periodic element table and the melting temperature of iron is 1538°C, the density of 7.8 g/cm³ about 3 times the density of aluminium, 2.7 g/cm³. Iron in a pure state is rarely obtained because pure iron easily reacts with oxygen in the air and in the process of fusion binds to carbon so that carbon iron is formed.

Iron and carbon steel are distinguished by their carbon content, for pure iron only has a small amount of carbon called ferrite which is relatively pure iron, whereas in most metals iron is steel with a carbon content between 0.01 and about 1.9% and the rest is called cast iron containing carbon between 1.9% and 6.5% maximum which in fact cast iron is produced around 4.3% due to lower melting temperatures whose production requires lower energy. Steel is divided into 3 categories are low carbon steel (LCS), medium carbon steel (MCS) and high carbon steel (HCS) with carbon content in a row between 0.01% and 0.025, 0.025 and 0.55, and 0.55 and 1.9%. Low carbon steel is also known as ST37 [1].

Black motorcycle rims are produced from electroplating that uses black chromium (CrO₃) with the conditions of the process on the current density and duration of immersion in a particular solution. The principle of electroplating based on Michael Faraday’s Law states that electrolysis cells can be used to determine the amount of reacting substances which is proportional to the electric charge used in a certain period. In both Voltaic cells and electrolysis cells, there is a quantitative relationship between the number of substances that react and the electrical charge involved in the reaction and its oxidation.

The principles of Faraday’s Law include: (1) the mass of the substance deposited in an electrode is proportional to the electric current (electron flow) involved in the electrochemical cell, and (2) the equivalent mass of the substance deposited on the electrode is proportional to the electric current flowed in the cell electrochemistry.

The Faraday formula is

\[ w = \frac{(e \ i \ t)}{F} \]  

(1)

where \( w \): mass of substance (g), \( e \): equivalent mass or (M/valence), \( i \): electric current (A), \( t \): time (second), \( F \): Faraday’s constant = 96,485 C/mol [2].

2. Related works

Chromium which is very resistant to corrosion, scratches and wears [3] is widely used as a decorative metal coating material.

A colourimetry shows the value of \( L^* \ a^* \ b^* \) for the colour state where if \( L \) is 0 (zero) means jet black and if 100 is white, if "a" is negative (-) means green and if "a" positive value (+) means red, and if "b" is negative (-) means blue and if "b" is positive (+) means yellow [4].

The results of the study revealed that high-speed oxy-fuel facilities can superimpose NiCrBSi superalloy powder and Cr₃C₂NiCr75/25 alloy powder on machine components that can reach hardness around 850 HV₀.₃ [5] which both alloy elements contain chromium.

Black chromium coatings are widely used in many applications as solar panels, optical instruments and decorative coatings of a product [6]. Nickel electroplating with 0.31 g/cm³ concentration produces the best nickel deposit with a thickness of 5.13 μm at 0.5V for 15 minutes [7]. The current density of 50 A/dm² in electroplating produces the best black homogeneity. In addition to the chromium oxide and hydroxide layers, there is also cobalt oxide, hydroxide and Co₃O₄ plays the most dominant role in affecting the level of blackness [8]. Before electrodeposition of black chromium, bright nickel coating is carried out on steel and copper plates to get the best corrosion resistance and good optical properties in the absorption of solar energy [9]. Trivalent chromium and cobalt coating annealed at 300°C showed results with an increase in hardness from 380 to 460 VHN, and increased corrosion resistance from 41.3 to 77.9%, which offers good absorption [10].

SEM results show that film coatings from chromic acid, acetic acid and barium acetate baths are denser with nano-sized granules than chromic acid, fluorosilicic acid and barium carbonate baths, which are porous, with micro-sized granules [11]. Trivalent chromium coating replaces hexavalent chromium coating because hexavalent chromium coating is toxic and pollutes the environment and health of...
workers even though it provides a hard and wear-resistant and corrosion-resistant coating [12]. The electrical conductivity of the coating results increases with increasing carbon content which has been distributed rather uniformly at all layer thicknesses [13]. Baths of trivalent chromium sulfate-containing formic acid and carbamide as deposits have a nanocrystalline type (3-5 nm) and carbon present as chromium carbide in the layer is evenly distributed with better wear characteristics than hexavalent chromium bath [14]. Cr (Ⅲ) from the Cr-C layer causes cracking due to increased internal stress by excessive carbon content in the main salt concentration and after heat treatment at 400°C, Cr2C3 and Cr7C3 that occur in the layer can increase hardness and show better wear resistance [15]. By using pulse currents, the hardness and wear parameters of the electrodeposits can be increased sufficiently for example, in $t_{on} = t_{off} = 1$ s, the hardness reaches a value of around 1250 HVN, whereas in steady-state electrolysis the hardness is around 900 HVN [16]. The carbon content of Cr-C alloy coatings depends on one of them at a lower pH value and a higher depositional current density resulting in a higher amount of carbon that can enter the alloy [17]. The solar selective coating made by electrodeposition technique from black chromium has the highest absorption rate at 94.6-96% with a voltage of 5V, the distance between the anode and cathode 5 cm and the immersion time of 5 minutes in an electrolytic bath [18].

3. Materials and methods

The research specimen was chosen in the form of nickel coated low carbon steel motorcycle rim with an arc length of 70 mm, 50 mm width, 1.4 mm thickness that was available and bought in trade for the 178 mm (17 inches) rim diameter is shown in Figure 1.

![Motorcycle rim with an arc length of 70 mm, 50 mm width, 1.4 mm thickness.](image)

Figure 1. Motorcycle rim with an arc length of 70 mm, 50 mm width, 1.4 mm thickness.

The electroplating procedure is carried out as follows: (1) Cutting of motorcycle rim with an arc length of 70 mm and making holes for specimen hanging, (2) Cleaning the specimen with a metal cleaner (NaOH 20%), (3) Soaking the specimen in the activation solution (50% HCl: 50% Aquadest) for 3 minutes, (4) Preparation of electrolyte solution for electroplating black chromium in a breaker glass with a concentration of chromic acid (CrO3) 40% and sodium nitrite (NaNO3) 0.5% in 1-litre aqua dest, (5) The electroplating is carried out with the principle shown in Figure 2 with the best conditions at a 5V, a current density of 50-60 A/dm², a duration of 8 minutes and at 50°C, (6) Clean specimens with aqua dest, and (7) Specimens cutting for heating and corrosion testing.

![The electroplating principle involves the measurement of voltage and current.](image)

Figure 2. The electroplating principle involves the measurement of voltage and current [19].
The black Chromium was measured by Colorflex machine on the surface before and after heating at 200, 250, 300, 350, 400°C for 2 hours and then calculate the colour fading. The black chromium corrosion test on motorcycle rim was carried out by immersion in the solution with a certain acidity level for 1 week so that the known difference in weight (weight lost) dissolved into the acid solution which was then calculated as a corrosion rate. The flow diagram of the colour resistance research is shown in Figure 3.

![Flow Diagram](image)

**Figure 3.** The flow diagram of the colour resistance research of the black chromium.

The methods studied were colour fading (after being heated at a certain temperature and duration of time) and weight loss after corroding.

The results of the composition test of the motorcycle rim specimens are shown in Table 1.

| No. | Element | %  | No. | Element | %  |
|-----|---------|----|-----|---------|----|
| 1   | C       | 0.058 | 10  | Al      | 0.033 |
| 2   | Si      | 0.013 | 11  | Co      | <0.005 |
| 3   | Mn      | 0.254 | 12  | Mg      | <0.005 |
| 4   | P       | 0.13  | 13  | Nb      | <0.005 |
| 5   | S       | <0.010 | 14  | Ti      | <0.005 |
| 6   | Cr      | <0.010 | 15  | V       | <0.005 |
| 7   | Mo      | <0.010 | 16  | W       | 0.100  |
| 8   | Ni      | 0.185 | 17  | Fe      | 99.42  |
| 9   | Cu      | <0.005 |      |         |       |

### 4. Results and discussion

The data in column $\Delta E$ in Table 2 is obtained from the formula $\Delta E = \sqrt{(L^*)^2 + (a^*)^2 + (b^*)^2}$. For the $L^*$ value obtained by reducing the standard $L^*$ value according to [https://colorlib.com/etc/metro-colors/](https://colorlib.com/etc/metro-colors/) which is $L^* = 10.767$ with the value obtained from the reading on the Colorflex machine that is 9.24 then squared, 10.767-9.24=1.527 which then squared is obtained 2.332, likewise for $a^*$ and $b^*$ obtained in the same way. Value of $\Delta E = \sqrt{(L^*)^2 + (a^*)^2 + (b^*)^2} = \sqrt{(2.332 + 0.3481 + 0.545)} = 1.7959$. The value of $\Delta E$ as a resultant value of a combination of 3 colour elements is, in fact, a rim specimen that has been coated with black chromium that has been heated for 2 hours at 200°C which in reality still does not change at all with the appearance as at room temperature, namely 100% black or jet black.
Table 2. Colorflex reading data for L*, a*, and b* black chromium motorcycle rims.

| Specimen code | L*  | a*  | b*  | ΔE   | Remarks       |
|---------------|-----|-----|-----|------|---------------|
|               | 10,767 | -0.59 | 0.74 |      |               |
| A (Without heating) | 9,24  | -0.59 | 0.74 |      | 100% black    |
| B (heating 2 h at 200°C) | 2,332 | 0.3481 | 0.545 | 1,7959 |               |
| C (heating 2 h at 250°C) | 12,7663 | 0.0841 | 1.7371 | 3,819 | 20% faded     |
| D (heating 2 h at 300°C) | 15,97 | -0.72 | 1.64 |      |               |
| E (heating 2 h at 350°C) | 27,0712 | 0.5184 | 2.6830 | 5,5021 | 40% faded     |
| F (heating 2 h at 400°C) | 30,5035 | 0.64 | 4.3180 | 5,9549 | 45% faded     |

Table 2 shows that heating the motorcycle rim after coated with black chromium at 200 to 400°C after reading with Colorflex shows a fading of 20 to 80%. Specifically, the ΔE value for the F code specimen Colorflex reading values are no longer appropriate, because of the possibility of overheating which has caused the black chromium layer to burn which may occur on the surface of the rim there is a thin layer of charcoal.

Specimens with code A is specimen without heating, and specimens that are heating at 200, 250, 300, 350 and 400°C have codes B, C, D, E, and F is shown in Figure 4. The faded color causes the absorption of solar energy to decrease as it has been stated that the highest absorption rate of 94.6-96% was achieved at the electroplating process at 5V which has been the same carried out in this study and previous researchers [18].

Figure 4. Specimens: A, without heating, and B-F, heating at 200, 250, 300, 350 and 400°C.

The corrosion rate of black chromium coating on the rim in one liter Aqua dest with 0.015 ml HCl for pH 3, with 0.01 ml HCl for pH 4, with 0.001 ml HCl for pH 5 and with 0.0001 ml HCl for pH 6, which is immersed for 168 hours (1 week) whose results are shown in Figure 5.

Figure 5. The corrosion rate of the black chromium coating on the rim in the HCl solution.
The corrosion resistance of black chrome coatings at the highest 95.9% was achieved at annealing at 300°C but decreased to 77.9% at 400°C which indicates that the colour resistance of more than 300°C has decreased [10]. Similar to heating at 400°C on black chromium on motorcycle rims experience high colour fading up to 80% is shown in Figure 6. In this study, a current density of 50 A/dm² was selected in the same electroplating process carried out by other researchers which produced the best black homogeneity where in addition to chromium oxide and hydroxide layers, there were also cobalt oxides, hydroxides and Co₃O₄ which played a dominant role in producing the dark level [8].

![Figure 6. Corrosion test specimen of black chromium on motorcycle rims before (top side) and after (bottom side) immersed in corrosive solutions.](image)

Testing the colour resistance of the 2 methods from the results of the black chromium electroplating shows that the heating test provides a simpler implementation and immediately results in fading degradation, while the other test for corrosion test requires long time because it awaits the process of corroding layer until the colour fades.

5. Conclusions
The conclusion of colour resistance testing of the black chromium rim are (1) The resistance of black chromium still shows a dark black by heating to 200°C for 2 hours, the rest at 250, 300, 350, 350, and 400°C experience fading successively at 20, 40, 45, 60, and 80%, and (2) Corrosion resistance decreases with increasing acidity which the colour begins to fade at pH 4 and more acid with corrosion rates respectively at 0.166, 0.136, 0.122 and 0.107 mm/year at pH 3, 4, 5, and 6 which the colour begins to fade at pH 4 and increase for more acid. For further works it is necessary to carry out hardness, scratch and compression tests of motorcycle rims so that it can be proven that the coating remains firmly attached and nothing is peeled off.

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