

## Novel Additives for Ni Electroplating that Eliminate Wastewater Production

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(Received on 12<sup>th</sup> March 2015, accept in revised form 4<sup>th</sup> July 2016)

**Summary:** The focus of this study is to improve the physical properties of electroplated Ni films, such as corrosion resistance, electrical resistivity, plating thickness, and adhesion force. The organic additives 2-mercaptobenzimidazole, 2-mercaptobenzothiazole, and thioglycolic acid were used in the electroplating bath for this purpose. The resulting Ni films were characterized by spectrophotometry, electron microscopy, and hardness tests. The implications for wastewater production associated with Ni plating are discussed within the context of these organic additives.

Keywords: Electroplated Ni, 2-mercaptobenzimidazole, 2-mercaptobenzothiazole, Thioglycolic acid

### Introduction

Market requirements in the metal plating industry have forced manufacturers and producers to develop new plating processes that increase corrosion life, electrical properties, hardness, and toughness. This requirement results in a need to study bath compositions and the organic chemicals used in the process, since these parameters affect plating bath efficiency. Watts-type Ni plating baths are the most commonly used, as the Ni salts they contain are readily available. This has led to the development of similar bath compositions, such as Ni sulfide baths [1] or baths that replace the traditional boric acid with lactic acid [2]. The electrolytic and electroless Ni baths developed by Ebrahimi *et al.* [3] represent improvements to the Ni plating process that are widely accepted by the metals industry. Several attempts have been made to improve the physical properties of electroplated Ni on an industrial scale by varying the bath composition through the use of chlorides, nitrates, acetates, and Ni methanesulphonic acid [4]. At the same time, there are several published and patented works based on the successful industrial application of Ni plating baths based on Ni sulfate ( $\text{NiSO}_4(\text{H}_2\text{O})_6$ ), Ni chloride ( $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$ ), and Ni sulfamate ( $\text{H}_4\text{N}_2\text{NiO}_6\text{S}_2$ ) salts [5]. The effects of diamin [6], propargyl alcohol (PA), butynediolethoxylate (BEO), and pyridinium sulphobetaine (PPS) additives were also investigated [7]. Gezerman *et al.* also studied the Ni plating process from the viewpoint of wastewater treatment and used an acetylacetonate complex salt [8-11].

Ni electroplating has also been investigated in detail within the context of electrodeposition of Ni-based composites and alloys. This is especially pertinent as many Ni-based alloys are used for industrial coatings. For instance, Wang *et al.* studied the electrochemical behavior of the Ni-P

electroplating process [12], which was later used as a thermal barrier due to its intrinsic thermal resistance properties [13]. In that same vein, the role of Ni electroplating during fabrication of Ni-TiC nanocomposites in traditional Watts-type baths have also been explored [14]. Ni-boride plating has also been achieved by Hofmann *et al.* on boron carbide particles [15].

In this study, the behaviors of 2-mercaptobenzimidazole, 2-mercaptobenzothiazole, and thioglycolic acid were investigated as electrolyte additives in Ni plating baths. The bath itself was composed from Ni acetate, Ni chloride, boric acid, and acetic acid rather than using a traditional Watts-type bath [16]. The behavior and property of the resulting Ni layers was comparable to materials prepared through electroless Ni plating processes. Additionally, the corrosion and adhesion disadvantages associated with electroplated Ni baths are avoided by adding these organic additives. Further, this new bath promises to mitigate wastewater problems associated with conventional Ni plating baths.

### Experimental

#### Chemicals and Solutions

2-Mercaptobenzimidazole (98.0 %), 2-mercaptobenzothiazole (99.0 %), and thioglycolic acid (98.0 %) were obtained from Merck, Istanbul, and used in this study. The acidic bath used in electroplated Ni was prepared from two stock solutions (Tables-1 and 2). Two baths of 75 and 1000ml were prepared from these two solutions. The pH was adjusted to 4.8 and the solutions were heated to 90°C under working conditions. Buffer solutions were prepared to replenish the basic components in

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the Ni plating bath. The bath was composed of two main solutions including the Ni sulfate solution and the hypophosphite solution. This buffer solution is known as the reduction solution. Ni sulfate (45 g) was diluted in distilled water to 100 ml. This solution was used for replenishing the Ni in the plating bath. The compounds shown in Table 7 were mixed in a beaker and diluted to 100 ml. The resulting solution was used for replenishing the hypophosphite.

Table-1: Chemical composition of the first stock solution in a Ni plating bath.

Chemical composition	CAS No.	Concentration (g/L)
Distilled water	7732-18-5	828
Nickel sulfate (99.9%)	7786-81-4	360
Sulfuric acid (99.9%)	7664-93-9	32

Table-2: Chemical composition of the second main solution in a Ni plating bath.

Chemical compound	CAS No.	Concentration (g/L)
Distilled water	7732-18-5	309
Potassium hydroxide (99.9%)	1310-58-3	220
Maleic anhydride (99.0%)	108-31-6	10
Lactic acid (90.0%)	50-21-5	133
Glycolic acid (98.0%)	79-14-1	133
Sodium acetate (99.9 %)	127-09-3	200
Sodium hypophosphite (99.9 %)	10039-56-2	320

### Electroplating Procedure

Before plating, the substrates were cleaned, dried, weighed, and labeled. After drying, the samples were immersed in 2% sulfuric acid for 2-5 s, rinsed with water, and placed in the Ni plating bath. Plating was performed at 90°C for 10 min at a fixed current density of 0.3 A/ cm<sup>2</sup>. After plating, all samples were rinsed with tap water, dried, and

weighed. The pH was then checked and Ni analysis was conducted. A total of 12 stainless steel substrates were plated, and the plating ratio for each plate was calculated. A total of four plating baths were prepared. Plating baths 1-4 were prepared by diluting 75 mL of the bath solution to 1 L. The bath compositions and plating results for each bath are shown in Tables 3-6. Representative samples from the selected substrates were imaged under a scanning electron microscope (SEM), and the results are shown in Figs 1-4.

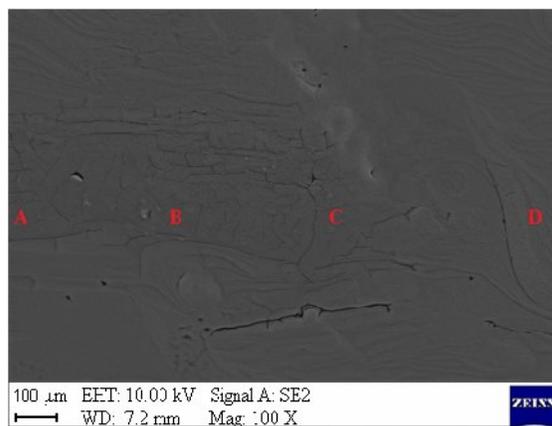


Fig. 1: SEM image of plated material (3 mL/L of 2-mercaptobenzimidazole + 4 mL/L of thioglycolic acid+ 2 mL/L of 2-mercaptobenzothiazole in Ni plating bath).

Table-3: Plating performed in bath solution No.1.

Material no.	Chemical additive	Weight before plating(g)	Weight after plating(g)	Plating speed(μm/h)
01	1,0 ml2-mercaptobenzimidazole	33.5632	33.5632	0
02	1,0 ml2-mercaptobenzothiazole	33.4147	33.4147	0
03	1,0 ml thioglycolic acid	33.7166	33.3940	0

Table-4: Plating performed in bath solution No.2.

Material no.	Chemical additive	Weight before plating(g)	Weight after plating(g)	Plating speed(μm/h)
04	2,0 ml2-mercaptobenzothiazole	33.9627	34.7547	25.42
05	2,0 ml2-mercaptobenzimidazole	33.4948	34.5026	32.35
06	2,0 ml thioglycolic acid	33.6508	34.4758	26.48

Table-5: Plating performed in bath solution No.3.S

Material no.	Chemical additive	Weight before plating(g)	Weight after plating(g)	Plating speed(μm/h)
07	3,0 ml thioglycolic acid	33.0306	33.0446	0.44
08	3,0 ml2-mercaptobenzimidazole	32.9714	32.5681	12.94
09	3,0 ml2-mercaptobenzothiazole	32.9390	32.9390	0

Table-6: Plating performed in bath solution No.4.

Material no.	Chemical additive	Weight before plating (g)	Weight after plating (g)	Plating speed(μm/h)
10	4,0 ml thioglycolic acid	33.0306	33.0446	0.44
11	4,0 ml2-mercaptobenzimidazole	32.9714	32.5681	12.94
12	4,0 ml2-mercaptobenzothiazole	32.9390	32.9390	0

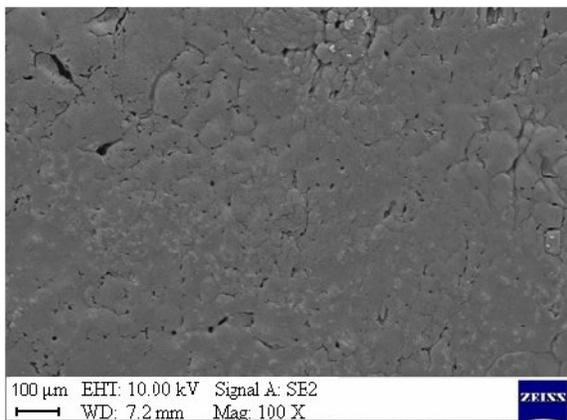


Fig. 2: SEM image of plated material (3 mL/L of 2-mercaptobenzimidazole in Ni plating bath).

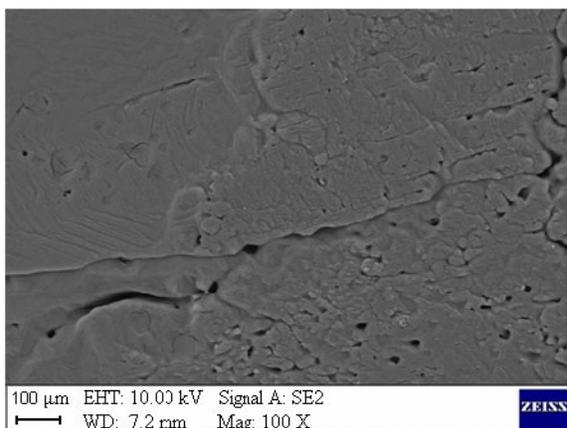


Fig. 3: SEM image of plated material (4 mL/L of thioglycolic acid in Ni plating bath).

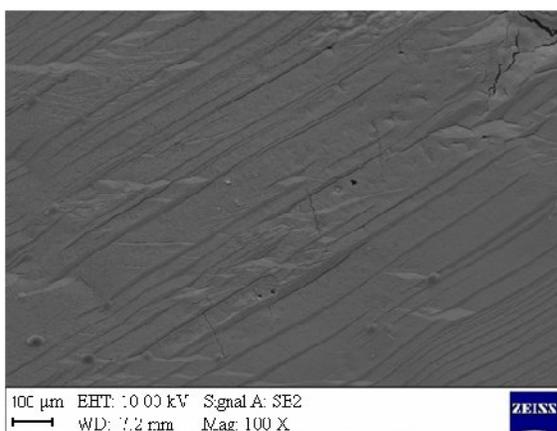


Fig. 4: SEM image of plated material no.4 (2 mL/L of 2-mercaptobenzothiazole in Ni plating bath).

Table-7: Components of a reduction solution.

Chemical Compound	CAS No.	Concentration(g/L)
Potassium hydroxide (99.9%)	1310-58-3	10
Maleic anhydride (99.0%)	108-31-6	0.5
Lactic acid (90.0%)	50-21-5	6.7
Glycolic acid (98.0%)	79-14-1	6.7
Sodium acetate (99.9 %)	127-09-3	6.7
Sodium hypophosphite (99.9 %)	10039-56-2	16.7
2-mercaptobenzimidazole (98.0%)	583-39-1	
2-mercaptobenzothiazole (99.0%)	149-30-4	
Thioglycolic acid (98.0%)	68-11-1	

#### Materials Characterization

For Ni analysis, 10 mL of the bath solution, 100 mL distilled water, 5 ml ammonia, and approximately 0.5 g murexide (99.0 %) were placed in an Erlenmeyer flask. The solution was immediately titrated with ethylenediaminetetraacetic acid (EDTA) until a purple color was observed, and the consumption of EDTA (S) was recorded. The consumption of EDTA (S) was converted to a concentration (g/L) of metallic Ni through the following equation:

$$(S) \times 0.587 = \text{g/L metallic Ni} [11].$$

The pH decreased as the plating progressed. Therefore, the pH was adjusted using dilute ammonia. Ni sulfate and reduction solutions were prepared for replenishing the material lost during electroplating. For every 1 g/L Ni, 10 ml of the Ni sulfate solution was added. After this addition, for each 10 mL of the Ni sulfate solution, 8 ml of the reduction solution was added.

The layer structure of the electroplated Ni was investigated by shear testing (Dage Series 4000 Bond tester) [17]. After shear testing, the fracture surfaces were investigated using SEM (Zeiss Supra 55) with an accelerating voltage of 10.0 kV, a working distance of 7.2 mm, and a magnification 100x. The thickness of the Ni films was measured using X-ray diffraction (Fischer Instruments GmbH, 2002). Melting points were determined according to the refractory–metallized areas method [18]. Density was measured using the associated dimensional change [19]. The mass and dimensions of the test material were measured using a three-coordinate measuring machine. The plating thickness was determined under a graduated-scale microscope after metallographic polishing. The electrical resistivity was measured using a super-megaohmmeter electrometer (Model RM 170). Adhesion strength was evaluated by a heat-quench test where plated materials were heated at 250 °C for 2 h and quenched in air. The microhardness of the Ni was measured using a diamond indenter. Materials electroplated from each of the four bath solutions

were subjected to a pull test using a universal testing machine for measurement of the tensile strength [19]. Pull tests were deemed successful if there was no separation of the Ni coating from the substrate and if it had a tensile strength force of approximately 3500 N. The tensile strength values of the plated materials were examined over the range of 3650–3800 N.

Elongation was evaluated using the “Pressure Bulge Test for Thin Film Characterization” [20]. In this test, a digital oscilloscope (Nicolet, model 40, bandwidth 100 MHz) was used for recording the pressure loading signal. Images were collected with a CCD camera (Sony, XC-75) after pressure. The abrasion resistance of Ni-plated materials in this study was evaluated according to ASTM D2670-67 [21]. For this analysis, a Falex machine was used.

The friction characteristics of the Ni layers were tested on a fully computerized microtribometer (Model UMT-2) [22] equipped with a friction counterpart of a cemented carbide ball (diameter = 5 mm). A load of 5 N and sliding speed of 2 mm/s were used. The total elapsed time for each plated material was 15 min.

A solderability test was designed to evaluate the solderability and wettability of the soldering material to the electroplated Ni layer. The test was performed by soldering the plated materials and evaluating the soldering points using a pull test for mechanical characterization of the soldering interface. Each test material was prepared from two pieces which were plated with approximately 20  $\mu\text{m}$  of electroplated Ni. After plating, the two pieces were placed on an aluminum jig and heated on a hot plate to the melting temperature of the solder (350–400 °C) to fill the 0.2 mm gap with solder. After cooling, each piece was removed from the screws of the jig and, the soldering parts were machined [19].

Corrosion resistance was evaluated by placing the plated material into a 5 % NaCl solution at a pH of 7.0. The time required for discoloration of the Ni during corrosion was recorded. To evaluate the corrosion performance of plated materials in this study, immersion for 96 h was sufficient.

The color of the metal plate was examined in the CIE (Commission Internationale De l'éclairage/The International Commission on Illumination)  $L^*a^*b^*$  color space [23] using a visible wavelength spectrophotometer (Macbeth CMC-CE-7000-XL0339) at 325 nm and CIE Standard

Illuminant D65, which is equivalent to 6500 K illumination.

## Results and Discussion

### Physical properties of electroplated Ni

Electroplated Ni materials have homogeneous metallic structures known as metallic glass, which are absent of microvoids. However, heat treatment can result in microvoid formation [17]. The amount of phosphorus, which depends on the chemical composition of the bath, changes the plating rate, layer formation, and mechanical strength. Hence, the structure of the plated Ni layer will also change. The shear height was determined to be 100  $\mu\text{m}$  at a shear rate of 550  $\mu\text{m}/\text{h}$ .

Uniform plating layers with the required thicknesses between 2.5–25  $\mu\text{m}$  were achieved. For parts that require higher corrosion resistance, a plating thickness between 25–75  $\mu\text{m}$  is preferred. The surface roughness increased as the plating thickness increases. Thickness values as measured by X-ray diffraction are shown in Table 8 and range from 10–15  $\mu\text{m}$  with adhesion forces between 2–2.8  $\text{kg}/\text{cm}^2$ .

Table-8: Interdependence of physical parameters in the plating process.

Adhesion force ( $\text{kg}\cdot\text{cm}^{-2}$ )	Thickness of the Ni plating ( $\mu\text{m}$ )
0	0
2	10
2.2	11
2.4	12
2.6	12
2.8	14
3.0	15

Uniform plating is important for achieving required material performance. In electroplating, the thickness depends on the material configuration, geometry, and distance to the anodes [4]. Electroplating can provide a uniform thickness over the entire material [5]. In the present study, the plating thickness was uniform over the entire material surface. As shown in Fig. 1, four different points were selected for SEM imaging of the plated material. Thicknesses measured at these points were similar for the entire surface of a sample (Table 9).

Table-9: Selected points in the plated material in Fig 1.

Signed point	Thickness of the Ni plating ( $\mu\text{m}$ )
A	10.5
B	11.1
C	10.7
D	10.3

Electroplated Ni is a eutectic alloy that has a wide range of melting points. The change in the melting range depends on the phosphorus content. As the phosphorus content decreases, the melting range increases. Thermal properties of electroplated Ni are different from the thermal properties of pure Ni. One such difference is the high temperature resistance to oxidation. The melting point of pure Ni is 1455°C. However, the melting point of electroplated Ni decreases significantly when different compounds are added to the plating bath. In this study, the melting point of Ni that was electroplated from a bath containing 2-mercaptobenzimidazole, 2-mercaptobenzothiazole, and thioglycolic acid was 1060°C.

The density of electroplated Ni decreases as the phosphorus content increases. The densities of electroplated Ni with low and high phosphorus contents were 8.5 and 7.75 kg/cm<sup>3</sup>, respectively [5]. The thickness of the plated Ni was between 10-15 µm. In this study, the density of the plated electroplated Ni was found to be in the range of 7.28 to 7.32 g/cm<sup>3</sup>.

The change in the electrical properties of the substrate depends on the Ni plating layer. Layers that have a high phosphorus content are less conductive than copper. The resistivity of a layer with low phosphorus content was 20 µΩcm [25]. For applications that require low electrical resistivity, thin plating layers are deposited. Heat treatment and bath composition can affect resistivity. Heat treatment of the Ni layer resulted in phosphorous precipitation and a corresponding doubling of the conductivity. Phosphorus also affects the thermal expansion of the Ni layer [5]. The measured electrical resistivity values are shown in Table-10. These results indicate that the electrical resistivity increases with addition of 2-mercaptobenzimidazole, 2-mercaptobenzothiazole, and thioglycolic acid.

Table-10: Electrical resistivity of the plated material.

Bath solution	Electrical resistivity(µΩcm)
1	19
2	20
3	18
4	17

#### *Mechanical properties of electroplated Ni*

Electroplated Ni has similar properties to other electroplated amorphous materials in that it has high mechanical and corrosion resistance while being elastic. The testing methods and results of the determination of several physical properties such as

penetration, hardness, tensile strength, and elongation are explained below.

The penetration of the Ni layer is significant on several substrates [26]. Microscopic particles on the substrate were cleaned using a bath solution, creating a metallic bond between the Ni layer and the substrate surface. The initial reaction occurred on all catalytic materials. However, penetration decreased on non-catalytic metals. The reaction was initiated by applying a very thin electroplated Ni layer. On aluminum substrates, hydrogen in the Ni layer was released by a baking process at 130 – 200°C for 1-4 h. Diffusion of the Ni layer into the substrate increased the bond strength. The adhesive strength between the Ni layer and the steel was 85 – 100 MPa. No cracks, blisters, discoloration, or peeling of the plating were observed after testing [19].

Hardness is the most important feature of electroplated Ni. The microhardness of the plated Ni layer was 500 - 700 (HV100). This value is equal to approximately 45 - 58HR(Rockwell), which is the same as that of hardened alloy steel [19]. Because of the thermal properties of materials such as brass, copper, and stainless steel, and the specific properties of the substrate, high temperature treatment could not be applied. In this case, if treatment was performed at a lower temperature for a longer time, the required hardness could have been obtained. A Rockwell hardness of 950–1000 was obtained after heat treatment at 340°C for 4–6 h or at 290°C for 10–12 h. A lower hardness was obtained upon heat treatment at 260°C. A small increase was obtained upon heat treatment at temperatures below 230°C. Hardening treatment is not preferred at lower temperatures. As such, heat treatment was performed for 2–4 h at 180–200°C to increase the adhesive strength between the substrate and the plated material. The heat treatment was also performed to decrease the tension by removing hydrogen from the plating layer. A Vickers hardness value was obtained with a load of 50 g by averaging four measurements from each bath. The microhardness of Ni layers before heat treatment was in the range of 760–785 HV. An increase in Vickers hardness from 188 to 294 HV was observed after heat treatment at 230°C for 2 h.

The elongation changed with the composition of the plated Ni material. The resistance to elongation was higher than some engineering materials such as zinc and copper. Thin electroplated Ni is quite flexible, and does not crack upon bending. As the thickness of the electroplated layer increases, the brittleness also increases. Therefore, Ni electroplating can be performed on a variety of

different shapes and complex morphologies. However, it cannot be applied on substrates that require bending, as small deformations can cause corrosion and low abrasion resistance. Low phosphorus ratios or sulfur containing agents can increase the resistance to rupture. According to the results of this experiment, the elongation of the plated layer changed from 1.1 to 2.4%.

Abrasion describes the removal of material from the surface. Ni metal and alloys possess significant resistance to abrasion. Laboratory experiments show that resistance to abrasion for heat-treated Ni is the same as hard chromium platings. This result suggests the need for high alloy steel materials or hard chromium platings for any surface. The abrasion testing results for each sample are listed in Table 11 for the maximum applied load. The maximum load listed for samples 1–2 was recorded without breaking. However, the maximum load for samples 3–4 was recorded just before breaking. These results suggest that if the amount of organic additives increases, the plated layers have increased abrasion resistance for all four baths.

Table-11: Falex testing results of Ni plating bath solutions.

Plated material in each bath solution	Maximum load(Nm)
1	338.9
2	451.9
3	338.9
4	107.3

The friction coefficient of the lubricated and unlubricated layers was 0.13 and 0.6, respectively. These qualities prevent overheating when using the material. Small friction coefficients also prevent effects like over-expansion and contraction due to heating and cooling by friction.

The electroplated Ni in this study could be soldered easily. In the electronics industry, Ni-plated metals such as aluminum are prepared using electrolytic processes. The welding point of Ni alloys is lower than pure Ni. Additionally, alloy impurities such as phosphorus diffuse and embrittle the steel, which makes welding difficult. A different process has been reported using high purity stainless steel anodes [19]. Electroplated Ni layers are easily soldered using an acidic flux. Without the flux, heat treatment can make soldering difficult.

Electroplated Ni plating can isolate the substrate from the ambient environment. As such, the electrolytic Ni layer can impart corrosion resistance

to the substrate material. This corrosion resistance depends on the phosphorus ratio, the thickness, surface pre-treatment, final treatment after plating, and the substrate itself. This resistance is due to its chemical passiveness, which is also a function of the phosphorus ratio [19]. Because it provides superior corrosion resistance; it can be used for designing a plating material. The material should not become harder after plating, because it can lower the corrosion resistance [19]. Electroplated Ni results in a more amorphous structure compared with electroplating. Heat treatment can decrease the phosphorous content in Ni layers, which affects the corrosion resistance and the properties of the amorphous structures. The amorphous structures convert into structures with micro-cracks because of physical changes. The corrosion resistance of the Ni layer decreases if its hardness increases during heat treatment. Therefore, heat treatment should be avoided if corrosion resistance of the material has to be retained [19]. To evaluate the resistance of the electroplated Ni in a corrosive atmosphere, an accelerated corrosion test was performed. If there was no discoloration on the plated surface in the stipulated time, the test was terminated. In this study, the plated material showed discoloration after 5 days in 5% NaCl solution.

A color analysis was performed using a spectrophotometer to observe the effects of 2-mercaptobenzimidazole, 2-mercaptobenzothiazole, and thioglycolic acid on the plated metal surfaces. These values are in accordance with European and Japanese standards. Two measurements were performed for each plate surface. Our aim was to achieve high sensitivity in the visible color region and to supply the closest values to market requirements. Visible color spectrophotometry is not currently used for color analysis in the metal plating industry. However, this technique was used in this study because of the sensitive viewing properties of 2-mercaptobenzimidazole, 2-mercaptobenzothiazole, and thioglycolic acid in Ni plating. This system enables a comparison of the measured color values. Organic chemicals such as 2-mercaptobenzimidazole, thioglycolic acid, and 2-mercaptobenzothiazole, which are added for improving the physical properties of Ni plating, were evaluated separately from each other. The effects of 3 mL/L of 2-mercaptobenzimidazole (Fig 5), 2 mL/L of 2-mercaptobenzothiazole (Fig 6), and, 4 mL/L of thioglycolic acid (Fig 7) were evaluated. At the same time, the optimum concentrations of these organic chemicals were also evaluated (Fig 8).

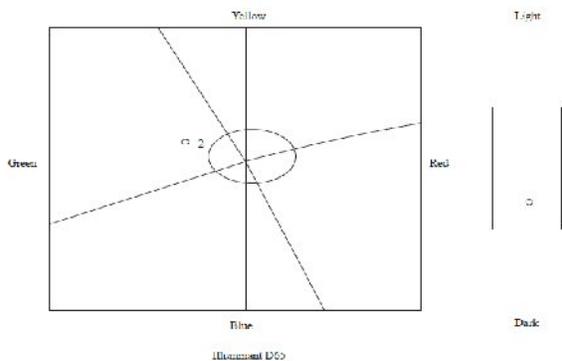


Fig. 5: Color measurement of plated material (3 mL/L of 2-mercaptobenzimidazole in Ni plating bath)(point marked “2” indicates the value in the second trial).

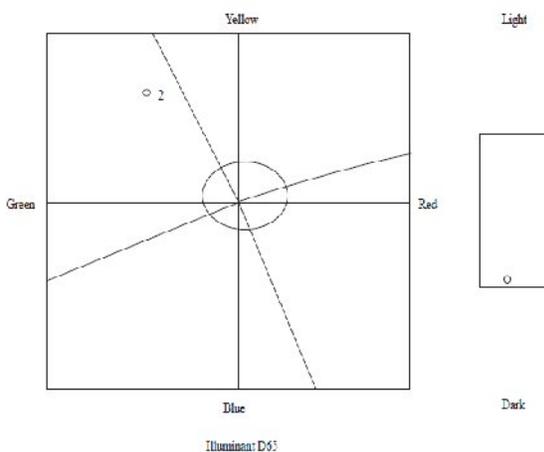


Fig. 6: Color measurement of plated material (2 mL/L of 2-mercaptobenzothiazole in Ni plating bath)(point marked “2” indicates the value in the second trial).

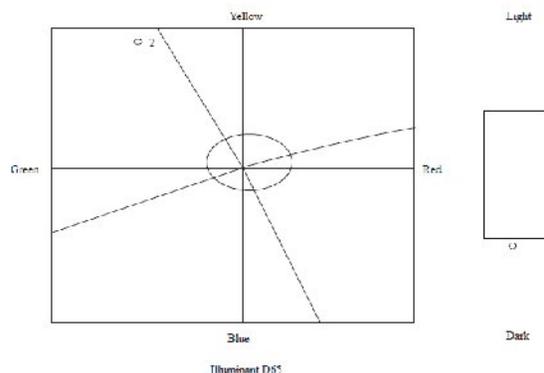


Fig. 7: Color measurement of plated material (4 mL/L of thioglycolic acid in Ni plating bath) (point marked “2” indicates the value in the second trial).

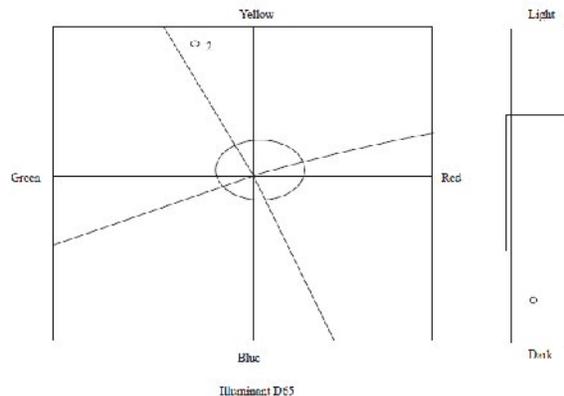


Fig. 8: Color measurement of plated material (3 mL/L of 2-mercaptobenzimidazole + 4 mL/L of thioglycolic acid+ 2 mL/L of 2-mercaptobenzothiazole in Ni plating bath) (point marked “2” indicates the value in the second trial)

## Conclusion

The use of electroplated Ni has increased rapidly in the last few years. Attributes such as thickness uniformity, material coating compatibility, corrosion resistance, abrasion resistance, and high hardness make it suitable for many industries. In this study, three different organic additives including 2-mercaptobenzimidazole, 2-mercaptobenzothiazole, and thioglycolic acid, were used for improving the Ni electroplating technique. These results suggest that 2-mercaptobenzimidazole improves performance by disrupting the crystal structure. However, 2-mercaptobenzothiazole had the largest effect on brightness. Thioglycolic acid helped the formation of the crystal structure. During electroplating, crystals grew; the plating layer became matte, and the plating speed decreased. The concentration of these chemical components in the bath did not exceed 5 mL/L. Higher concentrations resulted in decreased plating speeds. Upon replenishing the bath, if the amounts of these chemical compounds were more than 5% of the initial amounts, plating ceased entirely. If the concentration of each chemical was less than 2.5 mL/L, the bath could function without replenishment for 2 h. These data suggest ideal concentrations between 1.5–2.5 mL/L. Based on these results, the optimum mixture includes 3 mL/L of 2-mercaptobenzimidazole, 4 mL/L of thioglycolic acid, and 2 mL/L of 2-mercaptobenzothiazole.

Thioglycolic acid did not affect the color of the Ni plating, which is useful in maintaining the decorative properties of the plating. At the same time, its addition improved the physical properties of the

Ni. A thioglycolic acid concentration of 4 mL/L and a current density of 0.4 A/cm<sup>2</sup> were required to realize a plating thickness of 0.25 μm. In this study, several properties of electroplated Ni were improved. For example, cheaper and more easily available organic chemicals were employed, slower deposition rates were achieved, welding characteristics were improved, analytical control of the bath chemicals was easier, throwing power was improved, and uniform coatings were observed. At the same time, the hardness increased to 480 HV, which is higher than that of electrodeposited Ni at 200 HV. The plating hardness could also be increased to 1050 HV by heat treatment at 400°C for 1 h. Other improvements include higher wear resistance, solderability, brazability, about 1–3% elongation, and higher corrosion resistance versus traditional Ni and Ni alloy plating. A bath temperature of 90 °C, a current density of 0.3 A/cm<sup>2</sup>, and a deposition speed of 0.4 μm/min were determined to be the optimum experimental parameters. In this study, the mechanical and physical properties of the plated material have been investigated thoroughly. In addition, fewer chemical additives were used which decreases the amount of potential wastewater generation. As a result, the investment and production costs for manufacturers are also significantly lowered.

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