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Application Study of Computer Color Measuring Technology Used in the Process of Aluminum Coloring

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Abstract: Application of the computer color measuring system used in the process of aluminum coloring was emphatically researched. To objectively evaluate the quality of the products, the values about K/S and color difference were calculated. Through analyzing each factor such as dyeing temperature, the thickness of the oxidized-layer, pH value as well as dyeing time, the optimum condition is defined for the processing technology. Satisfactory products were obtained in solution with pH of 5, dyed at 60°C for 30 min and the film thickness was controlled within $16 \pm 0.5 \mu\text{m}$. The results showed that the best K/S value of the aluminum after dyeing treatment had reached 4.24 and fading color fastness was 4-5 level to dry rubbing, 3-4 level to wet rubbing while staining color fastness was 4 level to dry rubbing, 3 level to wet rubbing.

Key words: Color measuring, aluminum, application, coloring

INTRODUCTION

Aluminum and aluminum alloy are more and more used to replace steel and many non-metallic materials. Aluminum is a metallic element which is easy to react with oxygen, so aluminum products can be formed a natural oxidation film whose thickness is about $0.25 \times 10^{-2} \mu\text{m}$ but this film has many weaknesses, for example, its corrosion resistance and rubbing resistance is very poor (Du *et al.*, 2011) and products are single silvery white. The corrosion resistance of aluminum and aluminum alloys can be greatly increased by forming a thick oxide layer through the anodizing process in which the aluminum sample is anodically polarized in an appropriate electrolyte to form a thicker oxide layer than that of the naturally formed film (Cramer and Covino, 2003), then we can use different dyes to colored it.

At present, the aluminum's color quality control mainly applies visual assessment, therefore the quality of the products fluctuates greatly. On the other hand, in other fields such as fabric dyeing, technologies using computers to measure color are ripe (Moiz *et al.*, 2010), through the man-machine dialogue we can carry out color measurement. These technologies have many advantages: high speed, high accuracy, not being controlled by exterior light and there is no visual difference between people. If they can be introduced into the field of coloring metals, we can make colour management and quality detection modernization, decrease cost shorten the cycle

of production and effectively improve the production efficiency.

THE METHOD OF THE COMPUTERIZED COLOR MEASURING INSTRUMENT

The structure: As Fig. 1 shows, it is the structure of a computerized color measuring system, the light produced by the light source catches the sample via an integral sphere and reflected light from the sample is divided by the monochromator which spreads the light into a spectrum, then enters into a slit as monochromatic light in

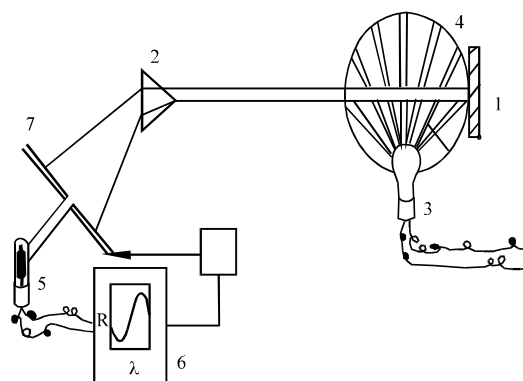


Fig. 1: The structure of the color measuring system. 1: Sample, 2: Monochromator, 3: Light source, 4: Integral sphere, 5: Photoelectric, 6: A/D converter and recorder and 7: Slit

order of decreasing wavelength, at last, it can be caught by a photoelectric detector, then be converted to an electrical signal which a chart or computer records. Transforming the electrical signals into digital codes that the computer can process by a A/D converter and combining with the spectral energy distribution of the light source, we can work out the spectral reflectance ρ of each measured wavelength.

Calculative about color depth -K/S: The Kubelka-Munk equation provides for calculation of a ratio, K/S, from measured reflectance values as is shown in Eq. 1.

$$K/S = \frac{(1 - \rho^\infty)^2}{2\rho^\infty} \quad (1)$$

where, ρ^∞ is the minimum fractional reflectance at a specific wavelength and the bigger the K/S value, the deeper the color.

Calculative about color difference: According to the spectral reflectance ρ of each measured wavelength, combined with Eq. 2-4, the tristimulus values X, Y and Z of the sample can be worked out.

$$X = \int_{380}^{780} S(\lambda) \bar{x}(\lambda) \rho(\lambda) d\lambda \quad (2)$$

$$Y = \int_{380}^{780} S(\lambda) \bar{y}(\lambda) \rho(\lambda) d\lambda \quad (3)$$

$$Z = \int_{380}^{780} S(\lambda) \bar{z}(\lambda) \rho(\lambda) d\lambda \quad (4)$$

From the X, Y, Z color tristimulus values, lightness index L^* , redness-greenness index a^* and blueness-yellowness index b^* can be calculated following the equations 5-7.

$$L^* = 116 (Y/Y_0)^{1/3} - 16 \quad (5)$$

$$a^* = 500[(X/X_0)^{1/3} - (Y/Y_0)^{1/3}] \quad (6)$$

$$b^* = 200[(Y/Y_0)^{1/3} - (Z/Z_0)^{1/3}] \quad (7)$$

where, X_0 , Y_0 and Z_0 refer to the tristimulus values of the illuminant which is used in the instrument. Total color difference, ΔE_{CIE} , is the actual distance in CIELAB color space between samples and its calculation can be listed as following:

Table 1: The relationship between ΔE_{CIE} and fading color fastness

ΔE_{CIE}	Fading color fastness
≤ 13.6	1
≤ 11.6	1-2
≤ 8.2	2
≤ 5.6	2-3
≤ 4.1	3
≤ 3.0	3-4
≤ 2.1	4
≤ 1.3	4-5
≤ 0.4	5

Table 2: The relationship between SSR and staining color fastness

SSR	Staining color fastness
< 1.25	1
1.75-1.25	1-2
2.24-1.75	2
2.74-2.25	2-3
3.24-2.75	3
3.74-3.25	3-4
4.24-3.75	4
4.86-4.25	4-5
> 4.87	5

$$\Delta E_{CIE} = [\Delta a^{*2} + \Delta b^{*2} + \Delta L^{*2}]^{0.5} \quad (8)$$

Tests for color fastness: Color fastness is an important indicator to measure the color quality of colored products and the changes of non-ferrous metals in the application are closely involved with rubbing condition. Fastness to crocking can be divided into two catalogs: fading color fastness and staining color fastness. We can calculate the ΔE_{CIE} value between standard examples and test samples, then according to Table 1 fading color fastness is obtained, as for staining color fastness we should use the ΔE_{CIE} value and Eq. 9 to work out SSR, then according to Table 2 staining color fastness is obtained.

$$SSR = 7.05 - 1.43 \ln (4.4 + \Delta E_{CIE}) \quad (9)$$

MATERIALS AND METHODS

The experiments were carried out using a type of aluminum named 6063 (3×10 cm, thickness 1 mm). Concentrated sulfuric acid, concentrated nitric acid, phosphoric acid, sodium hydroxide, sodium carbonate, sodium silicate sodium phosphate, sodium dodecylsulphonate, ammonium dihydrogen phosphate, acetic acid, aluminium oxide, the above chemical agents were purchased from J and K Chemical Co (China). Triton x-100 non-ion dispersion agent, OP-10 emulsifying agent, dispersing agent NNO were provided from Yancheng institute of technology. We also prepared a ultra-fine azo-dye acid red G by high-energy planetary ball mill (The average diameter of dyes was 135 nm and D_{90} was 206 nm).

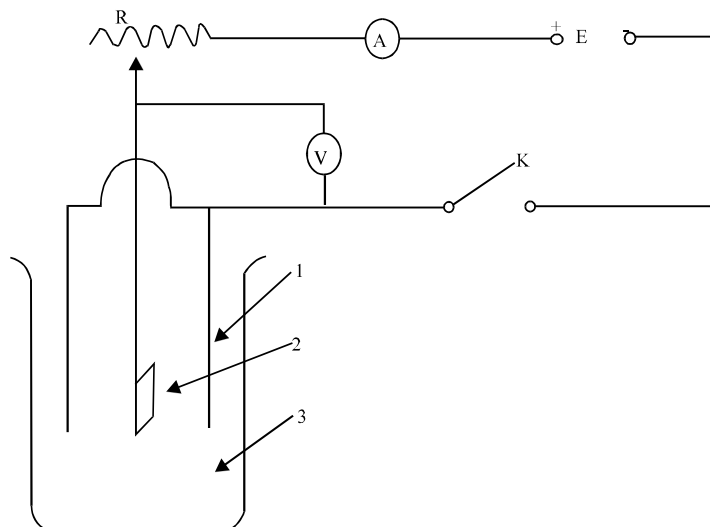


Fig. 2: The structure of anodic oxidization system. E: DC electrical, A: Source, V: Voltage meter, K: Switch, R: Electric resistance, 1: Cathode, 2: Anode and 3: Oxidation tank

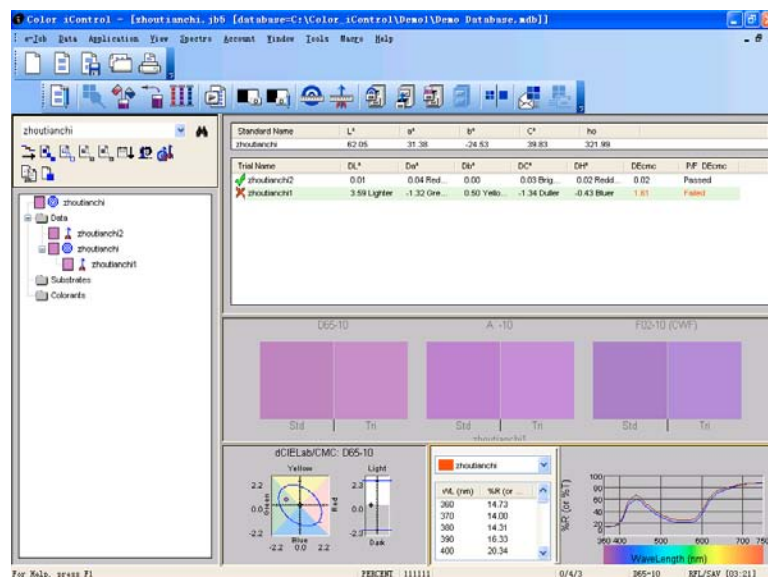


Fig. 3: The interface of the color measuring software

The technology route of aluminum oxidation and coloring: Degreasing→Alkaline washing→Chemical polishing→Anodic oxidization→Coloring→Water sealing→Drying.

The experiment device of anodic oxidization is shown in Fig. 2.

K/S value test: Using Coloreye7000A computer colour measuring system (Gretag Macbeth, U.S.A) to test K/S value, The software interface is shown as Fig. 3.

Color fastness test: Using Y(B)571-II Preset Rubbing Color Fastness Tester (Wengzhou Da Rong Textile Standard Instrument Factory, China) to test color fastness.

RESULTS AND DISCUSSION

Influence factors including dyeing temperature (T), the thickness of the oxidized-layer (δ), pH value and dyeing time (t), which affected the qualities of aluminum

Table 3: The effects of temperature on dyeing performance

Dyeing performance	Temperature (°C)				
	40	50	60	70	80
K/S	2.84	3.55	4.17	3.96	3.18
Dry rubbing					
Staining	3-4	3-4	4	3-4	3-4
Fading	4	4	4-5	4-5	4
Wet rubbing					
Staining	2	2-3	3	3	2-3
Fading	3	3	3-4	3-4	3

pH = 5, t = 30 min, $\delta = 16 \pm 0.5 \mu\text{m}$

Table 4: The effects of film thickness on dyeing performance

Dyeing performance	Thickness (μm)				
	6.1	12.2	16.4	22.3	27.6
K/S	1.25	3.16	4.24	4.16	4.18
Dry rubbing					
Staining	3-4	4	4	3-4	3-4
Fading	4	4-5	4-5	4	4
Wet rubbing					
Staining	2-3	2-3	3	2-3	2-3
Fading	3	3	3-4	3-4	3

pH = 5, t = 30 min, T = 60°C

Table 5: The effects of dyeing time on dyeing performance

Dyeing performance	Time (min)				
	10	20	30	40	50
K/S	2.86	3.56	4.08	4.11	4.14
Dry rubbing					
Staining	3	3-4	4	4	4
Fading	3-4	4	4-5	4-5	4-5
Wet rubbing					
Staining	2	2-3	3	3	3
Fading	3	3	3-4	3-4	3-4

pH = 5, T = 60°C, $\delta = 16 \pm 0.5 \mu\text{m}$

Table 6: The effects of pH value on dyeing performance

Dyeing performance	pH value				
	3	4	5	6	7
K/S	3.12	3.67	4.09	3.82	3.13
Dry rubbing					
Staining	3	3-4	4	4	3-4
Fading	3-4	4	4-5	4	3-4
Wet rubbing					
Staining	2-3	3	3	3-4	3
Fading	3-4	3-4	3-4	4	3-4

T = 60°C, t = 30 min, $\delta = 16 \pm 0.5 \mu\text{m}$

coloring were studied, respectively, their results are shown in Table 3-6, respectively.

Table 1 indicates that at first K/S and color fastness increase with the increasing heat treatment temperature, dyestuff particles easily spread into the oxidation film and the dyeing rate is accelerated, K/S and color fastness is improved but when Temperatures are above 70°C, they show a downward trend, this phenomenon is caused by the speeding up rate of hydration reaction on the oxidation film (Ye *et al.*, 2009) and dyeing performances can be suppressed, even be halted, because the oxidation

film is in a half-closed state. According to the data listed in the Table 3, the best dyeing temperature will be 60°C.

The thickness of oxidation film can be adjusted by changing anode voltages, in a certain range, improving voltage can accelerate the growing rate and the thickness of the oxidation film but it is necessary to realize that too high voltages result to the breakdown of the film. Table 4 indicates that at first K/S and color fastness increase with the increasing film thickness, thick oxide membrane can dye deeper color than thin oxide membrane because the relationship is positive correlation between the thickness of oxidation film and the ability of the dye's absorbance (Guo, 2004) and thin oxide membrane is easy-to-wear but when the thickness reaches a certain degree, the color depth will tend to be flat and the color fastness will decrease due to two factors: firstly, the aggregation of the dye on the surface of the film, which will lead to floating color (Walker *et al.*, 2001), secondly too high thickness results that some parts of the film is easy to drop from the matrix (Zhou, 2011).

Table 5 indicate that K/S and color fastness increase with the increasing dyeing time, general speaking, the longer the dyeing time, the deeper the product color, furthermore too shorter dyeing time will cause bigger color difference but too long dyeing time is also not suitable because the product color won't be deeper by the way extending the time after 30 min, at this time the adsorption capacity of oxidation film is close to saturation.

The adsorption ability of oxidation film raised with the dropping of pH value. That is because high concentration of H^+ can provide larger surface which has a lot of positive charge, absorbing anion dyes at acid conditions but too low pH value will lead to lower the color fastness and during the sealing process the color will be easy to partly lost. Furthermore, too low pH value will dissolve oxidation film and form precipitation or partly make dyestuffs lose their efficiency (Jung *et al.*, 2009). According to the data in the Table 6, the appropriate pH is in the range of 5-6.

CONCLUSION

The optimum products were obtained in solution with pH of 5, dyed at 60°C for 30 min and the film thickness was controlled within $16 \pm 0.5 \mu\text{m}$.

The technology parameters must be tightly controlled during the aluminum coloring process and computer color measuring system should be utilized to monitor and adjust the processing technology, thus the best quality products can be obtained. Only using modern maintenance and scientific management, we can improve the product quality, increase productivity and compress costs.

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