COLOR CHARACTERISTICS OF BINARY COPPER-BASE ALLOYS[①]

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ABSTRACT

The effect of Al, Zn, Sn, Mn, Si and Ni on the color characteristics of binary copper-base alloys has been researched systematically and quantitatively. The results show that all alloying elements decrease the red content of an alloy at different levels but have different effects on the yellow color. Al and Zn enhance the yellow content of an alloy, whereas Sn, Mn, Si and Ni decrease the yellow content. When the alloys with different karat gold colors are imitated, Al and Zn are the most important color mixing elements and Sn, Mn, Si and Ni can be used as auxiliary.

Key words: alloy color alloying elements red content yellow content binary copper-base alloys zinc aluminum

1 INTRODUCTION

Alloy color is very significant for making jewelry, souvenirs, metal dresses and architecture decorations. and the multicomponent alloying methods have been widely adopted to improve the surface color of copper-base gold imitating alloys in recent years[1-12]. The method of evaluating the alloy color with naked eye is basically adopted at present, which can neither describe alloy color precisely nor apply the quantitative color indexes to determine the effect of the alloying elements on the alloy color. This paper quantitatively describes the color behaviors of some elements in the copper-base binaries and thus provides scientific evidences for developing new types of gold imitating materials.

2 QUANTIFYING ALLOY COLOR

The surface color of any object in a given illumination condition has its own fixed position in a certain three-dimensional color space[13]. Therefore, a certain three-dimensional chromaticity coordinates may be used to quantify alloy color and the color difference between two different colors. The experiments[13] indicate that it is closest to the average human visual perception to evaluate the color difference between different colors in CIE1976$L^*a^*b^*$ uniform color space. Fig. 1 is a schematic diagram of this color space. This is a three-dimensional color space having components of lightness, L^*; red-green, a^*; and yellow-blue, b^*. The L^* values can range from 0 (black) to 100 (white). Positive a^* values correspond to red, negative values to green; positive b^* correspond to yellow, negative b^* values to blue. The L^*, a^* and b^* values of a certain alloy color can be obtained by measuring its spectral reflectance- wavelength curve in a given standard illumination condition and then using colorimetric formulae concerned to calculate. The color difference beween

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two colors is expressed in terms of ΔE^* and

$$\Delta E^* = \sqrt{(\Delta a^*)^2 + (\Delta b^*)^2 + (\Delta L^*)^2}$$

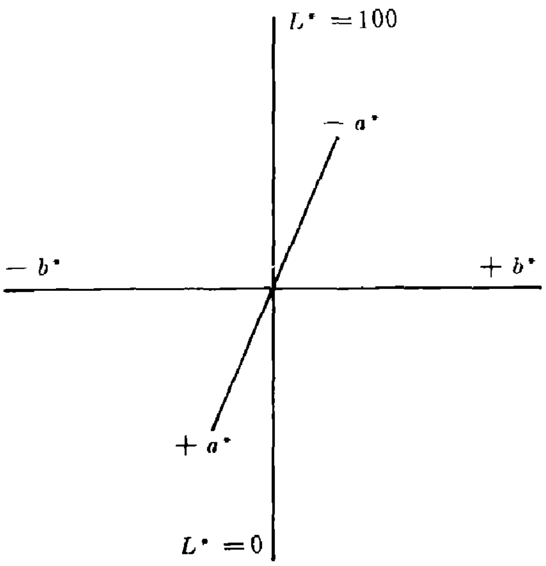

Fig. 1 A schematic diagram of CIE1976$L^*a^*b^*$ uniform color space

where

Δa^* is the red-green difference between two colors;

Δb^* is the yellow- blue difference between two colors;

ΔL^* is the lightness difference between two colors.

When the ΔE^* value is less than 1.0, the color difference between two colors may be neglected.

The saturation level of a certain color, i. e. chroma, is expressed in terms of c^* and calculated as

$$c^* = [(a^*)^2 + (b^*)^2]^{1/2}$$

The larger the value of c^*, the larger the chroma is. That c^* is equal to 0.0 representing neutral color between white and black.

3 EXPERIMENTAL PROCEDURE

The experimental alloys were placed inside a graphite crucible, melted in a RX-13 resistance furnace, and cast into moulds to form slabs 42 mm × 42 mm × 7 mm in dimension. Here, Mn and Si were added in the form of Cu-Mn and Cu-Si intermediate alloys respectively. The slabs were machined, ground and polished to a surface finish of 9 − 10 grade, then rinsed in alcohol and dried in a desiccator. The testing were performed within 24h after the samples were finally polished and rinsed.

In order to make a comparison between the chromaticity parameters of the samples and those of karat alloys given by Ref. [14], the sample color should be measured under the same conditions. For this purpose, a DMR- 22 spectrophotometer was used to measure the spectral reflectance- wavelength curves of all samples and the D65 standard light source and the 0/ *t* observing and measuring condition were adopted.

The L^*, a^* and b^* values of all samples and the ΔE^* values between each sample and 14, 18 and 24 kt gold were obtained by computer processing.

4 RESULTS AND ANALYSIS

4.1 *Color Characteristics of Copper and* 14, 18 *and* 24 kt *Gold*

The chromaticity parameters of copper and the three kinds of karat alloys are shown in Table 1.

Table 1 Chromaticity parameters of copper and the three kinds of karat alloys

Alloys	Chromaticity Parameters			
	L^*	a^*	b^*	c^*
Copper	81.53	14.08	18.22	23.03
14K	88.21	1.22	21.85	21.88
18K	85.88	4.37	23.52	23.99
24K	79.80	7.83	27.93	29.00

Table 1 shows that with the increase in gold content, the red content (a^* value), yellow content(b^* value), and chroma (c^*

value) of karat gold incraese, whereas the lightness (L^* value) decrease. Because the yellow contents of the karat alloys are far more than the red contents, the karat alloy colors are yellow with a tincture of red, i. e. golden yellow. It is due to such a variation tendency of chromaticity parameters that makes the visual perception of high karat gold colors soft, strong and yellow touched with red, and that of the low karat gold colors luminous, yellowish and light.

It can be seen by comparing the chromaticity parameters of the copper with those of the three kinds of karat alloys in Table 1 that the lightness and chroma values of copper are within those of the three kinds of karat alloys. but that the red content is too larger and the yellow is too smaller. Therefore, in order to make the copper color change towards the three kinds of karat alloy colors, the desirable adding elements should decrease the red content of the copper, enhance the yellow, and at the same time have little effect on the lightness and chroma values.

4.2 *Effect of Alloying Elements on Alloy Colors*

Figs. 2～5 show the effect of alloying elements on the chromaticity parameters of the alloy colors, where the horizontal lines represent the chromaticity parameters of 14, 18 and 24 kt gold respectively. Fig. 6 gives the effect of alloying elements on ΔE^* 18 values, the color differences between each sample and 18 kt gold. (Note: The variation in ΔE^* 14 and ΔE^* 24 values is similar to that in ΔE^* 18)

Fig. 2 shows that the addition of each alloying element to copper has no distinct regular effect on the lightness value of an alloy. Overall, the addition of each alloying element mades the lightness values of the alloys increase except for those containing greater than 6 wt. -% Mn and 4 wt. -% Ni respectively. But it should be noted that the lightness values of all the alloys are basically within those of the three kinds of karat alloys.

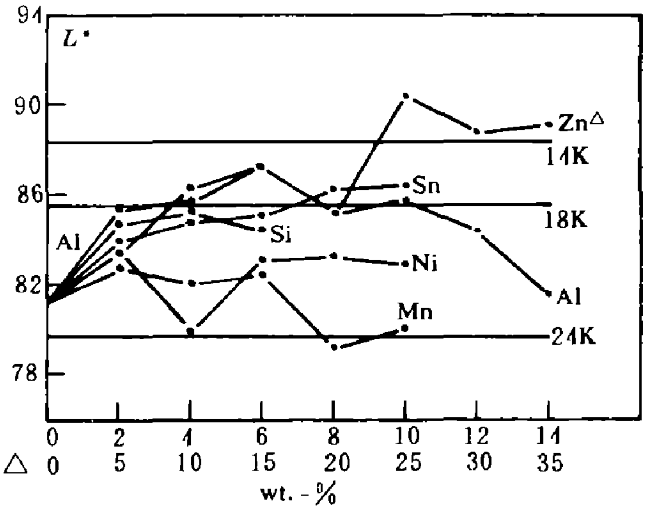

Fig. 2 Effect of alloying elements on L^*

Figs. 3 and 4 show that the addition of Mn, Sn and Ni decreases the red and yellow color content of an alloy steadily, thus has little effect on the alloy color. This point can also be supported by the variation of the color difference curves in Fig. 6. The addition of Si decreases the red content and yellow color of an alloy sharply, with the result that the alloys containing greater than 8 wt. -% Si are colorless. The addition of Al and Zn decreases the red content of an alloy, enhances the yellow color (less than 6 wt. -% Al for CuAl), and makes the a^* and b^* values change towards those of the three kinds of karat alloys, i. e. making the alloy color change towards the three kinds of karat alloy colors. It can also be seen from Fig. 6 that the color difference curves decrease gradually and reach the minimum points at around 8 wt. -% Zn for CuZn, at which the ΔE^* 18 values are 1. 27 and 1. 89 respectively; such values mean that the alloy colors are fairly close to the color of 18- karat gold.

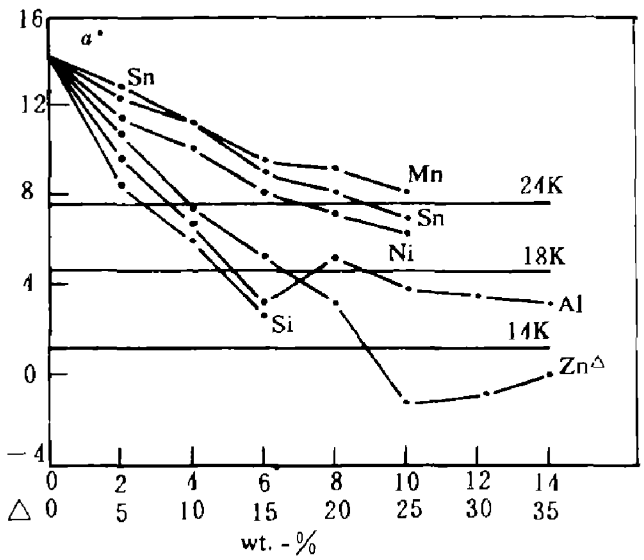

Fig. 3 Effect of alloying elements on a^*

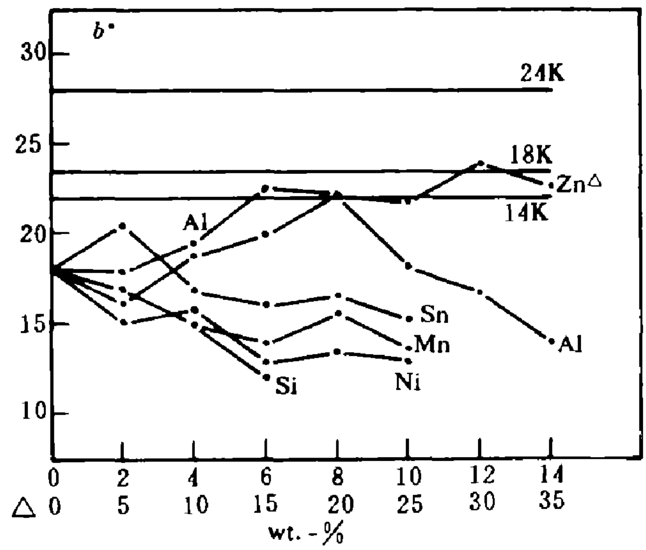

Fig. 4 Effect of alloying elements on b^*

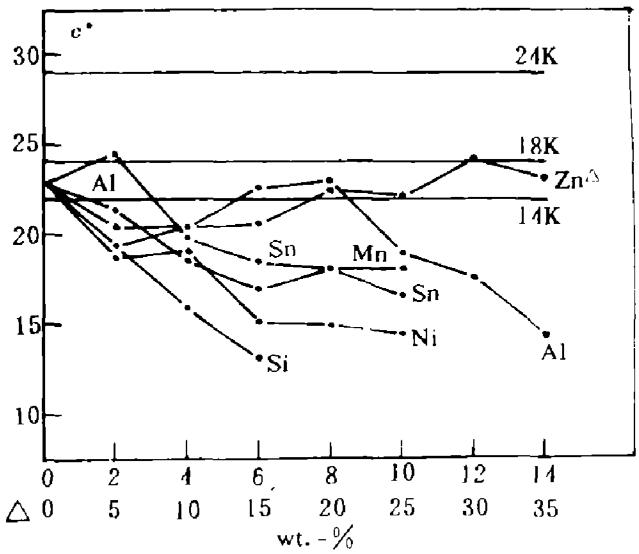

Fig. 5 Effect of alloying elements on c^*

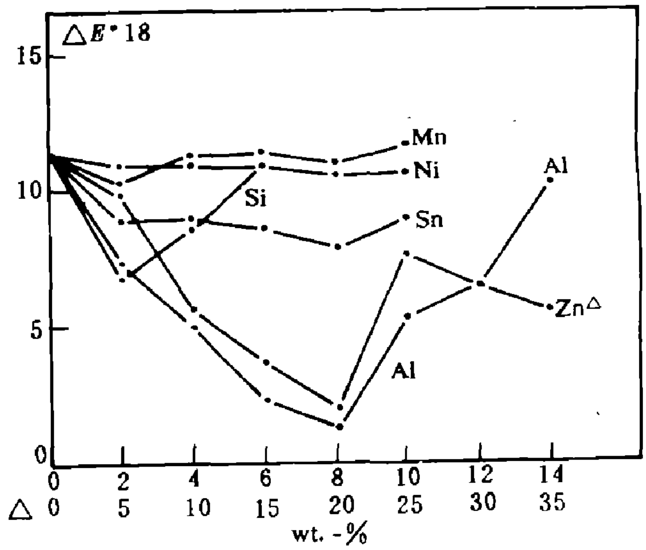

Fig. 6 Effect of alloying elements on ΔE^* 18

It can be seen by comparing Figs. 4, 5, and 6 that the variation tendency and degree of c^* values are almost consistent with those of b^* and contrary to those of ΔE^* 18 except for the alloys containing greater than 25 wt. -% Zn. This indicates that the variation of the yellow content of an alloy caused by the variation of alloying element content is the main reason affecting the alloy chroma and the color difference between an alloy and the three kinds of karat alloys. Fig. 5 shows that the chroma values of all the samples are apparently lower than the chroma value of the 24K-karat gold. Therefore, how to increase the chroma values of copper-base gold imitating alloys is the main problem to be solved. For the alloys containing greater than 25 wt. -% Zn, there is a negative a^*, indicating green; the alloy color has changed as compared with the three kinds of karat alloys, i. e. the alloy color is not the yellow touched with red already but the yellow touched with green. Therefore, the color difference values are still larger in spite of their high chroma values.

To sum up, only Al and Zn among the alloying elements investigated decrease the red content of an alloy and enhance the yellow color. Therefore, they are the most important color mixing elements when the alloys with different karat alloy colors are imitated; the optimum color mixing composition points are around 8 wt.-% Al and 20 wt.-% Zn respectively. Mn, Sn, Si and Ni decrease the red content and yellow color of an alloy simultaneously and thus can only be used as auxiliary color mixing elements when the alloys with different karat alloy colors are imitated. Because none of the alloys investigated can satisfy the condition of $\Delta E^* < 1.0$, i. e. none of the alloy colors can reach the three kinds of karat alloy colors, the color characteristics of ternary or multicomponent copper-base alloys should be studied further.

5 CONCLUSIONS

(1) Al and Zn decrease the red content of an alloy but incraese the yellow color. When the alloys with different karat alloy colors are imitated, Al and Zn are the most important color mixing elements. The optimum color mixing composition points are around 8 wt.-% Al and 20 wt.-% Zn respectively;

(2) Mn, Sn, Si and Ni decrease the red content and yellow color of an alloy and can only be used as auxiliary color mixing elements when the alloys with different karat alloy colors are imitated;

(3) Among the copper-base binaries investigated, the alloys with different karat alloy colors can not be obtained. The color characteristics of ternary or multicomponent copper-base alloys should be studied further;

(4) How to increase the chroma values of copper-base gold imitating alloys especially those imitating high karat alloy colors is the main problem to be solved.

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