Evaluation Method of Surface Texture on Aluminum and Copper Alloys by Parameters for Roughness and Color

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Abstract: We investigated surface texture which could affect appearance for product in industrial and commercial use. Presently, design-drawings indications are only symbols for geometrical tolerances, roughness and machining. However, the surface texture is expressed by feeling expressions of “roughness”, “glossiness” and “translucence”. By the way, indications for work fabrication process are empirical and ambiguous. Therefore, it is very difficult for defining the surface texture on products to use the indications for such conventional drawings indications. Therefore, we have tried to make a quantitative evaluation method for surface texture. The effects for surface roughness on glossiness and surface color were investigated in aluminum alloy (Al-Cu alloy A2017) and copper alloys (tough pitch copper C1100 and nickel silver C7541), respectively. The surface roughness for them were measured by using a mechanical stylus profilometry, and were evaluated in root mean square *Rq*. The experimental results showed that the glossiness exponentially increased, in the case *Rq* decreased. In the case, lightness *L** in CIE LAB decreased, then *Rq* decreased. Thus, it showed that relationship between *L** and *Rq* inverse correlation between glossiness and *Rq*. Moreover, surface color of all specimens showed that the blue spectrum increased when *Rq* decreased.

Keywords**:** *texture, surface roughness, glossiness, color, characterization*

1. Introduction

Surface texture is expressed by feeling expressions of “roughness”, “glossiness” and “translucence”. Currently, texture is remarked as an important factor for defining an image for solid–like products [1]. We investigated surface texture which could affect appearance for product in industrial and commercial use. However, the design-drawings indications are only symbols for geometrical tolerances, roughness and machining. [2] By the way, indications for work fabrication process are empirical and ambiguous. Therefore, it is very difficult for defining the surface texture on products to use the indications for such conventional drawings indications.

Therefore, we have tried to make a quantitative evaluation method for surface texture. The effects for surface roughness on glossiness and surface color were investigated in aluminum alloy (Al-Cu alloy A2017) and copper alloys (tough pitch copper C1100 and nickel silver C7541), respectively.

2. Experimental method

2.1 Specimen and surface roughness

Surface specimen's figure was prepared for 70×70mm, surface roughness was decided by polishing process using waterproof abrasive paper to be provided for arithmetical mean Ra=0.03～1.00μm in surface roughness. Specimen was prepared two types. One was polished in unidirection and another was in free direction.

We controlled the surface roughness by using an appropriate polishing method as follows. First, we treat a specimen with an abrasive paper with smaller grains in the horizontal and the vertical directions in turn, to obtain a sufficient surface roughness of the specimen. After desired smoothness is attained, and that the polishing mark remains only in one direction, we change the abrasive paper to the one with lager grains and resume polishing to attain a desired roughness. To ensure our method, we measured the average values (arithmetical mean "*Ra*") of surface roughness and the standard deviation values for tens of specimens some of the results are shown in the table 1. We are confident that they are small enough to ensure the effectiveness of our method.

Table1. Some of the measured results of the average and standard deviation values for surface roughness.

Arithmetical mean *Ra* [μm]	Standard deviation σ [μm]
0.112	0.0021
0.144	0.0025

The surface roughness was measured with a mechanical stylus profilometry named "SURFTEST SV-624" (Mitsutoyo Co., Ltd. made). The measuring conditions were cutoff 0.8mm and measuring length 4mm. Surface roughness value for specimen in unidirection was picked up by three points at interval of about 5mm in the direction for vertical to polishing direction. Surface roughness value for specimen in free direction was picked up by four points at center part in 0 °, 45 °, 90 ° and 135 ° directions. Surface roughness value was induced by averaging the measurement data.

2.2 Measurement methods for glossiness and surface color

Measurement for glossiness was done by equipment named "mirror-TRI-gloss" (BYK-Gardner Mfg.). Fig.1 shows conceptual diagram for glossiness measurement. Light source was white color which contains the spectral

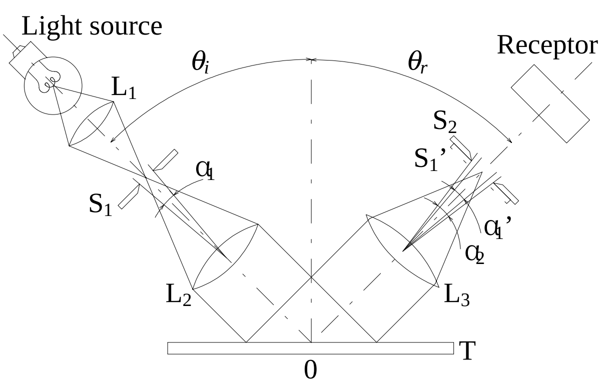


Fig.1 A conceptual diagram of the instrument to measure the specular glossiness ($\theta_i = \theta_r$).

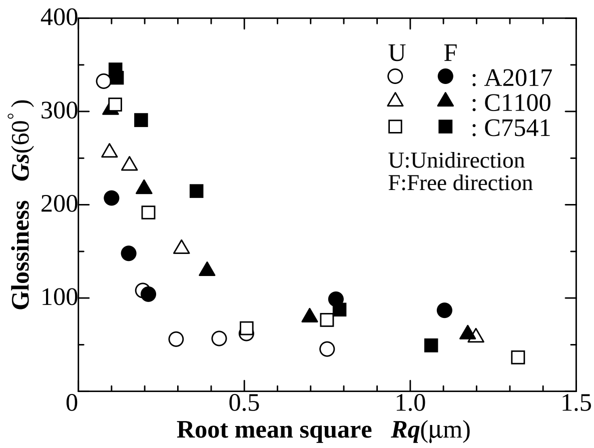


Fig.2 Relationship between Rq and Gs(60 °).

characteristics of CIE standard light source C. Incident angle to the specimen was set at 60 degree. Measurement position and points were the same as measurement conditions for surface roughness. Glossiness value was induced by averaging the measurement data.

Surface color was measured by spectral colorimeter named “CM-2600d” (Minolta Co., Ltd. made). The light source was the same one which was used for glossiness measurement. Measuring spot size was 6mm in diameter. Measured five positions were in center and about 5mm distance from the center spot in rectangular direction. These five values were averaged to get the surface color.

3. Experimental result and study

3.1 Relation between surface roughness and glossiness

Relation between surface roughness and glossiness was showed in Fig.2. In this, surface roughness was mentioned in root mean square by *Rq*. Fig.2 indicates that the smaller for *Rq*, the more in glossiness in exponential increase regardless of the type of test material or the direction of the roughness. Especially, threshold *Rq* for glossiness was less than about 0.2μm. The reason for increasing the glossiness probably comes from decreasing scattering light of concave and convex surface condition. By the way, Rayleigh criterion which is defined as surface smoothness was showed in equation (1). [3]

$$h < \lambda / 8\cos\theta \qquad \cdots (1)$$

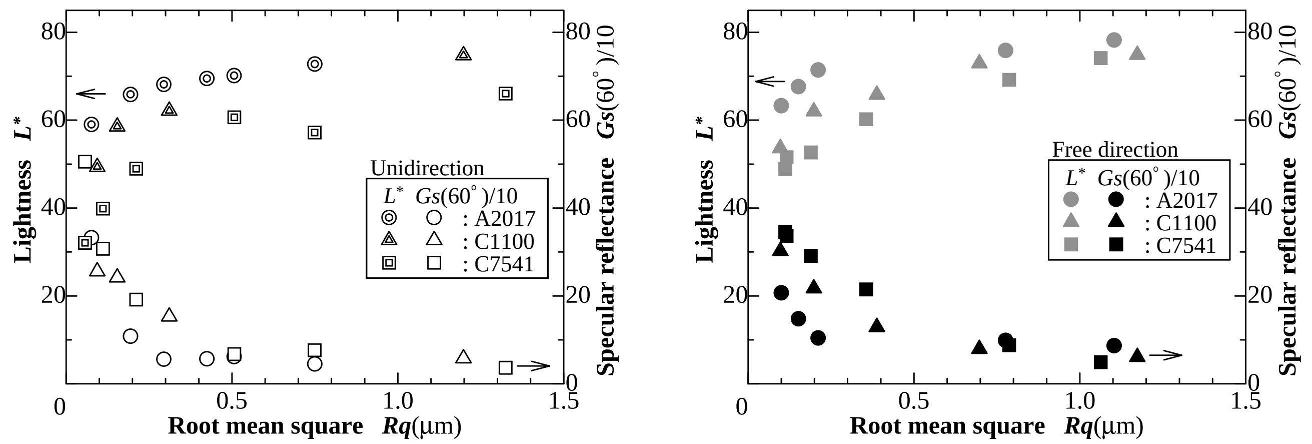
In equation (1), h is roughness, λ is wavelength and θ is incident angle to the specimen.

Wavelength range for the experiment was $0.38\mu m \leqq \lambda \leqq 0.78\mu m$, incident angle θ_i was 60 °. According to this condition and the criterion, the surface was estimated as “smooth”, and incident light was reflected in ideal condition when roughness “*h*“ was in the condition of $0.095\mu m \leqq h \leqq 0.195\mu m$. Therefore, root mean square *Rq* is less than 0.2μm, glossiness increased exponentially.

3.2 Relation between surface roughness and surface color

First, we examined influence between lightness *L** and surface roughness *Rq*. Fig.3 (a) shows relation between *Rq* and *L** in polishing in unidirection. Fig.3 (b) shows relation between *Rq* and *L** in polishing in free direction. For the reference, the right vertical axis for Fig.3 (a), (b) shows exact specular reflectance for glass (index *n*=1.567) in incident angle 60 degree. The reflective glossiness for glass was divided by 10[4].

According to Fig.3 (a) and Fig.3 (b), we confirmed tendency that smaller for *Rq*, smaller for lightness *L**, respectively. Lightness *L** was highest for A2017, which is brighter than C1100 and C7541. The lightness *L** is



(a) Unidirection (b) Free direction

Fig.3 Relationship between *Rq* and *L**.

anti-proportional to *Rq* in the range of less than 0.2µm. This means that glossiness comes from specular reflective component; however lightness L^* comes from scattering reflective component. Therefore, glossiness could be estimated according to measuring lightness L^*, vice versa.

Next, we also investigated hue and chroma effected by surface roughness *Rq* and showed relation between *Rq* and a^*, b^* chromaticity in Fig.4. According to Fig.4, color for A2017 could be achromatic color, because the C^*_{ab} (*a*, *b* chroma) was approximately 0.88, color for C7541 could be yellow with low chroma, because the C^*_{ab} was approximately 4.98, and positioned at positive on b^* axis, and color for C1100 could be yellow red with high chroma, because the C^*_{ab} was approximately 17.97, and positioned at positive on a^* and b^* axes, whereas, both axis values for a^*, b^* chromaticity was approximately the same.

Both Fig.5 (a) and Fig.5 (b) also show relation between *Rq* and a^*, b^* chromaticity, in this *Rq* polishing conditions were both unidirection polishing and free direction polishing, respectively. According to Fig.5 (a), color coordinate a^* of C1100 was coming down on the case the *Rq* value was decreasing. This means surface color is decreasing in chromaticness of red when the surface is smoother. On the other hand, no change was occurred in both A2017 and C7541 at the view point of value a^*, when the *Rq* was going smaller. However, the value of color coordinate b^* is shifting to negative direction. Especially, the moving to negative value of b^* was greater when the *Rq* was less than 0.2µm. Therefore, we investigated multiple regression equations for A2017, C1100 and C7541 from Fig.4. These equations (2) were showed as follows.

$$\left.\begin{aligned} \hat{y}_{A2017} &= 2.356x_1 - 0.327x_2 + 1.314 \\ \hat{y}_{C1100} &= 0.800x_1 - 0.164x_2 - 5.909 \\ \hat{y}_{C7541} &= 0.627x_1 + 0.292x_2 - 0.512 \end{aligned}\right\} \cdots (2)$$

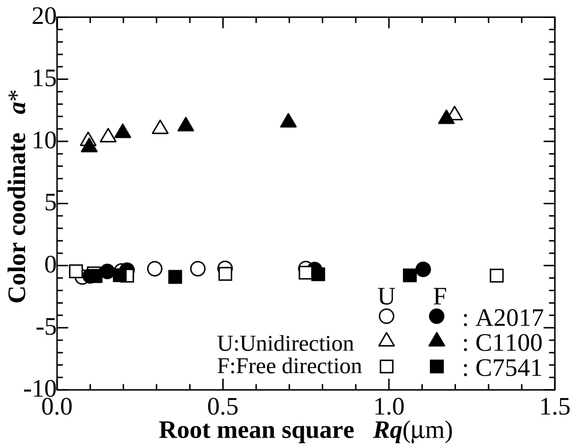
Where x_1 is a^* and x_2 is b^* in color coordinates.

From equation (2), multiple correlation coefficients are as follows.

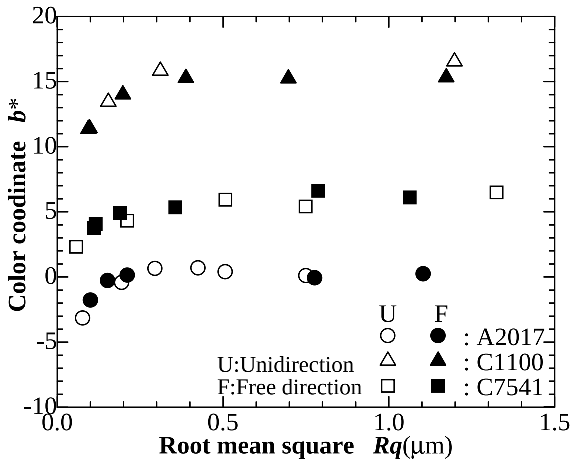
$R_{A2017}=0.676$, $R_{C1100}=0.937$, $R_{C7541}=0.854$

Therefore, surface color could be dependant to *Rq*, because the value of R_{A2017}, R_{C1100}, and R_{C7541} are over 0.5.

Spectral distribution curves for A2017, C7541, and C1100 in free direction polishing are shown in Fig.6(a)～



(a) chromaticity a^*



(b) chromaticity b^*

Fig.5 Relationship between *Rq* and a^*, b^* chromaticity.

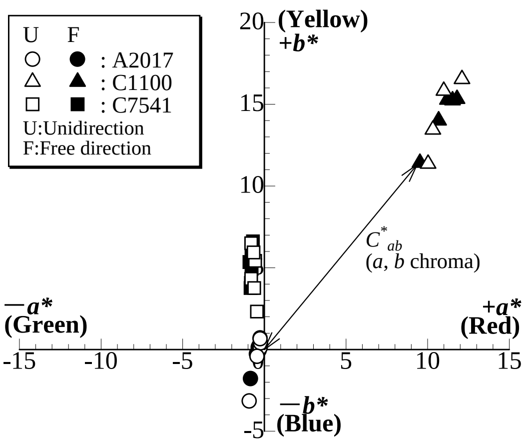
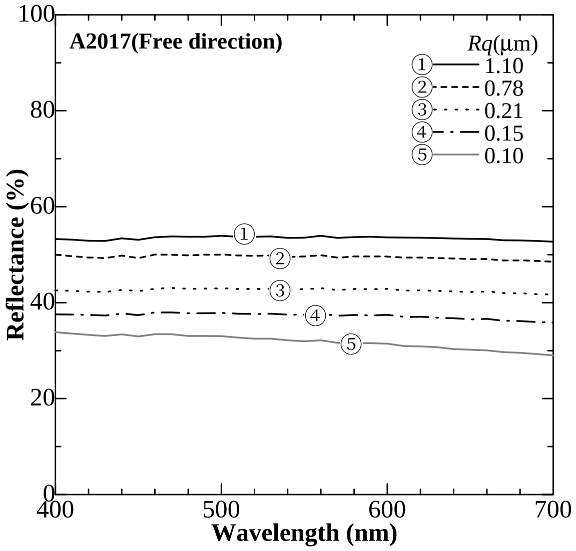
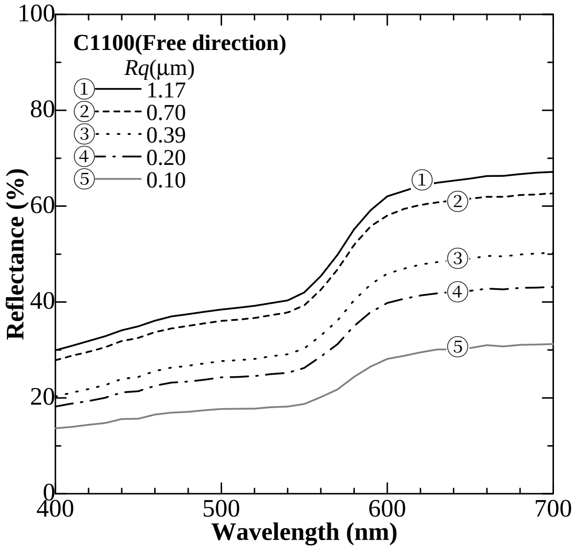


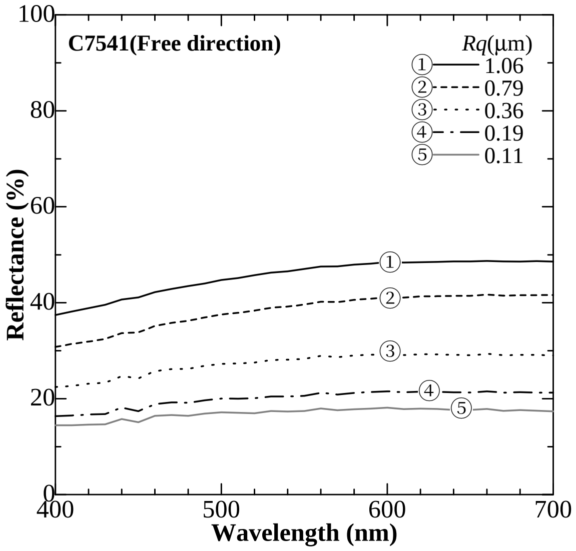
Fig.4 a^*, b^* chromaticity diagram.



(a) A2017 (Al-Cu alloy)



(b) C1100 (tough pitch copper)



(c) C7541 (nickel silver)

Fig.6 Spectral distribution curve. (Free direction)

(c). These figures might show the reflectivity in longer wavelength decreased in great deal compared with one in shorter wavelength when the *Rq* value was going smaller. This means, surface color showed that the blue spectrum increased when *Rq* decreased.

4. Conclusions

We investigated evaluation method for surface texture in quantitative analysis by examination the influence on glossiness and chromaticity change by preparing various surface roughness conditions. The surface conditions were measured for materials Al-Cu alloy A2017, tough pitch copper C1100 and nickel silver C7541. The results were as follows.

(1) The tendency was confirmed that the smaller the value *Rq*, the glossiness would be greater. Especially, glossiness value becomes in high, when the *Rq* is less than 0.2μm. This comes from decreasing scattering component caused by concave and convex on the surface.

(2) The tendency was confirmed that smaller for *Rq*, smaller for lightness *L** in CIE LAB. The relation between *Rq* and *L** is opposite for the relation between *Rq* and glossiness. Either lightness or glossiness is enough for estimation the relation between these parameters and *Rq*.

(3) The multiple correlation coefficients between color coordinates *a**, *b** and *Rq* for the materials A2017, C1100 and C7541 were over 0.5. Moreover, surface color showed that the blue spectrum increased when *Rq* decreased.

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