Effects of Color on the Perceived Qualities of Ceramic Tiles

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Abstract: The effects of color on perceived qualities (hardness, transparency, smoothness, depth, thickness, glossiness) of ceramic wares were studied using glossy, flat colored ceramic tiles. Since it was impossible to adjust color specifications of commercially available tiles, five samples that appeared to have same hue were chosen in each color. The qualities were investigated using a seven-steps SD method with 25 Japanese female students as subjects. The effects of color on the perceived quality were studied using regressions between an average perceived value (scale value) and the color specification value. The scale values for the perceived hardness, smoothness, depth, and glossiness decrease with increasing the metric lightness of the tile, while those for transparency and thickness increase. The effects of the chromaticness were assumed to be differences between the scale value for the chromatic and achromatic samples. The scale values for the perceived hardness, smoothness, depth, and glossiness increased with increasing the metric chromaticness, while those for transparency and thickness decreased. The effects of hue were detected as the slope of the linear regression function, and the effect of chromaticness was greatest for purple-blue hue and is smallest for yellow.

Key words: *Ceramic tile,Perceived quality,metric color,SD-method,Regretion line*

1. Introduction

We enjoy a comfortable life with many industrial products and consumer goods. How do we feel about them? What are the bases of our judgment? People estimate many product qualities visually by means of color, gloss, macroscopic shape, and microscopic structure. Although quality designs are very important for marketing, the perceived qualities are rarely studied except those of fiber goods and coatings.

Kyushu is famous for its ceramic industry. Since the Edo era, many beautiful porcelain designs, such as "*Imari*", "*Kakiemone*" and "*Nabeshima*", have been exported worldwide. Nowadays, people use many beautiful ceramic wares every day, e.g., rice bowls, dishes, teacups, tiles, etc. Except for biscuit wares such as "*Sueki*", the surfaces of ceramic wares are normally covered with siliceous glazes. Depending on the contents of the glaze, the baking method, over-coating of siliceous layer, etc., many kinds of beautiful surfaces can be formed, e.g., glossy, mat, opal, dimpled surfaces. Although there are many papers reported about coating qualities, only one paper has reported a relation between surface structure and visual impression in the studies of the perceived quality of ceramic wares [1]. We investigated the perceived qualities of commercially available high-gloss ceramic tiles.

2. Experimental

2. 1. Samples

Commercially available high-gloss flat ceramic tiles of uniform color (50 mm x 50 mm) were obtained. They were

Table 1. Color specification values and Glossiness

Sample No	L*	a*	b*	C*ab	Gs60
A-1	5.7	0.3	1.6	1.3	92.6
A-2	38.9	0.0	-1.8	2.3	99.3
A-3	71.3	-1.5	6.2	5.9	96.0
A-4	82.9	0.2	2.0	0.9	99.3
A-5	94.4	0.2	2.2	0.8	97.0
R-1	40.0	49.8	13.3	51.6	88.4
R-2	63.2	24.6	5.8	25.3	96.3
R-3	74.8	15.2	5.1	16.1	100.5
R-4	81.7	9.2	4.7	10.4	99.3
R-5	85.3	6.5	5.4	8.5	97.0
YR-1	53.1	36.9	37.8	52.9	88.4
YR-2	62.7	22.5	21.2	30.9	100.5
YR-3	72.7	14.9	16.1	21.9	101.5
YR-4	80.4	8.5	11.0	14.0	101.6
YR-5	87.3	4.1	12.5	13.1	93.9
Y-1	67.0	18.2	59.0	61.8	91.2
Y-2	73.5	12.4	56.9	58.2	97.0
Y-3	78.7	4.9	26.4	26.8	93.0
Y-4	82.1	2.2	22.4	22.6	95.2
Y-5	82.8	2.0	17.1	17.2	94.4
YG-1	50.7	36.9	37.8	31.9	96.0
YG-2	62.5	22.5	21.2	46.0	94.6
YG-3	64.8	14.9	16.1	36.0	93.7
YG-4	74.0	8.5	11.0	28.2	99.7
YG-5	81.6	4.1	12.5	17.9	100.4
PB-1	24.8	6.1	-25.1	25.8	102.0
PB-2	40.2	4.3	-33.0	33.2	95.6
PB-3	50.3	-3.3	-18.9	19.2	100.6
PB-4	70.0	-2.8	-10.3	10.7	101.3
PB-5	78.0	-1.1	-4.1	4.3	99.7

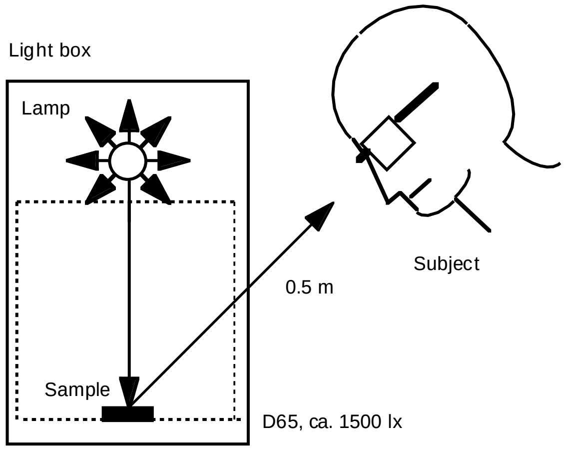

Fig. 1. Observation in the investigation

classified visually into six color groups of five tile samples each [colors; achromatic (A), red (R), yellow red (YR), yellow (Y), green (G), purple blue (PB)]. The samples were covered by a black mask with a 30 mm x 30 mm observation window. Color specification values of the tile sample by CIE 1976 L*a*b* color space (illuminant, D65; angle of vision, 2°) [2] were measured five times using a Topcon Luminance Colorimeter BM-7 type (angle of monitoring, 1°) at 500 mm distance upper incline) from the sample under D65 illumination (ca. 1500 lx at sample surface 0° illumination - 45°measurement). A measured area by the colorimeter was about 50 % of the sample surface. Metric chroma, C*ab, was also calculated by means of eq. 1 using the a* and b* values [3], listed in Table 1. Specular glossiness (Gs) at 60° [4] was measured five times using a UGV-5D Suga Digital Gloss Meter.

$$C^*ab = [(a^*)^2 + (b^*)^2]^{0.5} \qquad (1)$$

2. 2. Sensory Test

A Kenko standard daylight box B2 multi type was used to investigate the perceived qualities of the samples under D65 illumination (ca. 1500 lx at sample surface). The observations of the sample were carried out at the point measuring the color specification values (0° illumination angle –45° observation angle), as shown in Fig. 1. The perceived qualities of the sample were tested using seven- steps SD method (-3 ~ +3) with 25 Japanese female students (subjects). Before the investigations, subjects were shown a short description of each the perceived quality written in Japanese. The investigated qualities were perceived hardness (*yawarakai – katai*), transparency (*futoumeina – toumeina*), smoothness (*zarazara – turuturu*), depth (*fukami ga nai – fukami ga aru*), thickness (*atsumi ga nai – atsumi ga aru*), and glossiness (*tsuya ga nai – tsuya ga aru*). In the descriptions, the word on the former (left in Fig. 2) is negative and that on the latter (right) is positive. Scale value (the mean of the investigated values, **S**) is listed in Table 2.

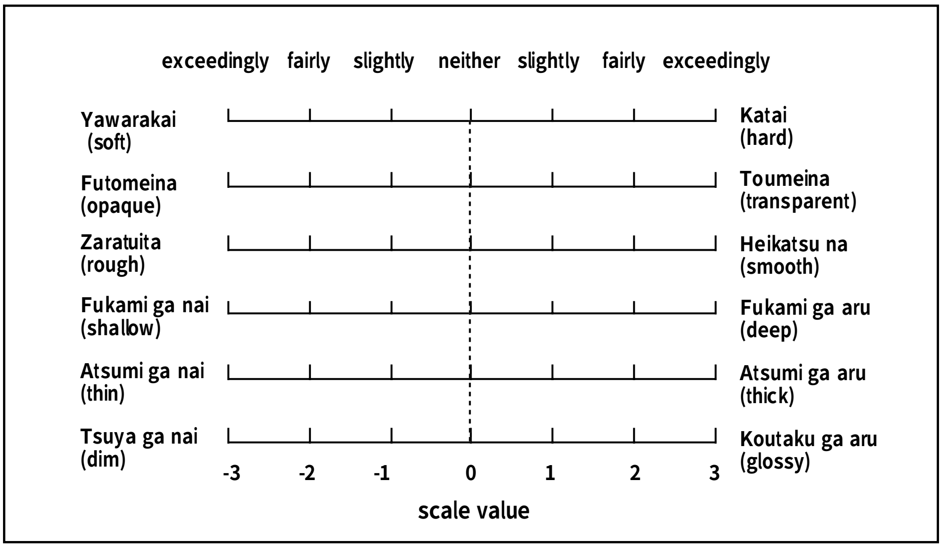

Fig. 2. Investigation sheet of sensory test

Table 2. Scale values for the perceived quality

Sample	Perceived Quality					
	hardness	transparency	smoothness	depth	thickness	glossiness
A-1	2.30	-1.41	2.46	2.38	-1.15	2.23
A-2	0.68	-1.05	1.15	1.46	-0.77	1.31
A-3	0.44	-0.02	0.77	0.08	0.62	0.62
A-4	-0.38	1.09	0.08	-1.23	0.31	0.54
A-5	-0.47	1.62	0.00	-2.00	0.77	0.31
R-1	0.72	-1.04	1.85	2.00	-0.85	2.31
R-2	-0.36	-0.62	1.00	1.15	-0.23	1.46
R-3	-0.69	0.19	0.38	0.15	0.62	0.62
R-4	-0.93	0.89	-0.62	-0.92	1.15	-0.15
R-5	-1.14	1.54	-1.00	-1.69	1.54	-0.62
YR-1	0.96	-1.64	1.46	2.15	-0.54	1.62
YR-2	-0.14	-0.85	1.15	1.38	-0.46	1.08
YR-3	-0.66	-0.33	0.46	0.54	-0.08	0.46
YR-4	-0.80	0.70	-0.08	-0.69	0.77	-0.08
YR-5	-0.70	1.66	-0.85	-1.54	1.23	-0.77
Y-1	0.77	0.00	1.77	2.15	0.08	2.08
Y-2	0.39	0.73	1.08	1.31	-0.08	1.77
Y-3	-0.48	1.46	0.08	0.15	0.15	1.08
Y-4	-0.94	0.78	-0.31	-1.00	0.92	-0.15
Y-5	-1.39	1.33	-0.62	-1.92	1.23	-1.08
G-1	1.07	-0.73	1.31	2.15	-1.00	1.62
G-2	0.19	-0.33	0.69	1.54	-0.54	1.46
G-3	-0.20	0.18	0.46	1.15	0.15	0.54
G-4	-1.13	0.77	0.15	0.08	0.69	-0.23
G-5	-1.35	1.34	0.00	-1.15	1.54	-0.77
PB-1	1.45	-0.90	1.77	2.31	-1.00	1.62
PB-2	0.95	-0.24	1.31	1.69	-1.08	1.38
PB-3	0.39	0.45	0.77	0.85	-0.62	0.77
PB-4	-0.40	1.35	-0.15	-0.62	0.62	-0.23
PB-5	-0.80	1.78	-0.77	-1.77	0.92	-0.85

3. Results and Discussion

3. 1. Sample Color

Figure 3 shows plots of a* against b* of the sample. Since there are good linear relationships passing through or closely to the origin, each group is regarded as having the same hue.

3. 2. Effect of L* and C*ab values on Perceived Quality

The perceived qualities of glossy ceramic ware seem to depend on both the Munsell value and chroma, as seen for coated surface [5,6]. For each color, the scale value for the perceived quality was plotted against metric lightness (L^*) and metric chroma (C^*ab) instead of the Munsell value and chroma, respectively. Figure 4 shows plots of the scale value for the perceived transparency against L^* and C^*ab of the red samples. This scale value increases linearly with increasing L*, while the scale values for the other qualities decrease. Conversely, these scale values increase linearly with increasing C*ab, while that scale value decreases.

The effects of the color specification value on the perceived quality were studied using primary regression functions, expressed as in eq. 1,

$$\mathbf{S = f\,L^*\ (\text{or}\ C^*ab\ ) + C,} \qquad (1)$$

where, **S** is the scale value for the perceived quality, and **f** and **C** are the slope and intercept of the primary regression function, respectively.

In the plots of the scale value **S** against L* or C*ab, there were good linear relations for each color and each quality. The effect of color on the perceived quality was studied by means of the correlation coefficients (**CC**) of the primary regression function (Table 3). Excellent **CC** values (average **CC** = 0.97) were obtained for the relationship between **S** and L^* [7]. In the relationships between **S** and C^*ab, high **CC** values were also obtained (average **CC** = 0.82). Thus, the perceived quality depends on both the color specification values, L* and C*ab.

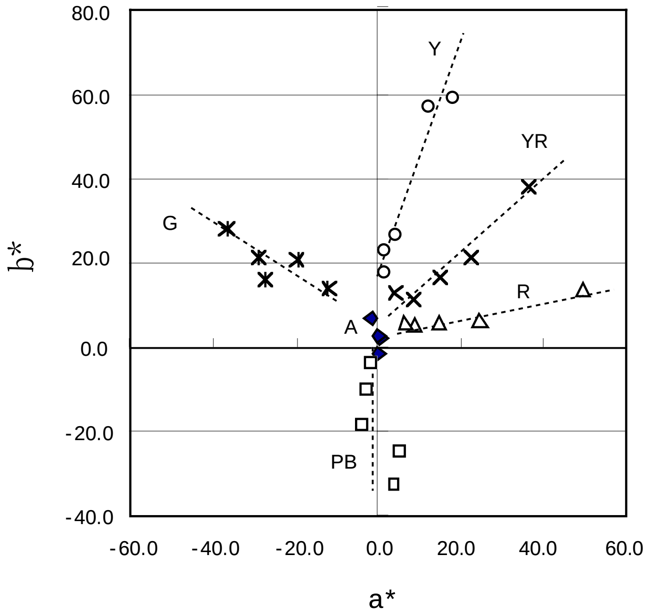

Fig. 3. Plots of a* value against b* value of the ceramic tiles

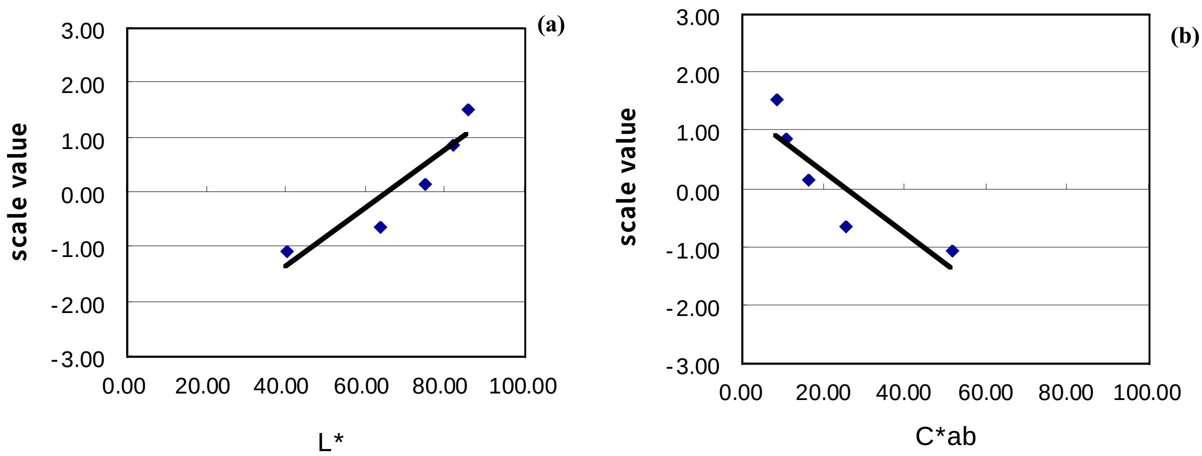

Fig. 4. Plots of the scale value (S) for the perceived transparency sense *vs*. the L* (a) and C*ab values (b) in red sample

3. 3. Separation of Effects

The effects of lightness and chromaticness must determine individually. We assume that effect of the lightness on the perceived quality is independent of its hue and chroma. Indeed, the excellent **CC** values were obtained for achromatic tiles (average **CC**= 0.95). Thus, the scale value **S** consists of the effects of lightness (**Sv**) and chromaticness (**Sc**), as shown in eq. 2,

$$\mathbf{S = Sv + Sc.} \quad (2)$$

For the chromatic tile samples, the effect of lightness on the perceived quality (**Sv**) can be obtained using the primary regression function for the achromatic tiles. The difference between **S** and **Sv** (**Sc = S - Sv**) must be the effect of the chromaticness. When this additivity holds, there is a good linear relationship between **Sc** and C^*ab for each color.

When the **Sc** value was plotted against C^*ab, a good linear relationship was obtained for each color and each quality (average **CC** values for each quality = 0.79). Unfortunately, there are some scattered results [average **CC** of GY sample = 0.39] . Since the effect of chromaticness **Sc** is determined as the difference between **S** and **Sv**, **Sc** has a relatively large error

Table 3. CC , f and C values of the primary registration functions

perceived quality	color	plots of S vs. L*			plots of S vs. C*ab		
		CC	f	C	CC	f	C
hardness	A	0.97	-0.04	2.62	0.75	-3.09	0.73
	R	1.00	-0.04	2.27	1.00	0.04	-1.41
	YR	0.89	-0.05	3.15	0.98	0.04	-1.44
	Y	0.97	-0.13	9.80	0.97	0.04	-1.89
	GY	0.99	-0.08	5.23	0.62	0.06	-2.17
	PB	1.00	-0.04	2.57	0.91	0.07	-1.05
transparency	A	0.90	0.04	-2.17	0.56	2.49	-4.98
	R	0.92	0.05	-3.50	0.88	-0.05	1.37
	YR	0.98	0.09	-6.76	0.90	-0.07	1.80
	Y	0.81	0.07	-4.58	0.79	-0.02	1.67
	GY	0.98	0.07	-4.37	0.75	-0.06	2.18
	PB	1.00	0.05	-2.19	0.90	-0.09	2.09
smoothness	A	0.93	-0.01	1.61	0.81	-1.29	3.40
	R	0.96	-0.06	4.52	0.93	0.06	-1.04
	YR	0.98	-0.07	5.21	0.88	0.05	-0.90
	Y	0.99	-0.15	11.87	0.98	0.05	-1.33
	GY	0.98	-0.04	3.38	0.51	0.03	-0.29
	PB	0.99	-0.05	3.10	0.92	0.08	-0.96
depth	A	0.99	-0.04	2.31	0.76	-3.36	6.67
	R	0.94	-0.08	5.47	0.91	0.08	-1.58
	YR	0.99	-0.11	8.13	0.91	0.08	-1.85
	Y	0.96	-0.24	18.57	0.95	0.07	-2.65
	GY	0.97	-0.11	7.97	0.78	0.10	-2.41
	PB	0.98	-0.08	4.50	0.93	0.13	2.02
thickness	A	0.99	0.03	-1.58	0.79	2.40	-4.77
	R	0.96	0.05	-3.13	0.93	-0.05	1.61
	YR	0.95	0.05	-3.68	0.82	-0.04	1.23
	Y	0.79	0.07	-4.82	0.82	-0.02	1.30
	GY	0.97	0.08	-5.37	0.90	-0.05	2.07
	PB	0.95	0.04	-2.38	0.96	-0.08	1.21
glossiness	A	0.92	-0.02	1.92	0.75	-1.97	4.56
	R	0.97	-0.06	5.05	0.94	0.06	-0.69
	YR	0.99	-0.07	5.33	0.92	0.05	-0.93
	Y	0.90	-0.18	14.57	0.90	0.06	-1.38
	GY	0.95	-0.08	6.10	0.80	0.08	-2.05
	PB	0.98	-0.05	3.05	0.95	0.09	-1.07

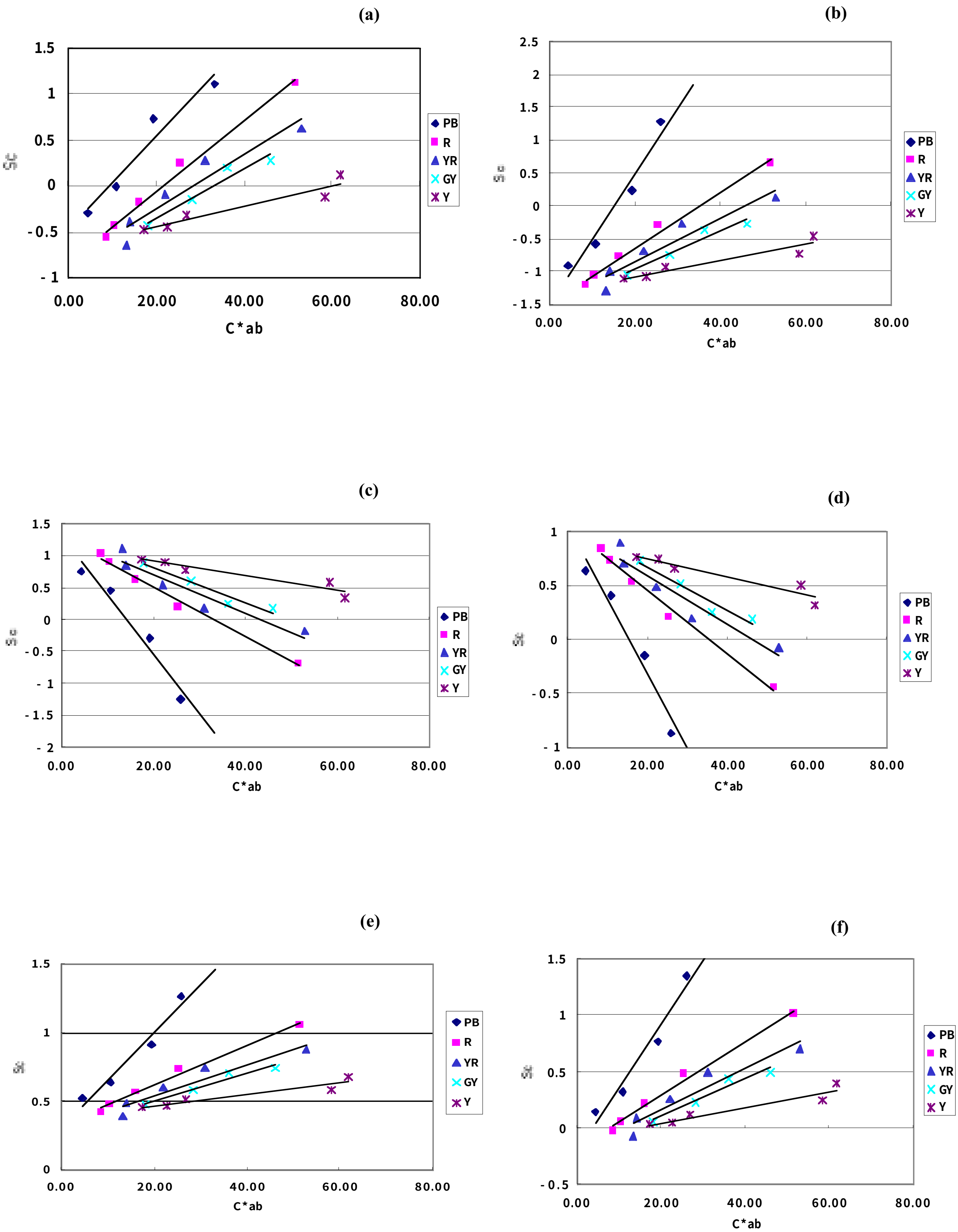

Fig. 5. Plots of Sc vs. C*ab in each color Perceived qualities: hardness (a), tranceparency (b) , smoothness (c) , depth (d) , thickness (e) ,glossiness (f)

Table 4. The results of the regression function between the Sc value and the C*ab value. The regstration functions were obtained ineach chroma

perceived quality	color	CC	f	C
hardness	P B	0.96	0.09	-0.83
	R	0.99	0.04	-0.82
	Y R	0.91	0.03	-0.83
	G Y	0.94	0.03	-0.88
	Y	0.90	0.01	-0.66
transparency	P B	0.96	-0.09	1.30
	R	0.99	-0.04	1.28
	Y R	0.91	-0.03	1.29
	G Y	0.94	-0.03	1.34
	Y	0.90	-0.01	1.13
smoothness	P B	0.96	0.03	0.33
	R	0.99	0.01	0.33
	Y R	0.91	0.01	0.33
	G Y	0.94	0.01	0.31
	Y	0.90	0.00	0.39
depth	P B	0.96	0.10	-1.49
	R	0.99	0.04	-1.48
	Y R	0.91	0.03	-1.49
	G Y	0.94	0.03	-1.54
	Y	0.99	0.01	-1.36
thickness	P B	0.96	-0.07	1.05
	R	0.99	-0.03	1.04
	Y R	0.91	-0.02	1.04
	G Y	0.94	-0.02	1.08
	Y	0.90	-0.01	0.92
glossiness	P B	0.96	0.06	-0.19
	R	0.99	0.02	-0.18
	Y R	0.91	0.02	-0.18
	G Y	0.94	0.02	-0.21
	Y	0.99	0.01	-0.11

compared with the directly measured values. We re-examined the previously obtained primary regression functions, excluding the poorest plot. Figure 5 plots **Sc** for each quality against C^*ab [hardness (Fig. 5a), transparency (5b), smoothness (5c), depth (5d), thickness (5e), and glossiness (5f)]. Except for the poorest plot, excellent **CC** values were obtained and are listed in Table 4 [average **CC** = 0.94 (hardness), 0.94 (transparency), 0.94 (smoothness), 0.96 (depth), 0.94 (thickness), and 0.96 (glossiness)]. Since the **Sc** values for perceived hardness, smoothness, depth, glossiness increase linearly with increasing C^*ab, these perceived qualities improve with increasing chromaticness. Conversely, because the **Sc** values for perceived transparency and thickness decrease linearly with increasing C^*ab, these perceived qualities become weaker with increasing chromaticness.

This method to determine the elemental effects is supported clearly by the intercept **C** of the linear relation re-examine, listed in Table 4. The intercept must be zero or close to zero independent of lightness and chromaticness [10]. The **C** values for the perceived smoothness and glossiness were sufficiently small [**C** = 0.03 ± 0.02 (smoothness), -0.17 ± 0.02 (glossiness)], while the **C** values for the other four perceived qualities were far from zero [**C** = -0.80 ± 0.06 (hardness), -0.86 ± 0.04 (depth), -1.03 ± 0.04 (thickness), 1.27 ± 0.06 (transparency)]. Since the average deviations of the **C** value are very small, the intercept is concluded to be independent of hue for each quality. It seems that the large absolute value of the intercept is due to other effects.

Table 5. Effect of lightness and chromaticness on perceived qualities of ceramic ware

perceived quality	results of tile, increasing of[a]			results of coating,[b] increase of[a]			
	L*	C*ab	color[c]	lightness	hue[c]	chromaticnes	hue[c]
hardness	decrease	increase	PB	-	-	-	-
transparency	increase	<u>decrease</u>	PB	increase	B	<u>increase</u>	B
smoothness	<u>decrease</u>	increase	PB	<u>increase</u>	B	unclear	unclear
depth	decrease	increase	PB	decrease	B	increase	B
thickness	<u>increase</u>	<u>decrease</u>	PB	<u>decrease</u>	unlrear	<u>increase</u>	unclear
glossiness	decrease	increase	PB	-	-	increase	unclear

a: change in the quality depending on the increases of lightness and chromaticness
b: reported results, refs. 8 and 9 ; c, most detectable color or hue

Therefore, the **S** value for the perceived quality consists of the additive effects of lightness and chromaticness.

Kawasumi and coworkers reported that the perceived depth decreased with increasing lightness and increased with increasing chromaticness [11,12]. We found the same results in studies for the perceived qualities of coating, listed in Table 5 [8,9]. Many of the results agree with those for a coated surface. In this table, the underlined results are discrepant results. Each tile sample is covered with a uniform, flat layer of colored glass [13], while a coated surface has a transparent varnish layer on the colored material. Therefore, we assum that the results reflect the differences in the structures of the samples.

3. 4. Effect of hue

For each perceived quality, the absolute **f** value of the PB samples was greatest and that of the Y samples was smallest in the color samples studied. This change seems to be caused by the effect of hue [14]. Since **Sc** for the perceived quality is proportional to C*ab, the effect of hue must be great in the sample with high C*ab. Thus, the weighted average index (θ) of metric hue angle, which is calculated using eq. 4, has been used as a variable of the axis instead of the mean of hue angle for each color. Figure 6 shows the plots of **f** for the perceived hardness against θ. This relation is similar to each other. Although we didn't study blue green samples, the **f** value was the minimum around θ = 90° and the maximum around -90°. The effect of hue is extremely great , as seen in Fig. 6.

$$\theta = \tan^{-1} \{ \Sigma C^*ab_i (b^*_i / a^*_i) / \Sigma C^*ab_i \} \quad (4).$$

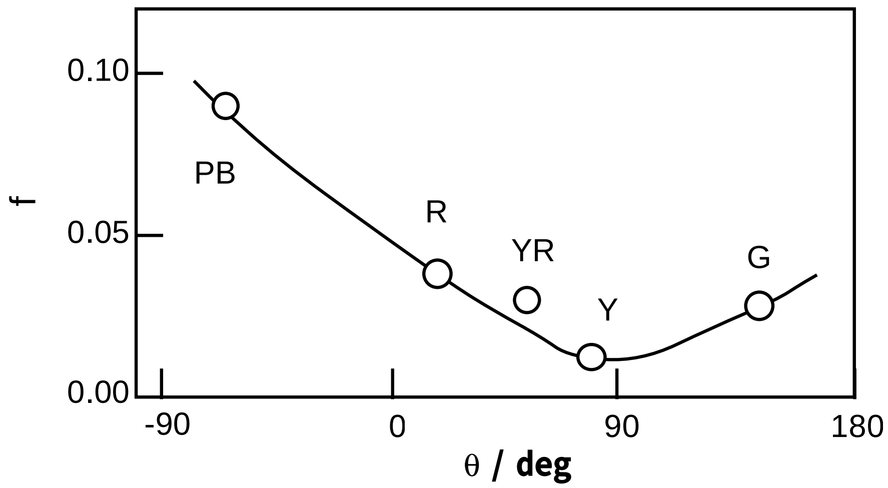

Fig. 6. Effect of hue on the f value for the perceived hardness

4. Conclusion

The effects of color specification values on the perceived qualities of ceramic tile were studied. The effects of lightness were determined using achromatic tiles. The effect of chromaticness were estimated as the difference between the experimental values for the chromatic and achromatic samples. When the difference was plotted against C*ab, we obtained a good linear relation. This method was supported by the excellent **CC** value and constant **C** value of the relation. While the scale values for perceived transparency and thickness increased with increasing lightness, those for hardness, smoothness, depth, and glossiness decreased. By contrast, the scale values for the first two qualities decreased with increasing chromaticness, while those for the last four qualities increased. The qualities were more readily distinguished in purple-blue tiles than in yellow ones. We obtained the same results in the studies using uneven lustrous colored tiles and flat lusterless tiles.

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10. In the relation between the C*ab value and the Sc value, the intercept indicates the scale value at C*ab = 0, that is the value taking off the effects of lightness and chromaticness. The effect of hue must be neglectableat C*ab = 0.0.
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13. The profiles of tile sample were observed by using a microscope. Most tiles have two colored layers on the biscuit ware. The upper layers are an uniform deep color and 80 to 150 µm of thickness. The lower layers are a pale color and 150 to 200 µm of thickness. Achromatic color tiles and a few colored tile have only one layer. When we observed at observed. Smooth surfaces of the ceramic tile indicated the coated materials were well-melted by baking.
14. We assume that the effect of chromaticness is the change in the **S** value, e.g., increase or decrease. The effect of hue is the degree of the change, i.e., the slope of the plots, **f**.