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Full Length Research Paper

Variation of clay brick colors and mechanical strength as affected by different firing temperatures

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This study was conducted to quantitatively determine the effect of firing temperature on color formation and to assess the relationship between mechanical strength and color components of clay bricks. Redness index, chroma, hue and color difference (∆E) of bricks fired at 700 to 1050°C in steps of 25°C under free access of air were measured with a colorimeter. Relations between temperature and each of the redness index and color difference indicated that reddening of clay bricks was the main reason of color difference that occurred after 975°C. A highly significant inverse relationship occurred between hue and firing temperature. Hue was the most significant color component describing the variability in strength of clay bricks (R^2 = 0.88) and may be used as a quality indicator for clay brick strength.

Key words: Brick, redness index, color difference, chroma, hue, firing temperature.

INTRODUCTION

Red and reddish colors have visual aesthetic effects in brick industries. Since many consumers think that there is a direct relationship between color and quality of bricks, the light color products have a little market value even if they meet the standard requirements (Borchelt, 2002). Karaman et al. (2006) showed a strong relationship between color and quality of bricks, and many of the mechanical features of bricks were adequately described by quantitative color parameters. However, many others suggested that color may not be used as an indicator of brick quality in case of artificial modification of brick color with coloring additives and changes of kiln temperature (Ritchie, 1974). Bricks start losing water in kilns and organic substances tied to clay material totally burn out at 300°C. Temperatures above 300°C create chemical reactions in internal structure of clay minerals. Finally, a small quantity of glass-like material occurs after 900°C, glues the elements in the clay through vitrification (Beamish and Donovan, 1993).

Chemical and structural transformations during firing determine the quality characteristics of brick products. Chemical and structural modifications of clay material improve mechanical strength of bricks (Real, 1977; Murad and Wagner, 1998). Regardless of natural color, clay containing iron in any form will burn when exposed to an oxidizing fire due to the formation of ferrous oxide. For the same raw materials and methods of manufacture, the darker colors are associated with higher firing temperatures, over absorptions and increased compressive strengths (Anonymous, 1986; Sidjanin et al., 2007).

Color is generally defined in terms of hue value and chroma. Hue is related to dominant reflected wavelength, saturation and amount of lights with other wavelengths besides the wavelength of reflected dominant light. The value or brightness of a color is based on the amount of light emitted from the object. These color quality indicators are named as color coordinates (Khan, 1998). The brick color is formed essentially in results of reactions present in a particular clay blend, when fired at high temperatures. Iron compounds are converted into ferric oxides with the initiation of vitrification. The

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Table 1. Average values of color parameters and mechanical strength of the clay bricks (n = 10 for each temperature).

Temperature (ºC)	Mechanical strength (MPa)	Hue	Chroma	Redness index	∆E*	∆E class**
700	9.1	53.86	27.78	0.56	1.18	2
725	10.0	52.59	28.62	0.61	4.63	4
750	10.5	52.15	32.31	0.47	1.83	2
775	10.9	52.56	33.74	0.45	0.25	1
800	11.4	52.26	33.59	0.45	0.9	1
825	11.8	51.12	34.18	0.46	3.09	3
850	13.0	47.83	35.26	0.59	1.09	2
875	14.4	46.90	35.79	0.65	2.3	3
900	15.0	44.66	34.79	0.78	0.98	1
925	17.4	44.16	33.86	0.81	2.04	3
950	20.4	43.20	32.51	0.94	2.56	3
975	26.5	44.42	30.90	1.13	2.74	3
1000	30.9	44.12	29.23	1.45	10.72	5
1025	37.5	38.23	20.91	4.44	11.32	5
1050	45.4	37.95	10.73	9.43	34.19	5

***∆**E: Color difference; ** 1: nonvisible. 2: visible by a trained eye. 3: visible by an untrained eye. 4: clearly visible. 5: strongly visible (Karaman et al., 2006).

objectives of this study were to quantitatively evaluate the effect of firing temperature on color properties of clay bricks and to assess the relationship between mechanical strength and color components of clay bricks.

MATERIALS AND METHODS

The air-dried clay was mixed with water to reach the optimum water content for good plasticity. The obtained body was dry pressed into a mold, and 4 · 4 · 4 cm^3 cubic blocks were prepared. The specimens were initially dried at room temperature for 24 h and then 24 h at 200°C in a muffle furnace. Bricks were fired in an electrical furnace at temperatures ranging from 700 to 1050°C in steps of 25°C increment. Ten blocks were fired at each temperature increment and used for strength test and colour measurement (Karaman et al., 2006). Lightness (L*) and chromaticity (a* and b*) of fired brick samples were measured with a colorimeter (Minolta CR-300 colorimeter). Color difference with increased temperature was determined by using a simple relation of the CIE Lab color space according to Equations 1 and 2:

$$\Delta E^*_{ab} = \left((L^*_2-L^*_1)^2 + (a^*_2-a^*_1)^2 + (b^*_2-b^*_1)^2 \right)^{1/2} = \left(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}\right)^{1/2} \quad (1)$$

$$RI = \frac{L((a^*)^2 + (b^*)^2)^{0.5}).10^{8.2}}{b^*.L^6}, \quad (2)$$

Where,

$$c^* = (a^{*2} + b^{*2})^{1/2} \text{ and } h^* = \arctan(b/a) \quad (3)$$

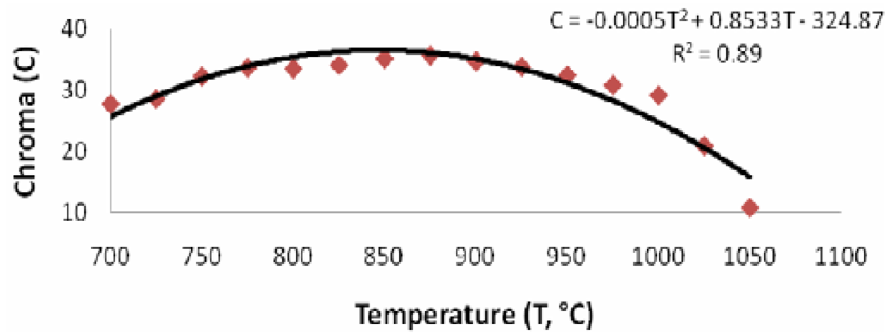
Color differences are judged by visual observations. The following classifications were adopted to indicate the color differences:

0<∆E<1 indicates usually non-visible difference,
1<∆E<2 indicates small difference, visible only by trained eye,
2<∆E<3.5 indicates medium difference, visible by an untrained eye,
3.5<∆E<5 indicates clearly visible difference,
∆E>5 indicates strong visible difference.

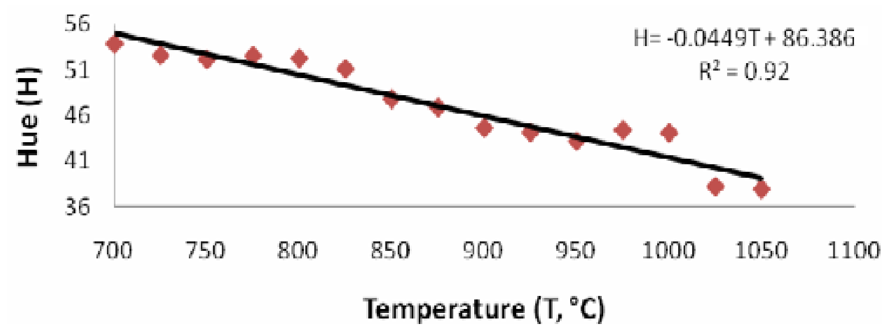
Normality test was conducted to test the hypothesis that assumes each property at each firing step which has a normal distribution. Regression analyses were performed between firing temperatures and each color component, and between compressive strength and each color component. The results from the regression analyses were evaluated based on mean absolute error and coefficient of determination, and color components adequately describing the compressive strength as a function of firing temperature were determined.

RESULTS AND DISCUSSION

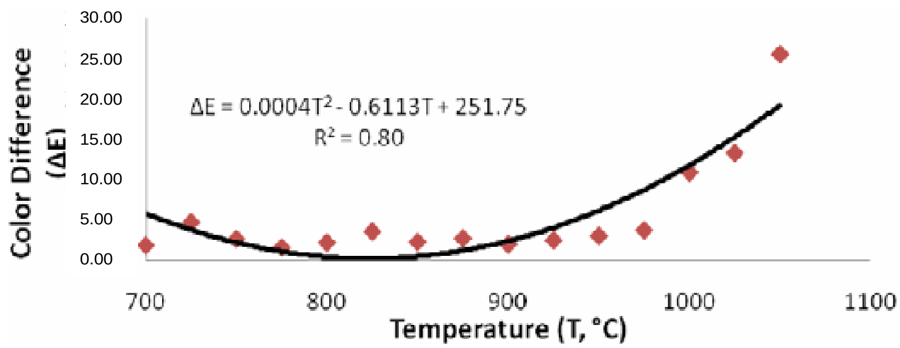
Clay bricks produced from the same clay blend yielded different color properties when fired at different temperatures. The color of bricks changed from yellow through dark red when the temperature was raised from 700 to 875°C. Hue of bricks decreased and redness index and color difference values increased with increasing temperature (Table 1). Chroma of fired bricks initially increased with increasing temperature up to 925°C and then started to decrease with further increase in temperature. Evaluations of the effect of firing temperature on color formation revealed regressions between firing temperature (as independent variable) and color components (Figure 1a, b, c and d). A very strong polynomial relationship occurred in each case that described more than 80% of the variability in independent variable. Regression curves obtained for color difference



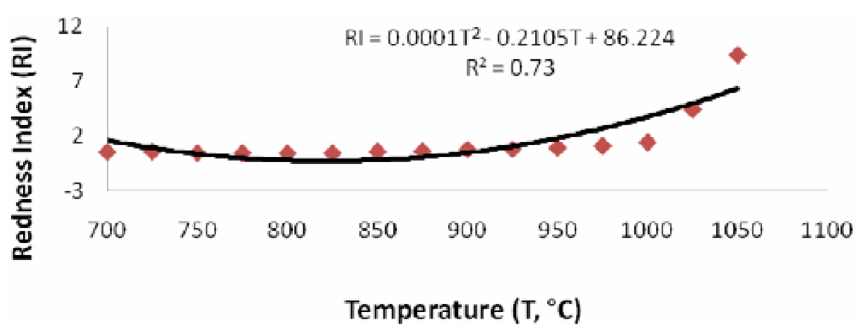
(a)



(b)



(c)



(d)

Figure 1. Relationships between firing temperature (FT) and color parameters of clay bricks; (a) between firing temperature; (FT) and chroma; (b) between FT and hue; (c) between FT and color difference; and (d) between FT and redness index.

and redness index were quite similar to each other. Both parameters slightly changed up to 975°C, after which sharply increased with increasing temperature. Similarity in redness index and color difference curves indicates that the reddening of clay bricks was the main reason for color change after 975°C. Increasing temperature

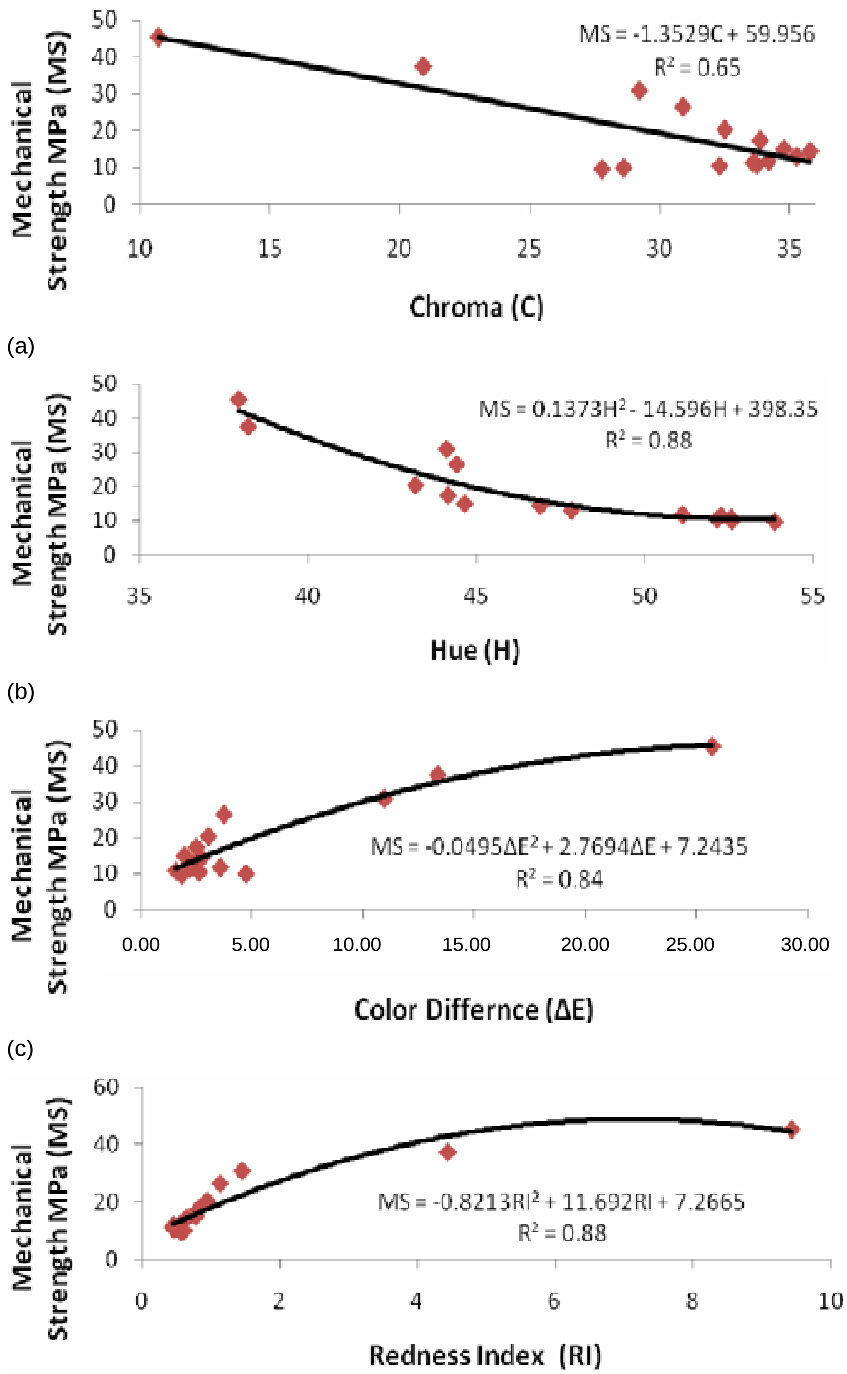


Figure 2. Relationships between mechanical strength (MS) and color parameters of clay bricks; (a) between mechanical strength (MS) and chroma; (b) between MS and hue; (c) between MS and color difference; (d) between MS and redness index.

resulted in decrease in hue of clay bricks (Figure1b). The effect of firing temperature on hue was inverse linear like in overall range of temperature studied. Contrary to color difference and redness index, hue was affected quite differently in local ranges of firing temperature. Because, the destruction of brick composition probably resulted in formation of byproducts with varying hue, Chroma and firing temperature had a strong polynomial relationship ($R^2 = 0.89$).

The regression technique was applied to estimate mechanical strength from easily measured color components (Figure 2a, b, c and d). The relationship between compressive strength and chroma was not satisfactory. A moderately significant inverse linear relation between chroma and mechanical strength described the 65% of variability in mechanical strength. Since chroma is known as the purity, intensity or richness of a color, the inconsistent relation between values of chroma and mechanical strength would be due to the formation of by-products which is attributed to the heterogeneity of raw material used in brick production. Relation between hue and mechanical strength is illustrated in Figure 2b. A prominent intricate association is visible in Figure 2. Although, the relationship between two variables could be described by a linear regression equation in the entire range, the undulating shape of the experimental values suggested that hue may not be an indicator of mechanical strength in some local ranges of mechanical strength. Mechanical strength decreased sharply against increasing hue, then decreased asymptotically for greater values of hue. Although, the overall relationship was described by a second degree polynomial, some discrepancies occurred.

In the range from 42 to 44 for hue, one may notice similar discrepancies between hue and firing temperature (Figure 2b) suggesting that by-product occurred between 900 and 1020°C of firing temperature as indicated by range from 42 to 44 of hue, considerably affected the mechanical strength. Mechanical strength behaved quite inconsistently against the ΔE values in the range from 0 to 5 of ΔE, then increased sharply (Figure 2c). The variation of mechanical strength in the low range of ΔE would be due to the frequently forming byproducts. A considerably tied relation occurred between redness index and mechanical strength in the range from 1 to 2 for redness index, indicated by the high slope of the curve at this locality (Figure 2d). This observation is quite consistent between redness index and firing temperature, expectedly as firing temperature is an important indicator of mechanical strength. The variation in color due to the increase in temperature is presented by color difference. It was reported that color difference could be judged visually and be classified into five groups (Moschik et al., 2003). Brick color difference was strongly visible after 1000°C which is the reddening line of fired bricks in this study.

Conclusions

Effects of firing temperature on color formation were investigated and the relationship between mechanical strength and color components of clay bricks were evaluated in this study. The results indicated that color components (hue, redness index and color difference) calculated from easily measured L*, a* and b* values may be used to predict the compressive strength of clay bricks used in this study. Chroma of the clay bricks may be used to assess the homogeneity of clay blend used in preparation of clay bricks.

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