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Fading and color changes in colored asphalt quantified by the image analysis method

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Abstract

Colored asphalt pavement can create better visual setting as well as improve the safety and smoothness of driving. In this research, colored asphalt samples with various amounts of dye are examined to study the surface color changes at different aging periods. Distributions of surface colors on the samples are analyzed in both the RGB and HSI color spaces. Two types of dyes, green and red, with five different ratios are mixed with clear asphalt to make colored asphalt samples. The samples are exposed to ultraviolet light in the QUV tester for five different aging spans. Results show that the amount and type of dye added, and the different aging spans affect fading in the colored asphalt. Results also indicate that clear asphalt mixed with 5% or more of dye is capable of manufacturing better-colored asphalt. Finally, colored asphalt with red dye showed better resistance to ultraviolet light.

Keywords: Colored asphalt pavement; QUV test; Image analysis

1. Introduction

Color asphalt has been applied in different usages related to daily life. Moxon [1] applied light colored asphalt, Mexphalt CP2 made by Shell, to the surface of a dam in France. The colored asphalt works as a heat shield by reflecting ultraviolet light from the surface, thus lowering the temperature by 5–10 °C in prolonged sunlight. In order to improve the safety of bicycle-motor vehicle crossings in America, the city of Portland selected 10 conflict areas to pave with paint and blue thermoplastic as the colored pavement and employ a novel signage system. Results show that the overwhelming majority of cyclists as well as a majority of motorists surveyed felt the colored pavement enhanced the safety of crossings (Hunter et al. [2]). Smith [3] discovered that interlocking color concrete pavements offer many options for applications in both architecture and engineering. He also noted that colored pavements could potentially lower the cost of maintenance and effectively resist deterioration due to deicing salts.

In Taiwan, asphalt concrete pavement is dominantly paved in the local and providential highways. These pavements were constructed primarily in the series of black color and hence make cities look monotonously. Development of colored asphalt pavement would not only create cities with colorful outlook but also improve the safety of driving. Currently, the application of these pavements has been applied mainly to the parking areas, scenic routes, parks, and other important governmental units. However, fading of the colored asphalt pavement caused by the climate and other factors is commonly seen in both the construction and usage of pavement. This fading of color will result in the loss of beauty in the pavement and the repaving of the surface. Consequently, this will increase the cost of maintenance of pavement, which is contrary to the original intention of the colored asphalt. For some cases, its color faded seriously within 1 year. Since demands in colored asphalt are high, and in response to improvements of living standard in Taiwan, governmental agencies have planned a number of projects for colored asphalt pave-

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Table 1
Components of red and green dyes

Color materials	Chemical element	*k*-ratio (calc.)	Atomic weight	% of chemical elements	No. of cations
Red dye	Cr–K	0.8407	67.27	86.98	49.33
	O–K	0.1052	32.73	13.02	–
	Total		100	100	49.33
Green dye	Fe–K	0.1052	87.14	95.94	162.684
	O–K	0.0255	12.86	4.06	–
	Total		100	100	162.684

ments. Such areas as the rest areas on the highway and the scenic route are targeted. The total costs of these projects are worth more than millions US dollars. Moreover, the government plans to invest more in the future. However, other than contractors or manufacturers, information related to the properties of colored asphalt is limited to such owners as the governments. The quality of pavements both in the construction and their usage is of concern to owners too. Furthermore, standard techniques and procedures to evaluate the fading of color need to be established. Hence, the need to control the quality of colored asphalt pavements are of great urgency. Luo et al. [4] developed an user-friendly software, called the 'image color intensity analyzer', and applied it to the study of surface color changes in fire-damaged mortar at different elevated temperatures in the RGB (Red–Green–Blue) color space. A digital camera was used to capture images before uploading them to a PC, and the analyzer aided in obtaining intensities of red, green, and blue for quantifying color changes at different temperatures. Thus, variations in the intensities of red (R), green (G), and blue (B) were investigated in order to assess the highest temperature of fire-damaged mortar. To analyze the surface color changes in bricks with different proportion of sewage sludge ash added at various firing temperatures, images of surfaces of bricks were analyzed by the 'image color intensity analyzer' to obtain the R, G, and B intensities. Then, the optimum amount of sludge ash added to the bricks was found (Luo and Lin [5]).

In this research, with the aid of the accelerated ultraviolet light weathering tester (QUV tester), the fading of colored asphalt samples was investigated. Image analysis and the software 'image color intensity analyzer' were applied to study sample color changes in both the RGB and HSI color spaces. Finally, the distribution of colors in both spaces was obtained before and after aging tests to assess the quality of the color asphalt samples.

2. Research methods

2.1. Sources of material

The clear asphalt applied in this study was extracted from the mixture of gum, asphaltence, grease, and polarized materials and was manufactured by a local asphalt materials plant. Dyes used were acquired from a European plant. Chemical components of red and green dyes were analyzed by an electron microscope and are shown in Table 1. The main chemical components of red dye are Cr and K. Green dye, however, is composed of Fe and K. By heating the clear asphalt in an oven to 160 °C and then mixing them with red and green dyes in different designated ratios, the colored asphalt was prepared for this study. Aging tests of colored asphalt were then carried out.

2.2. Manufacture of specimens and test procedures

To make the colored asphalt, red and green dyes were added to 100.0 g of clear asphalt in the ratios of 0, 2.5, 5.0, 7.5 and 10%. When heated, clear asphalt is close to color yellow. Next, the colored asphalt mixture with a weight of 1.0 g was loaded to specimen holders. These holders were mounted on the QUV frame in the chamber of tester. In the QUV test, samples were exposed to fluorescent ultraviolet lamps for different durations of 0, 6, 12, 24 and 48 h at 60 °C. Subsequently, samples were left in a darkroom and prepared for photographing by a digital camera. Then, images using a resolution of 140×140 with 20 thousand pixels were uploaded to a PC. Later, they are analyzed by the 'image color intensity analyzer' [4] to obtain intensities of the three primary color components. Color changes in the asphalt samples caused by the aging were examined in both the RGB and HIS (Hue-Saturation-Intensity) color spaces.

2.3. QUV test

QUV tests are performed in the ultraviolet light accelerated weathering tester. The tester, which complies with ISO9000 requirements, is part of Q-Panel Lab Products. The model applied to this study is QUV/basic and is able to simulate moisture and UV exposure. In order to investigate color changes of the outdoor colored asphalt pavement over months or even years, colored asphalt samples are left in the QUV tester under the simulated conditions to observe color changes. Furthermore, the effects of service time, durability, and practicability on the colored asphalt are investigated to provide

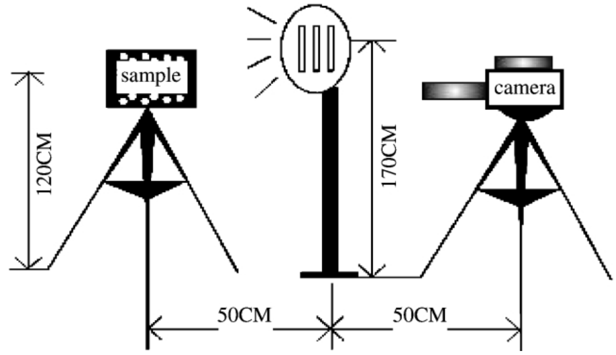


Fig. 1. Set-up for photographing.

information for future application. Relationships between color changes and aging of asphalt are observed with the help of the QUV accelerated weathering tester.

2.4. Photographing and image processing

A digital camera, model type C-2500L from Olympus, was used to capture digital images for this study. Before digital images were taken, white balance was adjusted for the digital camera by electronically compensating for variations in lights through adjusting the relative brightness of the three primary components of color; red, green, and blue. After white balance was attained, the true color of the aging colored asphalt samples was photographed under the set-up as shown in Fig. 1. Images were later uploaded to a PC and then analyzed by the software 'image color intensity analyzer' to acquire the intensities of red, green, and blue in each image. Finally, relationships of color changes in asphalt samples before and after aging tests were studied.

2.5. RGB and HSI color space systems

Commonly, the format of images taken by a digital camera is in the RGB color space. RGB is the acronym of red, green, and blue. This space is usually represented as a color cube in a Cartesian coordinate system. R, G, and B are in the *x*-, *y*- and *z*-axis, respectively, and each axis is defined between 0 and 255 for 8-bits color. Hence, point (0,0,0) stands for black color, point (255, 255, 255) represents white and the diagonal of the cube characterizes the brightness or gray-scale of color. The RGB color space is shown in Fig. 2a. Apart from the RGB color space, the HSI color space is also close to how humans perceive colors. HSI is the short form for hue, saturation, and intensity, respectively. In general, hue, saturation, and intensity are obtained by different transformation formulae by converting the numerical values of R, G, and B in the RGB color space to the HSI color space. One set of the equations, as defined by Gonzalez and Woods [6], is applied to this research and is shown below:

$$I = \frac{\mathrm{R}+\mathrm{G}+\mathrm{B}}{3} \tag{1}$$

$$S = 1 - \frac{\min\{\mathrm{R,G,B}\}}{I} \tag{2}$$

$$H = \cos^{-1}\left\{ \frac{0.5\times\left[(\mathrm{R}-\mathrm{G})+(\mathrm{R}-\mathrm{B})\right]}{\sqrt{(\mathrm{R}-\mathrm{G})^2+(\mathrm{R}-\mathrm{B})\times(\mathrm{G}-\mathrm{B})}} \right\} \tag{3}$$

Hue relates to the wavelength of colors such as red, yellow, and green. Saturation is the amount of whiteness in the color mixture. Intensity refers to the brightness or grayscale of color. Normally, HSI space is described in a cylindrical coordinate system, as shown in Fig. 2b. The angular magnitude represents hue and, generally, red color is located at 0°. Consequently, hue is viewed as the number of degrees that other colors deviate from red. For example, green is 120° away from red and blue

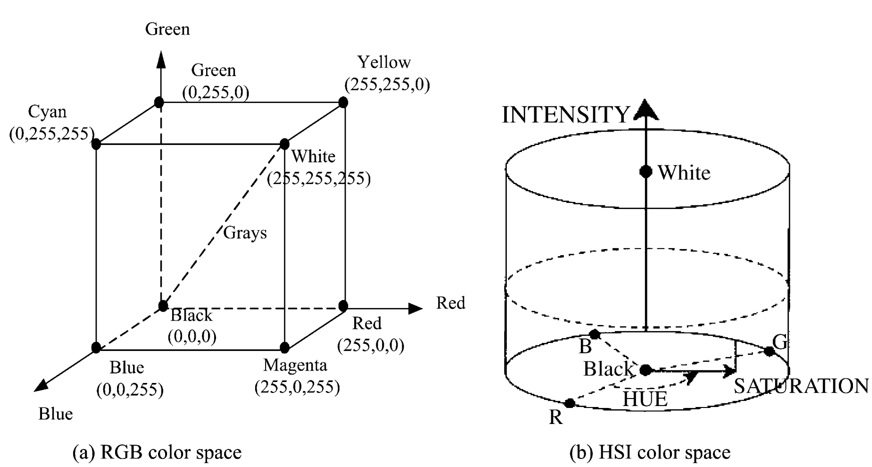
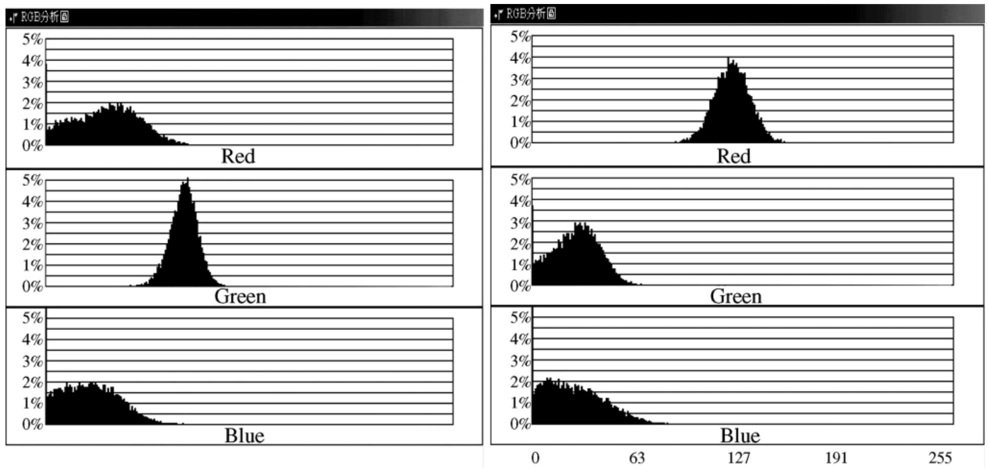


Fig. 2. The RGB and HSI color spaces.



(a) green dye (b) red dye

Fig. 3. The histograms of colored asphalt with green and red dye.

is 240° off. The radial distance of the cylinder is a measure of saturation. The perimeter of the cylinder stands for 100% of saturation, whereas the central axis is 0% saturation. Intensity is the height measured along the central axis, and varies from black to white as the height rises from the origin to the top of cylinder. In this study, the color changes of colored asphalt samples before and after aging tests are investigated both in the RGB and HSI color spaces.

3. Results and discussion

Typical distributions of R, G, and B plotted by the analyzer are displayed in Fig. 3a,b for colored asphalt samples with green and red dyes, respectively. For green dye, intensities of G are normally distributed between 63 and 127, and R and B are spread between 0 and 63. This implies that the amount of green is higher than that of red and blue, and the surface colors of samples are mainly green in the colored asphalt with green dye. Then again, in Fig. 3b, intensities of R are concentrated approximately 127, and G and B are distributed between 0 and 63 for colored asphalt samples with red dye. Hence, the intensities of red component show that it is the dominant color among the three primary components and surface colors are mostly in red for samples with red dye.

Figs. 4–6 show the relationships between intensities of R, G, and B and the amounts of green dye added to the colored asphalt samples after being left in the QUV tester from 0 to 48 h. The intensities of R decrease with an increasing amount of green dyes from 150 to approximately 50, as seen in Fig. 4. Fig. 5 displays similar results for G component. In Fig. 6, the intensities of B rises slightly with increasing amounts of green dyes and are between 15 and 30. This indicates that the amount of green dye influences the intensities of three primary color components. When the amount of green dye is higher than 5%, the distributions of intensity in R, G, and B show fewer changes, as illustrated in Figs. 4–6. This implies that clear asphalt should mix with 5% or more of green dye to manufacture better-colored asphalt. Furthermore, the intensities of R, G, and B rise with increasing quantity of ultraviolet light from 0 to 48 h at different given amounts of green dye. Although the increments are different for each component, their vividness turns from gray into white as far as the brightness of surface colors is concerned. It implies that surface colors of asphalt samples with green dye fades when

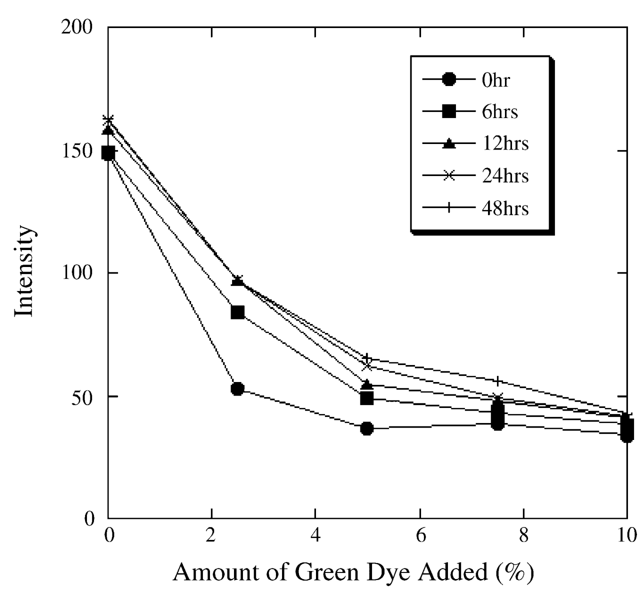


Fig. 4. Relationships between intensities of R and the amounts of green dye added to colored asphalt samples.

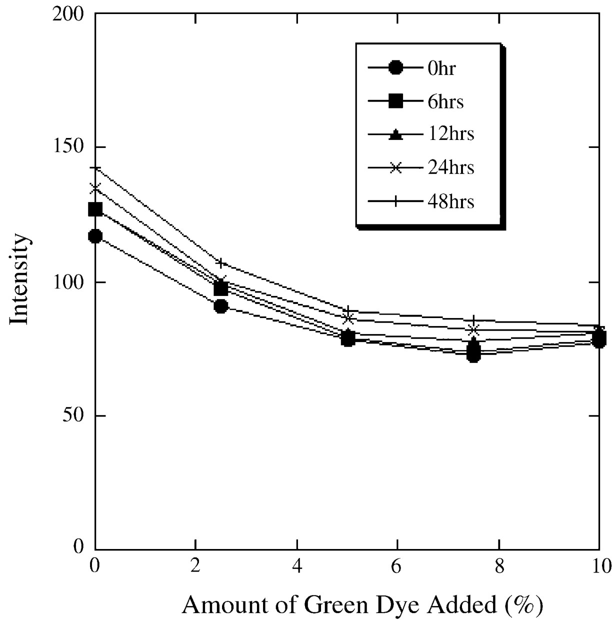


Fig. 5. Relationships between intensities of G and the amounts of green dye added to colored asphalt samples.

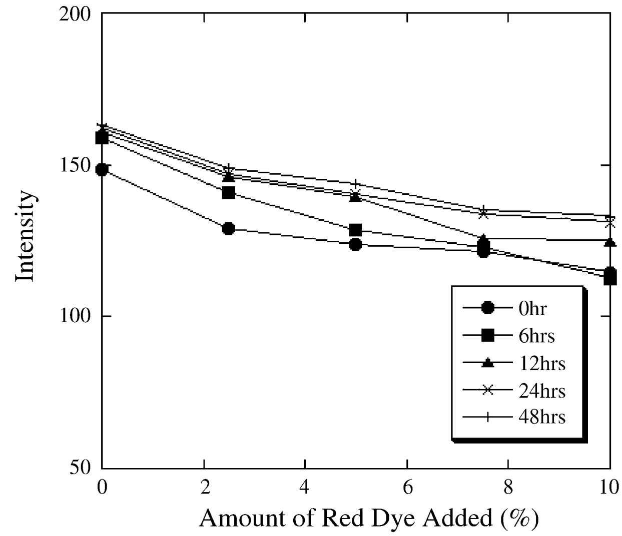


Fig. 7. Relationships between intensities of R and the amounts of red dye added to colored asphalt samples.

exposed to ultraviolet light in the QUV tests. Similar variations of intensities of three primary color components were obtained for asphalt samples with red dye. For example, the intensities of R decrease with increasing amount of red dye and longer exposures to ultraviolet light result in higher of intensities of R in the QUV tests, as shown in Fig. 7. When the decrements of intensities of R for samples with green and red dye are compared, the decrements of R in green dye are higher than those in red dye. This indicates that samples with red dye may have better resistance to the fading of colors.

Figs. 8–10 show the distributions between *H*, *S*, and *I*, with different amounts of green dye added at various times of aging. Since the color of clear asphalt is in the range of yellow color, the hue of colored asphalt turns from yellow to green with an increasing amount of green dye, as shown in Fig. 8. Furthermore, when aging becomes noticeable, the yellow color fades away and green dye develops into the dominant hue for all

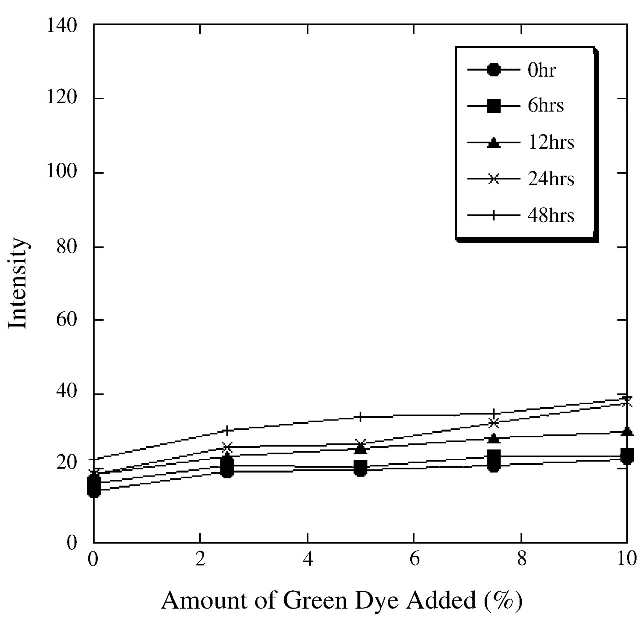


Fig. 6. Relationships between intensities of B and the amounts of green dye added to colored asphalt samples.

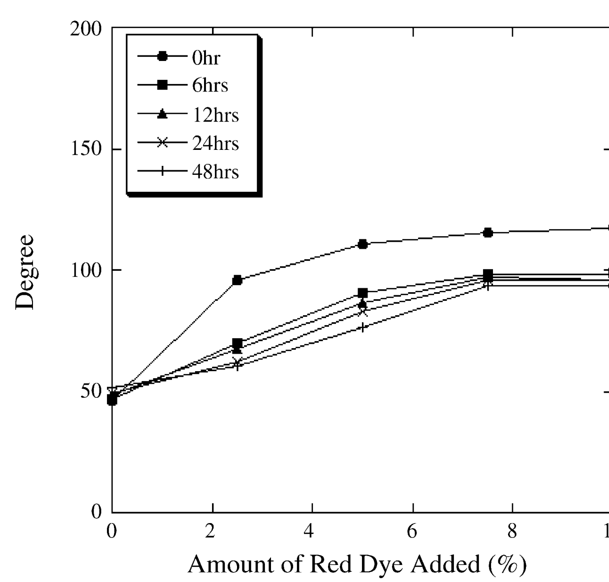


Fig. 8. Relationships between hue (H) and the amounts of green dye added to colored asphalt samples.

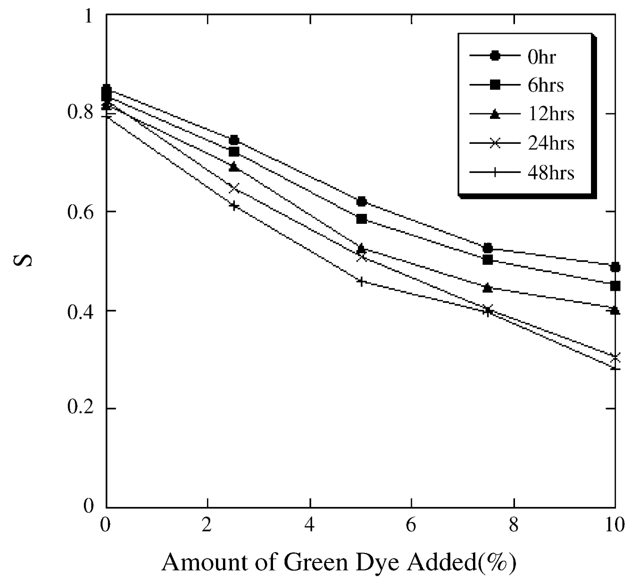


Fig. 9. Relationships between saturation (S) and the amounts of green dye added to colored asphalt samples.

amounts of dye added in the colored asphalt samples. Similar results are observed for the case of red dye additives as seen in Fig. 11. Since the colored asphalt samples would turn their hue back to dyes added to them after aging begins, the component of hue in HSI color space provides little information for judging the performances between green and red dyes in asphalt samples.

As stated earlier, saturation is defined as the quantity of whiteness added to hue. Fig. 9 shows that S becomes less when more green dye are added to asphalt samples.

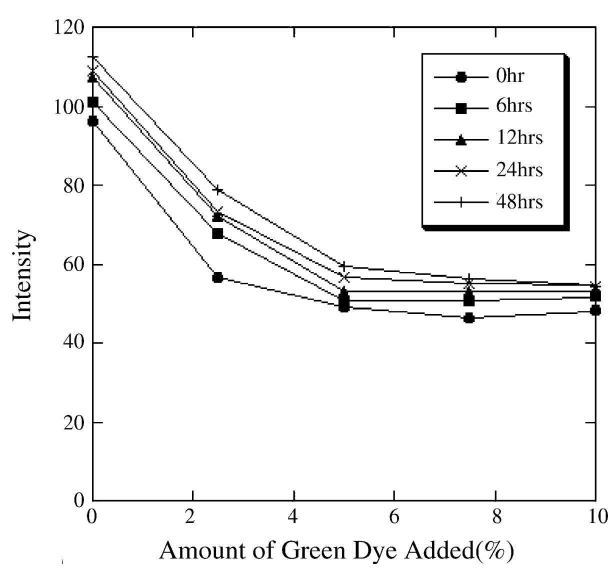


Fig. 10. Relationships between intensity (I) and the amounts of green dye added to colored asphalt samples.

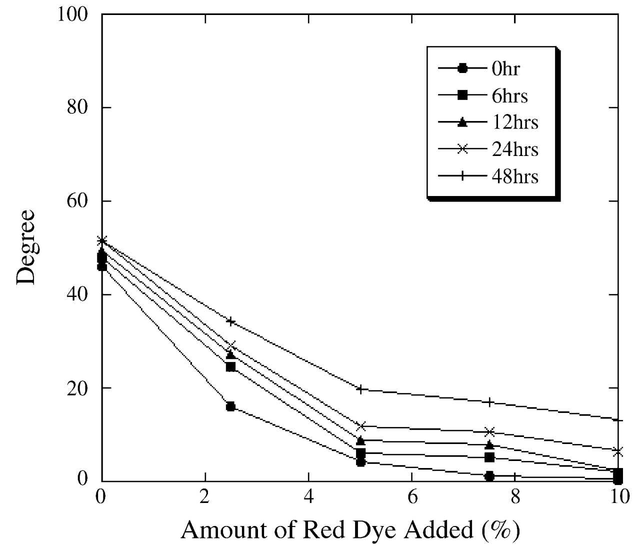


Fig. 11. Relationships between hue (H) and the amounts of red dye added to colored asphalt samples.

The figure also displays that the longer the samples are left in the QUV tester, the less whiteness is present in the samples. This indicates that the colored asphalt samples fade when exposed to ultraviolet light. Similar results are observed for asphalt samples with red dye, as shown in Fig. 12. Again, when saturations of samples for both green and red dyes are compared, variations of S with the amount of dye added and the time of exposure to ultraviolet light for samples with red dye are smoother than that for samples with green dye. This tells us that red dye may have better performance than green dye

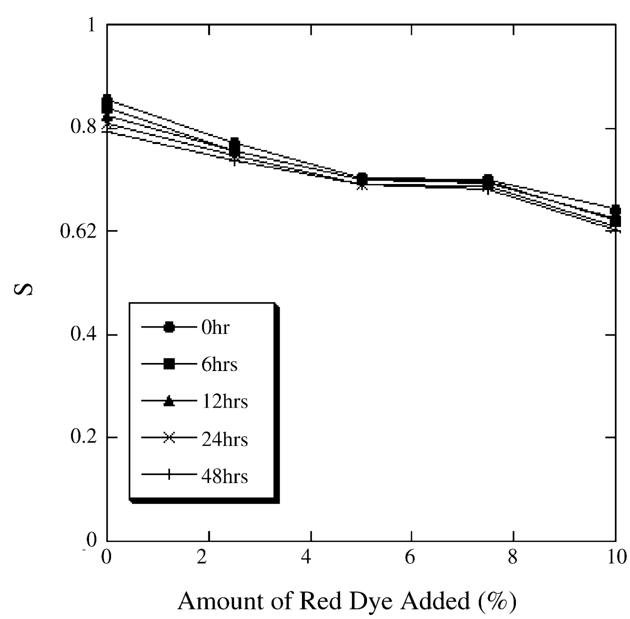


Fig. 12. Relationships between saturation (S) and the amounts of red dye added to colored asphalt samples.

when aging is considered. In Fig. 10, the brightness of samples turns darker when more green dye are added and turns brighter when samples were exposed to ultraviolet light for a longer time. Similar observations are also noticed in samples with red dye. The longer the exposure to ultraviolet light, more severe fading occurs in asphalt samples. Hence, variations in intensity also provide useful information in judging the fading of color for asphalt samples. It is concluded that digital analysis and the software 'image color intensity analyzer' could provide detailed insight to the process of fading of color in colored asphalt.

4. Conclusions

The following results are summarized from this study:

1. The intensities of R, G, and B rise with increasing quantities of ultraviolet light at different given amounts of dye. When brightness of surface colors is considered, their vividness turns from gray into white. This implies that exposure time to ultraviolet light affects the fading of color in colored asphalt.
2. When the amount of green dye is higher than 5%, the distributions of intensity in R, G, and B changes less. This indicates that clear asphalt should mix with 5% or more of green dyes for manufacturing better-colored asphalt.
3. Red dye may have better resistance to the fading of colors than green dye in colored asphalt when exposed to various amounts of time in the QUV tests.
4. The hue of colored asphalt changes from clear asphalt to the color of dyes added with increasing amounts of dye. Furthermore, when aging becomes noticeable, the color of clear asphalt fades away and the color of dye develops into the dominant hue for all amount of dyes added in the colored asphalt.
5. It is concluded that digital analysis and the software 'image color intensity analyzer' could provide detailed insight to the process of fading of color in colored asphalt.

References

[1] Moxon S. High factor asphalt. Int Water Power Dam Construct 1997;49(9):28–30.

[2] Hunter WW, Harkey DL, Stewart JR, Birk ML. Evaluation of blue bike-lane treatment in Portland, Oregon, In: Transportation Research Record 1705, TRB, National Research Council, Washington, D.C., 2000; pp. 107–115.

[3] Smith DR, Concrete pavers, Construction Specifier 1994; 47(5): 110–122.

[4] Luo HL, Lin DF, Lee JR, The design and application of windows to the assessment of fire-damaged specimens of sand and cement mortar using digital image process, In: Proceedings of the Ninth International Conference on Computing in Civil and Building Engineering, The International Society for Computing in Civil and Building Engineering, Taipei, Taiwan, 2002; pp. 189–194.

[5] Luo HL, Lin DF, The evaluation of color changes in sewage sludge ash brick by using image analysis method. The Practice Periodical of Hazardous, Toxic and Radioactive Waste Management, ASCE, 2003;7(4):214–223.

[6] Gonzalez RC, Woods RF. Digital Image Processing. Reading, MA: Addison Wesley, 1992.