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A study on the color change benefits of sustainable green building materials

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HIGHLIGHTS

- Green building materials should be endued spatial art and entertaining quality.
- Measure the RGB values of bricks at different temperatures and times.
- Groups A to D, and mixed with allochroic powders of different specifications.

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ABSTRACT

Environmental issues have become a topical subject in recent years. Numerous recycling resources can be found in our living environment, such as fallen leaves, wood chips, recovered iron powder, waste newspaper, waste concrete, reservoir silt, etc., which are utilizable waste materials. Related regulations stipulate that the waste blending ratio of recycling green building materials should be higher than 50%. In this study, three waste materials, including wood chips, concrete, and waste newspaper, were mixed with gypsum and dissolved in thermochromic material, which is made into bricks. The thermal radiation of sunlight can be absorbed by the bricks to change the hue. The experimental modules were divided into ABCD groups, which were mixed with allochroic powder of different specifications. The RGB values of bricks at different temperatures and hours were measured by a color analyzer. The results showed that the rate of change in the RGB values of the ABCD groups is higher than 10.9% when the day–night temperature difference exceeds 5 °C. These allochroic bricks can be applied to the external walls of buildings, providing landscape, building, and interior designers with another media for artistic creation.

1. Introduction

In recent years, environmental issues, including green building materials, have been a topical subject. Color-changing green building materials can enhance the willingness to use and beatify the green buildings. According to related regulations in Taiwan, the usage rate of indoor green building materials shall be higher than 45% of the total area, and that of outdoor materials shall be higher than 10%. This suggests that the use of green building materials is widely accepted. Lin [12] added printing paste in thermochromic microcapsule prints, and used temperature change to display the human imprint, called "body symbols". Huang [7] combined thermochromic pigments with electrothermal textiles for the development and design of electrothermal household textiles. Liu [13] applied the photochromic staining technique to mobile communication products. Chen [5] used thermochromic powder to observe whether there was current or heat conveyance. Regarding nondestructive inspection methods, Jung [9] used allochroic coating material to observe the distribution and shape of the cavities and pores inside objects with the naked eye. Wu [23] coated allochroic coating material on the surface of concrete specimens, and as the thermal conductivity of concrete is different from that of reinforcing steel bars, the surface color changed at different speeds during the course of heat transfer. Annerel and Taerwe [2] changed the color of concrete, studied the color space, and used an assessment instrument to detect the corresponding fire risk and fire damage. Short et al. [22] indicated that a fire-damaged concrete structure is usually evaluated by visual inspection. If the color turns from the normal color into pink or red, such significant color change means the concrete strength is damaged during heating, thus, contributing to the structural damage detection rate.

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Cement mortar properties, which are important factors for evaluating high temperature, can be inspected at high temperature by color, surface temperature, image analysis, and quantized brightness distribution [15]. Lin and Luo [11] indicated that colored asphalt pavement can create a better visual environment by enhancing driving safety and smoothness, and has better UV resistance.

Allen et al. [1] and Bartlett et al. [3] indicated that European countries developed the concept of recycling earlier than Japan or the U.S., while the U.K. set a goal to achieve zero carbon emissions from houses by 2016. The Ministry of Culture of the Taiwan [16] indicated that the waste from building demolition accounted for over 85%, which should be used efficiently to reduce the impact of waste on the environment. Kim et al. [10], Roulet [20], and Zhang [24] found that about 40% of resources from building demolition were reused, and 60% were sent to dump areas, thus, the impact on the environment could be reduced by completely planning the 60% waste. Velasco et al. [18] suggested that bricks made of waste were environmentally friendly. Monalisa et al. [17] pointed out that the latest trend for building materials was to reuse surplus and unused materials, and recycling such waste materials could reduce the consumption of natural resources, thus, reducing energy consumption and pollution. Jiang [8] proposed the blending ratio of the regenerated green building materials and the recycled waste need to achieve for more than 50%. Zhang [25] suggested that traditional bricks are made of high temperature kilned clay or OPC concrete, meaning high energy consumption and carbon emissions. The production of waste-based bricks has been widely researched for environmental protection and sustainable development, and waste recycled building materials have become the trend. Sergio et al. [21] mentioned that burnt waste ceramics contributed to energy saving and ceramic performance. According to a comparison between earthen gypsum and industrial gypsum (cement), the production of earthen gypsum consumes relatively less energy, and the production flow is simple. The process of mineral–made, general building cement accounts for 63–85% of overall mineral energy, and produces CO_2, which highlights the importance of natural building materials.

In terms of the principle of allochroic microcapsules, chromatics, and hue evaluation, Lu [14] proposed that the color of thermochromic dye could be changed by controlling temperature, solvent polarity, and pH value for molecular rearrangement. Thus, the molecules of organic dyestuffs and pigments could be rearranged to create different thermochromic materials. The New Prismatic Enterprise Co. [19] indicated that the color change principle of allochroic microcapsule is color development at low temperature and achromaticity at high temperature. At temperatures ranging between −15 °C and 70 °C, each temperature results in 15 colors, which could be mixed with each other. Moreover, pigments of other products and multistage color changes are allowed. Chang-chian [4] found that the RGB color lights are of an ‘‘additive mixture’’. The sum of three color lights is white, the difference of them is black, and the gray level color is between black and white. The pairwise color mixtures of color light RGB are three primary colors of pigment, i.e. R + G = Yellow, G + B = Cyan, B + R = Magenta. In 1931, the International Commission on Illumination selected the standard wavelengths of basic stimulating RGB color mixtures as 700.0 nm, 546.1 nm, and 435.8 nm. Chen [5] used anti-UV waterproof weather resistant coating material, a light stabilizer, and antioxidant to protect the allochroic powder. Moreover, he defined the hue values of three primary colors, yellow (R value 255, G value 255, B value 0), blue (R value 0, G value 0, B value 255), and red (R value 255, G value 0, B value 0). In terms of yellow allochroic powder 31 °C, the allochroic powder turns yellow when the temperature is 31 °C, it is colorless at high temperature, and only develops color at low temperature. The color analyzer used by Chang-chian [4] could measure the RGB and HSL values of an object’s surface color, and the surface coating colors of different cement mortar specimens were measured using a color analyzer.

2. Research hypotheses

2.1. Null hypothesis (H_0)

The three waste materials performed no color difference under the same temperature conditions.

2.2. Alternative hypothesis (H_1)

The three waste materials performed color difference under the same temperature conditions.

3. Materials and methods

3.1. Research materials

In terms of the procurability evaluation of waste materials, the micromolecules of waste newspaper, wood chips, and concrete blocks were mixed with allochroic powder and gypsum powder to create thermochromic bricks. The layers from bottom to top of each waste material brick included a 1.19 cm bottom layer, a 0.3 cm allochroic layer, and a 0.01 cm surface protection coating, for a total thickness of 1.5 cm.

Brick size was unified at 5 cm × 5 cm × 1.5 cm (L × W × H), and according to Gao et al. [6], the gypsum board was fire proof and sound proof. Therefore, the anhydrite was mixed with allochroic powder and different wastes to create bricks. The mold was a 7 cm × 7 cm × 2 cm square, hollow, plastic mold. The brick making procedure is described as follows. For the bottom layer, wastes were made into micromolecules smaller than 0.3 cm, and mixed with gypsum and water. For the material proportions, 15 g (25%) of gypsum, 60% waste and 15% water were mixed with 0.5 ml of antioxidant and stabilizer respectively for 1 min. The mixture was poured into a mold at a thickness of 1.19 cm. For the allochroic layer, 1.5–2 g allochroic powder (8%) was mixed with gypsum, accounting for 60%, and water accounting for 32%, to make the allochroic layer. The allochroic layer was 0.3 cm thick, and dried for about 24 h. For surface protection coating, 0.01 cm thick weather resistant surface protection coating was applied after the experiment was completed. The experimental modules were divided into ABCD groups according to the allochroic powder proportion. Each group contained three materials, and allochroic powder at different temperatures was added, as shown in Table 1. Group A used the contrasting colors of blue – orange pigments (0.5 g model: acryliuqe301) with allochroic powder (blue 25 °C, 2 g). Group B was mixed with allochroic powder of two temperatures (yellow 31 °C, 1 g, blue 25 °C, 1 g). Group C was mixed with allochroic powder of three temperatures (yellow 31 °C, 0.5 g, blue 25 °C, 0.5 g, red 20 °C, 0.5 g). Group D was mixed with allochroic powder of three temperatures (yellow 40 °C, 0.5 g, blue 31 °C, 0.5 g, red 20 °C, 0.5 g). The actual photo of the completed bricks is as shown in Table 2.

In terms of experimental apparatuses and equipment, color analyzer TECPEL Tech-Link – TES 135 was used for RGB analysis, and a digital thermometer was used for brick temperature measurement within a range of −10 °C to +70 °C. The digital camera was a Sony DSC-W620, with 14.1 megapixels. Soil moisture and acidity meter DM-15 was used for brick moisture distribution, with a measuring range of: 1–8.

3.2. Research design

The ABCD groups were tested outdoors, and the experimental site was the Sustainable Environment and Building Laboratory at MingDao University in Taiwan. The groups were tested from September 25, 2012 to November 5, 2012. The test bricks were placed on an outdoor cement floor, observed hourly from 5:00 a.m. to 10:00 p.m., and measured by color analyzer. The color analyzer was affixed to the brick surface for five times of rapid measurement, and the average value was taken. The rate of change in the RGB of the various groups was analyzed

Table 1
Specifications of allochroic powder for ABCD groups.

Groups Allochroic powder	A	B	C	D
Yellow	None	31 °C (1 g)	31 °C (0.5 g)	40 °C (0.5 g)
Blue	25 °C (2 g)	25 °C (1 g)	25 °C (0.5 g)	31 °C (0.5 g)
Red	None	None	20 °C (0.5 g)	20 °C (0.5 g)