Influencing factors of efflorescence degree of cement-based decorative mortar

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Abstract. The cement-based decorative mortar is a kind of good finishing material with abundant shape and colour. But the colour aberration of surface efflorescence seriously hinders the further application of cement-based decorative mortar. In the paper, it is researched of quantitative analysis on effect of calcium hydroxide content and porosity on the efflorescence degree by the function of efflorescence degree and grey scales based on image processing technology. The results show that the efflorescence degree will heighten as the content of calcium hydroxide increases, and there is a safe value of mortar without efflorescence. The open porosity plays another decisive role in the efflorescence degree of mortar. The efflorescence degree of mortar increases with the increase of porosity, and the relationship between them is linear.

1. Introduction
Cement-based decorative mortars are provided with rich shape, wide range of color change, durable protecting building. But the efflorescence and color aberration are aesthetically undesirable, which hinder the further application of cement-based decorative mortars. The Ca2+ coming for cement hydration is the main component of efflorescence. The open pore is the passage of water in and out of mortar, which is also the passageway of efflorescence, so the open porosity greatly affects the degree of alkali efflorescence. So far, mainstream characterization methods are analysis and short of quantitative feature [1-7]. Consequently, this paper discusses the effect of calcium hydroxide content and porosity on the efflorescence degree of cement-based decorative mortar.

2. Materials and methods
Cement: P.O 32.5 white cement from Chongqing Tengfei Cement Plant.
Sand: 20-120 mesh quartz sand.
Colouring agent: Iron oxide red.
Metakaolin: The chemical composition is showed in Table 1.
Basic mix ratio: the mix proportions of mortar is showed Table 2.
Table 1. The chemical composition of metakaolin (%).

| chemical composition | SiO₂ | Al₂O₃ | Fe₂O₃ | TiO₂ | Na₂O+ K₂O | CaO+MgO |
|----------------------|------|-------|-------|------|------------|---------|
| Content (%)          | 54   | 43    | 1.1   | 1.2  | 0.4        | 0.3     |

Table 2. Mix proportions of mortar.

| material   | cement | sand  | colouring agent | water | metakaolin |
|------------|--------|-------|-----------------|-------|------------|
| dosage (g) | 600    | 1400  | 10              | 225   | variable   |

The porosity was tested by the nitrogen adsorption test method. The water absorption was dry absorption of saturated surfaces after 24 hours of immersion. The efflorescence degree was calculated by formula 1, in which the alphabet f means efflorescence degree, pi means the percentage of a certain gray level corresponding pixel to total pixel, ri means efflorescence influence coefficient. It was generalized from relevance of efflorescence degree and gray scales by the image processing techniques.

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    f = \sum_{i=b_i+15}^{255} r_i \times p_i
\]

(Formula 1.)

3. Effect of Ca(OH)₂ content of hydration product on the efflorescence degree

CaCO₃ and Ca(OH)₂ are main efflorescence components of cement-based decorative mortar, and CaCO₃ is formed by the reaction of Ca(OH)₂ with CO₂ in the air. It is necessary to research the effect of Ca(OH)₂ content of hydration product on the efflorescence degree, and obtain the safe range of Ca(OH)₂ content to avoid efflorescence.

Ca(OH)₂ is inevitable in the hydration of white Portland cement, which can be reduced by the reaction with pozzolanic active admixture. Among many active substances, fly ash is the cheapest and easiest to obtain, but its early activity is very low until about 120 days to react with Ca(OH)₂, and its dark colour will affect the decorative properties of mortar[8]. The activity of silica fume in early stage is better than fly ash, but it can't be brought into play until about 90 days, and its particle size is much finer than cement to increase the water requirement of mixing obviously while maintaining the fluidity of mortar[9-10]. The early reaction rate of nano-silica is high, but the particle is too fine to scatter, and the mixing water requirement will increase sharply with increasing content of nano-silica[11]. The main components of metakaolin are amorphous Al₂O₃ and SiO₂, the early activity of metakaolin is similar to nanometer SiO₂, and the particle fineness is closest to cement[9]. Therefore, metakaolin is chosen as consuming Ca(OH)₂ agent in this paper.

The thermal analysis technology can be used to quantitatively analysing the hydration products of cement effectively. Such as, Thermogravimetric analysis can extract the information of the amount of water lost and the amount of carbon dioxide released from the decomposition of cement hydration products. The dehydration and decomposition peaks of cement hydration products can be extracted by differential scanning thermal analysis. Differential scanning calorimeter analysis can extract the dehydration and decomposition peaks of cement hydration products. The thermogravimetric curve is showed in Figure 1 and the differential scanning calorimeter curve is showed in Figure 2 of the sample, its reference mix ratio of mortar is that 32.5 grade white cement: sand: iron oxide red: water=1: 2.30: 0.015: 0.35.
As Figure 1, The dehydration temperature of Ca(OH)$_2$ is 400-500 °C, and the decomposition temperature of CaCO$_3$ is 620-820 °C. As Figure 2, the curve has a weak endothermic peak at about 444 °C, which is the thermal effect of Ca(OH)$_2$ dehydration at this temperature, and an obvious endothermic peak at about 765 °C, which is the thermal effect of CaCO$_3$ decomposition at this temperature. The content of Ca(OH)$_2$ in hydration products can be obtained by calculating the ratio of energy absorbed by each sample in the corresponding peak or valley to the reference value. The relationship between the efflorescence degree and the content of Ca(OH)$_2$ in mortar samples of 1 day and 7 day is showed in Figure 3.

As Figure 3, the regularity of the efflorescence degree of finishing mortar is similar to that of one day and seven days, and the efflorescence degree of mortar increases with the increase of Ca(OH)$_2$ content.

The correlation between the efflorescence degree and Ca(OH)$_2$ content is analyzed by the principle of least square method, and the results show that there is a good linear correlation between them, as formula 2 and formula 3. In which the alphabet x means Ca(OH)$_2$ content, Y means efflorescence degree, R$^2$ means the degree of correlation.

Initial efflorescence, $Y=16.236x-43.4481$, $R^2=0.9978$  \hspace{1cm} (Formula 2.)
Secondary efflorescence, \( Y = 6.0463x - 21.4779 \), \( R^2 = 0.9935 \)  \( \text{(Formula 3.)} \)

As Figure 3, the efflorescence degree on one day is obviously higher than the efflorescence degree at 7 days at the same Ca(OH)\(_2\) content, which is because the hydration degree of cement at 7 days is obviously better than that of one day, and C-S-H gels formed by hydration make the mortar structure denser and block some channels of alkali ion migration to the surface.

The comparison of several sets of samples shows that there is no efflorescence phenomenon on the mortar surface when the efflorescence degree value is no more than 4.2. As combined with Figure 3, the decorative mortar eliminates initial efflorescence when the Ca(OH)\(_2\) content is below 3.24%, while the decorative mortar abstains secondary efflorescence when the Ca(OH)\(_2\) content 4.82%. In other words, the Ca(OH)\(_2\) content of 3.24% is the safe value of mortar without initial efflorescence, and the Ca(OH)\(_2\) content of 4.82% is the safe value of mortar without secondary efflorescence. Consequently, it can eliminate the efflorescence phenomenon of cement-based decorative mortar that reducing the amount of the Ca(OH)\(_2\) in cement hydration products or consuming the Ca(OH)\(_2\) to below the safe value.

4. Effect of porosity and pore structure on the efflorescence degree

The cement-based decorative mortar is a porous material. The external moisture easily gets in and out of capillary channels and micro-cracks of mortar, as a medium in which alkali ions migrate to the mortar surface. In particular, the opening porosity is the most important factor affecting the permeability of mortar [12-13].

The relationship between open porosity and mortar water absorption is shown in Figure 4, and the relationship between open porosity and efflorescence degree of mortar is shown in Figure 5.

As Figure 4, the water absorption of mortar increases with the increase of opening porosity at the age of 1 day or 7 days. The increasing rate of water absorption of mortar is obviously increasing when the opening porosity exceeds 24% at the age of 1 day, and the increasing rate of water absorption of mortar is obviously increasing when the opening porosity exceeds 16% at the age of 7 days. In other words, the opening porosity of mortar has a great influence on its water absorption, especially when the opening porosity exceeds inflection point.
5. Conclusions
The efflorescence degree of cement-based decorative mortar increases with the increase of Ca(OH)$_2$ content, and there is a good linear correlation between them. The Ca(OH)$_2$ content of 3.24% is the safe value of mortar without initial efflorescence, and the Ca(OH)$_2$ content of 4.82% is the safe value of mortar without secondary efflorescence.

The efflorescence degree of cement-based decorative mortar is closely related to the opening porosity, and the opening porosity plays a decisive role in the efflorescence degree of mortar. The efflorescence degree of mortar increases with the increase of opening porosity, and there is a good linear correlation between them.

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