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# 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 $Ca^{2+}$ 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 | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $TiO_2$ | $Na_2O$+ $K_2O$ | $CaO$+$MgO$ |
|---|---|---|---|---|---|---|
| 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 test 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.
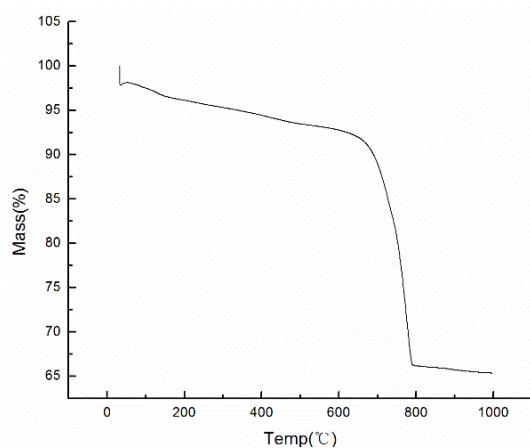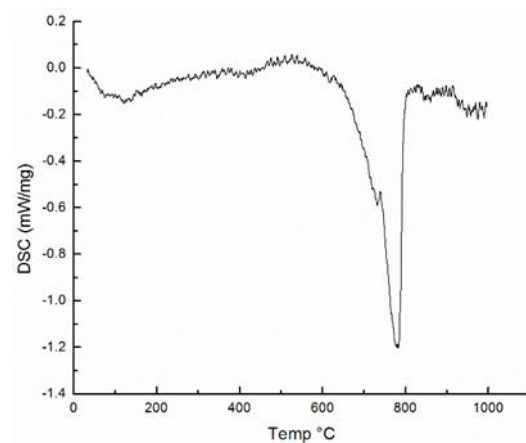
$$f = \sum_{i=b_i+15}^{j=255} r_i \times p_i \qquad \textbf{(Formula 1.)}$$

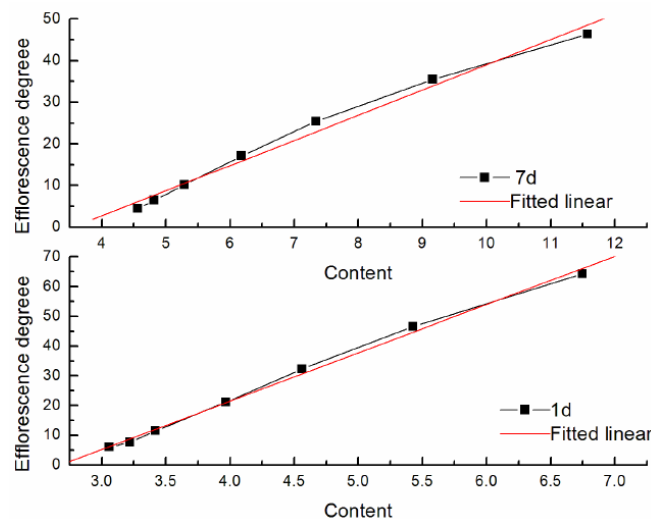### 3. Effect of Ca(OH)$_2$ content of hydration product on the efflorescence degree

$CaCO_3$ and $Ca(OH)_2$ are main efflorescence components of cement-based decorative mortar, and $CaCO_3$ is formed by the reaction of $Ca(OH)_2$ with $CO_2$ 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 $Al_2O_3$ and $SiO_2$, the early activity of metakaolin is similar to nanometer $SiO_2$, 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.

**Figure 1.** TG of cement hydration products.     **Figure 2.** DSC of cement hydration products.

As Figure 1, The dehydration temperature of $Ca(OH)_2$ is 400-500℃, and the decomposition temperature of $CaCO_3$ is 620-820℃. As Figure 2, the curve has a weak endothermic peak at about 444 ℃, which is the thermal effect of $Ca(OH)_2$ dehydration at this temperature, and an obvious endothermic peak at about 765 ℃, 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.



**Figure 3.** Relations $Ca(OH)_2$ content and efflorescence degree at1d and 7d.

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, $Y=16.236x-43.4481$, $R^2=0.9978$                        **(Formula 2.)**

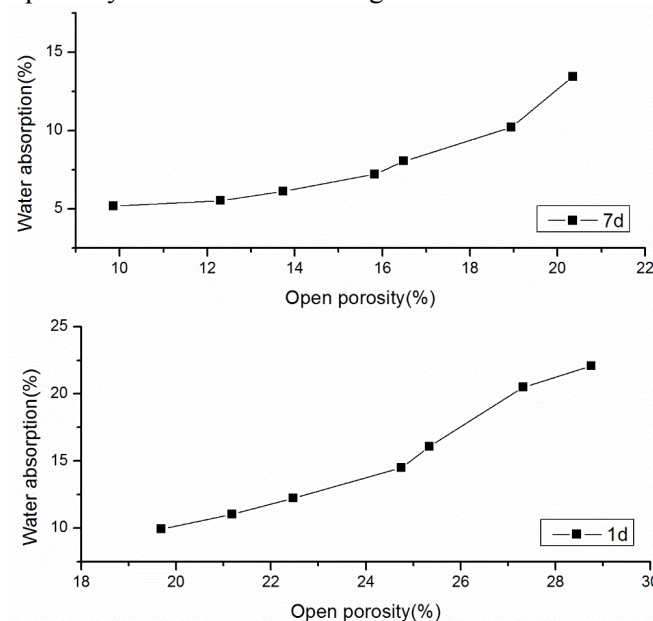Secondary efflorescence, Y=6.0463x-21.4779, $R^2$=0.9935            **(Formula 3.)**

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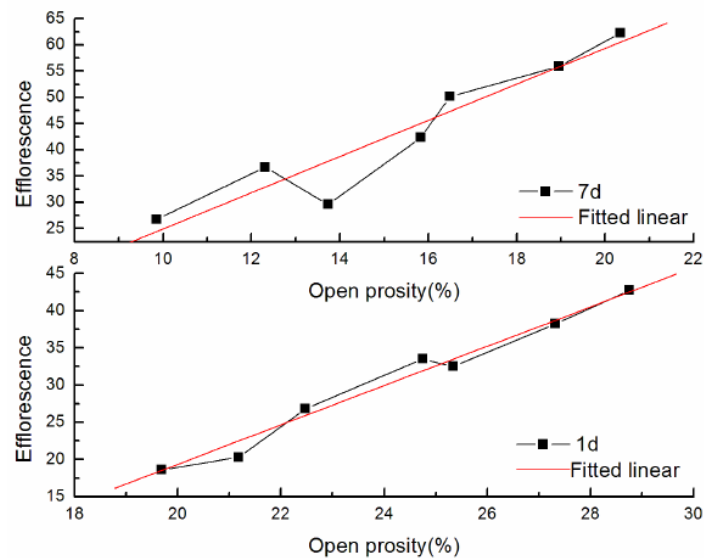
The cement-based decorative mortar is a porous material. The external moisture easily gets in and out of capillary channels and micro-cracks of mortar, as a medium in which alkali ions migrate to the mortar surface. In particular, the opening porosity is the most important factor affecting the permeability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



**Figure 4.** Relations between open porosity and water absorption.

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.

**Figure 5.** Relations between open porosity of mortar and efflorescence degree.

As Figure 5, the efflorescence degree of mortar increases with the increase of opening porosity at the age of 1 day or 7 days. When the opening porosity of mortar increases from 19.69% to 28.76% at the age of 1 day, the efflorescence degree value of mortar increases from 18.6 to 42.7, an increase of 130%. When the opening porosity of mortar increases from 9.86% to 20.35% at the age of 7 day, the efflorescence degree value of mortar increases from 26.8 to 62.3, an increase of 132%.

The correlation between the efflorescence degree and opening porosity is analyzed by the principle of least square method, and the results show that there is a good linear correlation between them, as formula 4 and formula 5. In which the alphabet x means opening porosity, Y means efflorescence degree, $R^2$ means the degree of correlation.

Initial efflorescence, $Y=2.7016x-35.04976$, $R^2=0.980$                    (**Formula 4.**)

Secondary efflorescence, $Y=3.44317x-9.47778$, $R^2=0.949$               (**Formula 5.**)

It can be seen that the efflorescence degree of finishing mortar is closely related to the opening porosity, and the opening porosity plays a decisive role in the efflorescence degree of mortar.

## 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.

**References**

[1]    Kang S P and Kwon S J 2017 Effects of red mud and alkali-activated slag cement on efflorescence in cement mortar *Construction and Building Materials* Vol.**133** p.459-

467

[2]     Zhu H M, Wang P M and Zhang G F 2017 Effect of air entraining agent on efflorescence of cement-based decorative mortar and its mechanism *Jianzhu Cailiao Xuebao/Journal of Building Materials* **20**(1) p.1-6

[3]     Zhu H M, WangP M and Zhang G F 2015 Influence of vinyl acetate/ethylene copolymer powder on secondary efflorescence in Portland cement-based decorative mortar *Journal of Zhejiang University: Science A* **16**(2) p.143-150

[4]     Miki I, KawatakeK K and ShigemotoN Y 2010 Efflorescence behavior caused by aggregates in mortar blocks *Kagaku Kogaku Ronbunshu* **36**(5) p.519-525

[5]     Alves R, Faria P and Simão J 2017 Experimental characterization of a Madeira Island basalt traditionally applied in a regional decorative mortar *Journal of Building Engineering* **13** p.326-335

[6]     Li H X, Yang X J, Suo Z, Xia Y B and He D H 2014 Red cement-based decorative mortar prepared with dry electroplating sludge containing Pb as red pigment *Journal Wuhan University of Technology, Materials Science Edition* **29**(2) p.291-297

[7]     Li H X, Yang X J, Xu W, Wu J G, Xu J C, Zhang G F and Xia Y B 2014 Application of dry composite electroplating sludge into preparation of cement-based decorative mortar as green pigment *Journal of Cleaner Production* **66** p.101-106

[8]     Ye D Z 2007 Study on effect of silica fume on structure and properties of cement mortar and properties of cement paste *Journal of Bei jing Technology and Business University(Natural S cience Edit ion)* **25**(6) p.11-15

[9]     Li Y, Tang M and Nie Y Q 2002 Effect of nano-sio$_x$ and silica fume on cement paste water demand *Journal of Shenyang Arch. and Civ. Eng. Univ.* **18**(4) p.278-281

[10]    Jiang G, Jie L D and Sun W 2015 Effects of metakaolin on properties of high performance mortar *Journal of Southeast University ( Natural Science Edition)* **45**(1) p.121-125

[11]    Zhu H M, Wang P M and Zhang G F 2017 Effect of air entraining agent on efflorescence of cement-based decorative mortar and its mechanism *Jianzhu Cailiao Xuebao/Journal of Building Materials* **20**(1) p 1-6

[12]    Mei Y J, Wang P M, Liang N X and Li Z Y 2007 Mechanism of the effect of styrene-butadiene latex on the water *Journal of Building Materials* **276**(3) p.276-281

[13]    Chen S, Li W L, Wang Q C, Li S and Li J X 2014 Research of cement mortar air content on the effects of pore characteristics and frost resistance *Bulletin of the Chinese Ceramic Society* **33**(6) p.1293-1297