Experimental Study of Effects of Efflorescence Control Admixture in Cement Mortar

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Abstract

This research work focuses on the effectiveness of efflorescence control admixture in reducing efflorescence on ordinary Portland cement mortar. Two different exposure conditions were set up to accelerate the development of efflorescence on mortar specimens. Efflorescence was quantified by digital image processing using MATLAB. A total of 132 mortar cubes of six-inch size were cast from 1:6 mortar with and without admixture. 108 specimens were left in waterlogged soil and 24 were partially submerged in sodium sulfate solution for 28, 56, and 90 days, and photographs of these specimens were processed. A comparison of 276 photographs of the specimens shows there is a considerable reduction in efflorescence in the case of specimens in waterlogged soil, whereas in sodium sulphate solution there was not much reduction in efflorescence. However, it is concluded that efflorescence control admixture can effectively prevent efflorescence in normal environmental conditions.

Keywords—Efflorescence, image processing, exposure conditions, Efflorescence control admixture, RGB (Red, Green, Blue)

1 Introduction

CEMENT mortar is extensively used as a binding material in masonry as well as a protective coating in the form of plastering. Ordinary portland cement is manufactured from materials containing calcium carbonate and clay. Presence of salts in one of the materials of mortar cause efflorescence. Sand obtained from the seashore or a river estuary contains salt [20]. Ultimately a whitish layer of salt appears on the surface of the mortar, badly affecting the aesthetic look of the whole masonry. This whitish salt layer is called efflorescence and is common in ceramic building materials, and cement-based materials like mortar and concrete [1], [2], [3]. Efflorescence in cement mortar and concrete most commonly occurs due to the leaching of soluble salts and most commonly due to calcium hydroxide, through mixed water. When this dissolved calcium hydroxide in water migrating through pores reaches the surface, it reacts with carbon dioxide from the atmosphere to produce calcium carbonate by carbonation reaction, which often appears as a white salt deposit on the surface of the structure [5], [6], [7]. Efflorescence is of two types; one which appears in the early hydration period of cement is called primary efflorescence and the other which appears after months or years due to environmental effects is called secondary efflorescence. Secondary efflorescence appears over a longer period for various factors and reasons [2]. As efflorescence is an aesthetic phenomenon rather than a structural one, it is mostly not dangerous for structures from a strength point of view [8]. The appearance of efflorescence often creates controversies between clients and constructors regarding the quality of their work. Also, the removal of efflorescence is a tedious and expensive job. Efflorescence should be prevented before formation rather than removing it by other means. Various materials have been used to minimize the formation of efflorescence in cement. An effective method of preventing efflorescence is the use of efflorescence control admixtures (ECA), which provide water repellency and crystal modification thereby reducing the chances of efflorescence. The use of hydrophobic admixtures also called ECAs such as mineral oil, vegetable oils, paraffin waxes, long-chain fatty acids, hydrocarbon resins, and bitumen can effectively decrease water absorption and then limit efflorescence in concrete or mortar. For example, stearate-containing materials (e.g. calcium stearate)

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have been commonly used as ECA in concrete formulations [24]. This research work aims to investigate the role of admixtures in controlling efflorescence in ce-ment-based materials and using the technological approach to evaluate efflorescence such as the digital image processing technique.

2 Literature Review

Many scholars have taken various efforts to study the mechanism of the formation of efflorescence and its miti-gation methods. Two main problems faced by researchers are the lack of availability of standardized methods for the quantification of efflorescence and ambiguous methods of accelerated efflorescence formation [1], [2]. The findings of previous studies are summarized in Table 1

3 Material and Testing

In this study cubical specimens of sixinch size were prepared from cement mortar with and without ECA. Cement mortar was prepared from ordinary Portland cement and locally available bolhari sand in a ratio of 1:6, with a watercement ratio of 0.5. A total of 132 mortar cubes were cast in two batches with and without admixture. Triethoxyoctylsilane was used as (ECA). Specimens were placed in two different exposure conditions of waterlogged soil and sodium sulphate solution for the period of 28, 56, and 90 days. After 7 days of curing, out of a total of 132 specimens, 108 Specimens were placed in the form of stacks of three layers with six cubes in each layer in waterlogged soil and 24 specimens were partially submerged to 1-inch depth in a sodium sulphate solution. The sodium sulphate Na2SO4 saturated solution was prepared under controlled conditions (200C and 50% relative humidity) and left for 24 hours to eliminate any undissolved sulphate crystal. A measure of 172.4 g salt in 1 litre of deionized water was added to saturate the solution. The saline solution was kept in beakers (110 ml solution in each beaker. After a specified period photographs of specimens were taken with the help of a digital camera at the same condition of light, from the same height, and distance to avoid variation in results between different batches. Digital image processing was carried out to compare the proportion of efflorescence on specimens. A total of 276 photographs were taken and processed for the quantification of efflorescence. In MATLAB digital photographs were converted from RGB (Red, Green, Blue) color images to grayscale images by using the rgb2gray function of the toolbox. Then grayscale images were segmented by thresholding. Gray thresholding was a critical step in classifying the unaffected area of the specimens and the area affected by efflorescence. To avoid errors in results, unaffected areas were specified manually by the user input method. After manually selecting the unaffected area, the algorithm determined the corresponding thresholding value for the rest of the images based on user input. In addition, the algorithm computes and indicates the degradation percentage depending on the level of the affected area. In this way, the area of efflorescence per total area of specimen was determined and results were compiled.

4 Results and Discussion

MATLAB digital image processing results for the specimens in two different exposure conditions are tabulated and results are plotted for comparison.

It may be observed from Table 2 and Figure 1 that in the case of waterlogged soil, the average area of efflorescence per total area of specimen in normal mortar is greater than the efflorescence in a mortar with ECA. Furthermore for normal mortar, there is an increasing trend in efflorescence area with an increase in exposure periods from 28 to 56 days. From 56 to 90 days there is a slight increment in the efflorescence area. This is because most of the primary efflorescence formed in the first 28 days of the exposure period. Similarly, when we look at the trend line for mortar with ECA, this increasing trend is not remarkable but a very slight increment from 28 to 56 days is observed. This is because efflorescence control admixture has effectively prevented the development of efflorescence over the exposure period. From Table 3, it can also be observed that at 28 days there is 14.91% more efflorescence in normal mortar as compared to the mortar with ECA. Similarly, for 56 and 90 days, this difference is 26.24% and 27.93%, respectively. On average there is a 23.02 percent reduction in efflorescence, which is a considerable reduction of efflorescence in a mortar with ECA. It can also be observed from these statistics that most of the efflorescence in a mortar with ECA has developed in the first 28 days, and after 28 days, there is a very slight increase in efflorescence. When specimens were placed in the form of stacks, moisture rose by capillary and induced efflorescence. Hence bottom layers showed more efflorescence as compared to the middle and top layers. Average results of the proportion of efflorescence are also compared in Figure 3 for the bottom, middle, and top layers of stacks of cubes in waterlogged soil.

It can be seen from Figure ?? that when cubes were placed in the form of stacks in three layers, the bottom layer of cubes showed slightly more efflorescence i.e.,

TABLE 1: Summarised Literature Review

S. No.	Researchers	Year	Parameters of Study	Results
1	Dow et al. [1]	(2003)	Investigated calcium carbonate efflorescence on Portland cement and building materials.	This study revealed the role of soluble alkalis in the formation of efflorescence on building materials. These alkalis increase the solubility of hydrated lime which ultimately forms calcium carbonate efflorescence.
2	Liu et al. [3]	(2019)	Conducted Research on characterization methods of efflorescence on cement-based decorative mortar.	The results show that the effects of colors in different grey scales on mortar appearance can be distinguished by the image processing techniques and colors in efflorescence region would be affected when their grey scales were 15 higher than that of matrix color.
3	Sutan et al. [12]	(2014)	studied the effect of pozzolanic industrial by-products i-e silica fume and fly ash in efflorescence mitigation on ordinary Portland cement mortar.	Results showed that 10% Silica fume (SF) reduced efflorescence up to 52.9% in comparison to normal mortar. The study also revealed that cement replacement of more than 30% is detrimental to efflorescence mitigation. It might be due to the lack of water content to initiate pozzolanic reaction because of the agglomeration of fine SF particles.
4	Kang et al. [8]	(2017)	Studied Effects of red mud and Alkali-Activated Slag Cement on efflorescence in cement mortar. Paint.net software was used to analyze the efflorescence.	The efflorescence area is less than 10% for the replacement ratio of red mud up to 5%. However when the replacement ratio of red mud increases over 10.0% efflorescence area rapidly increases.
5	Weng et al. [5]	(2013)	Studied the effect of metakaolin on the strength and efflorescence quantity of cement-based composites. Quantification of efflorescence was done by MATLAB image processing.	The inclusion of metakaolin decreased the extent of efflorescence in all specimens except for those with 20% and 25% metakaolin. Specimens with 15% metakaolin showed the least efflorescence.
6	Hennetier et al. [2]	(2001)	Quantification of efflorescence in ceramic building material was done by Matlab image processing.	According to the results of this study, the amount of efflorescence formed is greatly influenced by temperature and even more so by water pressure.
7	Cultrone et al. [18]	(2008)	Studied the influence of salt efflorescence on weathering of composed building materials. Four types of mortar were prepared (pure lime mortar, mortar + air entraining agent, mortar + pozzolana, mortar + air entraining agent + pozzolana).	All other Mortars caused efflorescence and salt weathering. Only mortar with air entraining agent showed less efflorescence because admixture created closed porosity thereby reducing the rise of moisture through pores. Consequently, efflorescence was minimized.
8	Kanduth et al. [10]	(2013)	Evaluation of efflorescence in mortar and concrete containing a Surface treated calcium carbonate product was carried out. OMYCARB an efflorescence control admixture was used to prevent efflorescence.	Based on the laboratory results generated in this study, the addition of OMYACARB did prevent efflorescence by changing the water transport in the mortar mixes. The addition of 10% OMYCARB was enough to prevent efflorescence.
9	Delair et al. [4]	(2007)	Studied efflorescence formation process on cementitious materials. In this study, three types of metakaolin were used differing in particle size.	Based on this study 10% substitution of metakaolin with a particle size diameter of 4.7µm showed less efflorescence as compared to other types.
10	Zhang et al. [9]	(2020)	Investigated the effect of carbonation curing on efflorescence formation in concrete pavers. A CO2 chamber was used for the carbonation of concrete specimens and the MATLAB image processing technique was used for the quantification of efflorescence.	Based on this study it is concluded that pure CO2 curing seemed to be successful in eliminating the occurrence of efflorescence compared to the conventional hydration-cured control specimens. in two different ways. First, the curing process consumed calcium hydroxide, the necessary chemical component for carbonate-based efflorescence. Second, the formation of efflorescence requires water to migrate up to the surface. The carbonation curing technique could densify the concrete surface and decrease the absorption consequently.

TABLE 2: SPECIMENS AND EXPOSURE CONDITIONS

Specimens		Exposure period (in days)			Exposure condition
		28	56	90	
Mortar Cubes. 6” size	Controlled	4	4	4	Partially submerged up to 1” depth in a sodium sulphate solution.
	With ECA	4	4	4	
Mortar Cubes. 6” size	Controlled	18	18	18	In the form of stacks of cubes in waterlogged soil.
	With ECA	18	18	18	

TABLE 3: AVERAGE AREA OF EFFLORESCENCE PER TOTAL AREA OF THE SPECIMEN IN WATER-LOGGED SOIL (UNIT %)

	Exposure period in days					
	28 days		56 days		90 days	
	Normal Mortar	Mortar with ECA	Normal mortar	Mortar with ECA	Normal mortar	Mortar with ECA
Bottom Layer	32.31	14.06	50.22	21.16	52.77	20.43
Middle Layer	28.43	13.72	45.92	19.99	48.77	21.37
Top Layer	24.66	12.90	43.90	20.18	45.21	21.15
Average	**28.47**	**13.56**	**46.68**	**20.44**	**48.91**	**20.98**
Difference	**28.47-13.56 = 14.91**		**46.68-20.44 = 26.24**		**48.91-20.98 = 27.93**	

TABLE 4: Average Area of efflorescence per total area of the specimen in sodium sulphate solution (unit %)

	Exposure period in days					
	28 days		56 days		90 days	
	Normal Mortar	Mortar with ECA	Normal mortar	Mortar with ECA	Normal mortar	Mortar with ECA
Cube 1	30.25	24.35	47.56	41.22	54.30	44.45
Cube 2	25.99	22.18	47.16	37.28	46.18	39.05
Cube 3	27.38	27.5	46.50	40.50	47.51	37.69
Cube 4	**33.22**	**23.29**	**48.91**	**36.73**	**48.71**	**32.54**
Average	**29.21**		**47.53**		**49.17**	
Difference	**29.21-24.33=4.88**		**47.53-38.93=8.6**		**49.17-38.43=10.74**	

7% to 8% more than the top layers in the case of normal mortar. This difference was negligible i.e 1% to 2% for mortar with ECA, because admixture has resisted efflorescence equally even in direct contact with soil MATLAB image processing results for specimens in sodium sulphate solution are also presented in Table 4 and results are plotted for comparison.

From Figure 3 it can be observed that in the case of specimens partially submerged to a 1-inch depth in sodium sulphate solution, there is not much reduction of efflorescence by ECA. Furthermore, for normal mortar, there is an increasing trend in the efflorescence area with an increase in exposure periods from 28 to 56 days, but from 56 to 90 days there is not much increment in the efflorescence area. The same trend of increase in efflorescence is observed for mortar with admixture. From Table 4 it can be observed that at 28 days, there is only 4.88% more efflorescence in normal mortar as compared to the mortar with ECA. Similarly, for 56 and 90 days, this difference is 8.6% and 10.74% and on average it is an 8.07% reduction in efflorescence by admixture. Which is not a notable reduction in efflorescence area in mortar by ECA.

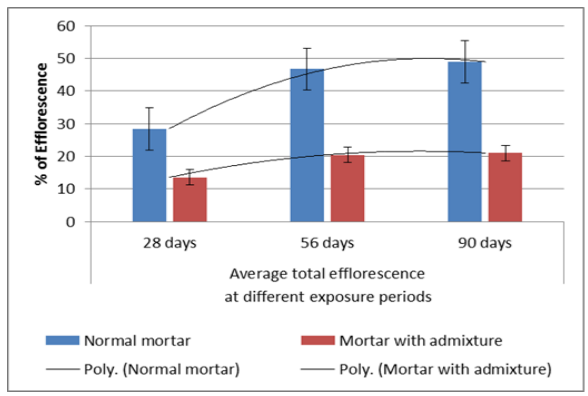

Fig. 1: Average area of efflorescence per total area of specimen in waterlogged soil (unit:%)

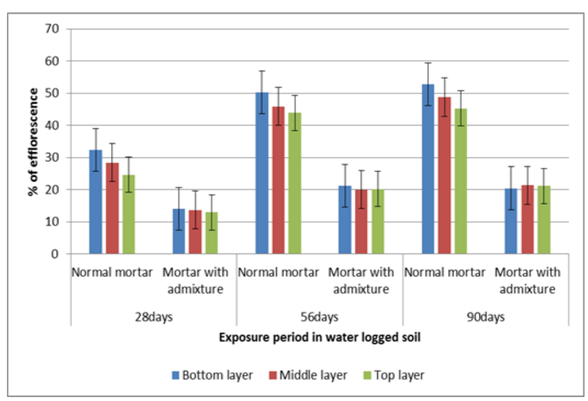

Fig. 2: Average area of efflorescence per total area of specimen on different layers of stacks in waterlogged soil (unit:%)

5 Conclusion

Based on conducted research it can be concluded that Triethoxyoctylsilane as ECA is effective to control the initiation and propagation of efflorescence in cement mortar in contact with waterlogged soil. However, it is not much effective in a sodium sulphate solution.

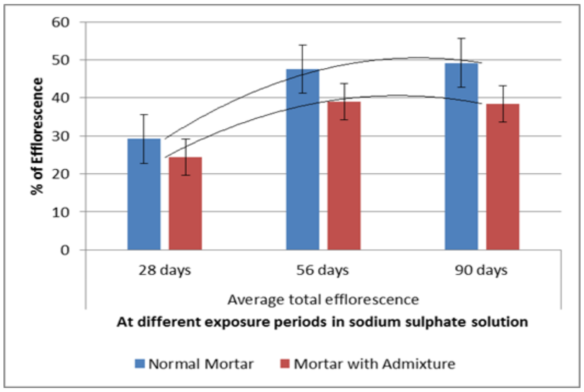

Fig. 3: Average area of efflorescence per total area of specimen in sodium sulphate solution (unit:%)

6 Recommendations

Based on the outcome of the image processing results presented in this research work, it is recommended that Triethoxyoctylsilane for normal exposure conditions should be used as ECA. For aggressive environments like sulphate-bearing ground and marine structures, oth-er more effective admixtures should be developed for the reduction of efflorescence.

7 Limitations of Study

The main limitations are as follows, firstly, the defects affect the image gray value such as color aberration and small pits on the surface inevitably formed in the process of mortar molding, but there is no effective method to eliminate the influence of the above defects on the image gray value. Secondly, The brightness of the surface colors of mortar varies with the moisture content of mortar, which will affect the grayscale value of efflorescence re-gion color and the base color. Thirdly, the image gray value varies with a deviation of light in the process of photography and uneven exposure of the image. There-fore, it is necessary to make the mortar spread evenly, ventilate and dry to a similar humidity, the same light in the process of photography as far as possible.

References

[1] Dow, C., and Fredrik Paul Glasser. “Calcium carbonate efflorescence on Portland cement and building materials.“ Cement and Concrete Research 33, no. 1 (2003): 147-154.
[2] Hennetier, Luc, J. V. Almeida, Antonio MS Correia, and Victor M. Ferreira. “Efflorescence and its quantification in ceramic building materials.” British Ceramic Transactions 100, no. 2 (2001): 72-76.
[3] Liu, X. F., J. H. Peng, J. X. Zhang, and J. D. Qu. “Research on characterization methods of efflorescence on cement-based decorative mortar.” In IOP Conference Series: Materials Science and Engineering, vol. 504, no. 1, p. 012007. IOP Publishing, 2019.
[4] Delair, Stéphanie, René Guyonnet, Alexandre Govin, and Bernard Guilhot. “Study of efflorescence forming process on cementitious materials//Etude du processus de formation des efflorescences sur des matériaux cimentaires.”
[5] Weng, Tsai-Lung, Wei-Ting Lin, and An Cheng. “Effect of metakaolin on strength and efflorescence quantity of cement-based composites.” The Scientific World Journal 2013 (2013).
[6] Chwast, Jacek, Jelena Todorović, Hans Janssen, and Jan Elsen. “Gypsum efflorescence on clay brick masonry: Field survey and literature study.” Construction and Building Materials 85 (2015): 57-64.
[7] Brocken, Harold, and Timo G. Nijland. “White efflorescence on brick masonry and concrete masonry blocks, with special emphasis on sulfate efflorescence on concrete blocks.” Construction and Building Materials 18, no. 5 (2004): 315-323.
[8] Kang, Suk-Pyo, and Seung-Jun Kwon. “Effects of red mud and alkali-activated slag cement on efflorescence in cement mortar.” Construction and Building Materials 133 (2017): 459-467.
[9] Zhang, Shipeng, Zaid Ghouleh, and Yixin Shao. “Effect of carbonation curing on efflorescence formation in concrete paver blocks.” Journal of Materials in Civil Engineering 32, no. 6 (2020): 04020127.
[10] Kanduth, B., & Gelinas, J. B. (2013). U.S. Patent No. 8,580,030. Washington, DC: U.S. Patent and Trademark Office.
[11] Xue, Bin, and Chunxiang Qian. “Mitigation of efflorescence of wallboard by means of bio-mineralization.” Frontiers in microbiology 6 (2015): 1155.
[12] Sutan, Norsuzailina Mohamed, Sinin Hamdan, Ibrahim Yakub, and Zainal Abidin Talib. “Efflorescence mitigation by pozzolanic industrial by-products.” Malaysian Journal of Civil Engineering 26, no. 2 (2014): 198-208.
[13] Vickers, Thomas, and Mosongo Moukwa. “Evaluation of test methods and environmental conditions to promote efflorescence formation under laboratory conditions.” Journal of testing and evaluation 24, no. 2 (1996): 80-83.
[14] Griffin, Donald F., and Robert L. Henry. “Integral Sodium Chloride Effect on Strength, Water Vapor Transmission, and Efflorescence of Concrete.” In Journal Proceedings, vol. 58, no. 12, pp. 751-772. 1961.
[15] Higgins, D. D. Efflorescence on concrete. No. Monograph. 1982.
[16] Bolte, Gerd, and Wolfgang Dienemann. “Efflorescence on concrete products-causes and strategies for avoidance.” ZKG INTERNATIONAL 57, no. 9 (2004): 78-86.
[17] Kresse, P. “Efflorescence-mechanism of occurrence and possibilities of prevention.” Betonwerk+ Fertigteil-Technik 53, no. 3 (1987): 160-168.
[18] Cultrone, Giuseppe, and Eduardo Sebastian. “Laboratory simulation showing the influence of salt efflorescence on the weathering of composite building materials.” Environmental geology 56 (2008): 729-740.
[19] Shetty, M. S., and A. K. Jain. Concrete Technology (Theory and Practice), 8e. S. Chand Publishing, 2019.
[20] Neville, Adam M., and Jeffrey John Brooks. Concrete technology. Vol. 438. England: Longman Scientific & Technical, 1987.
[21] Allahverdi, A., E. Najafi Kani, K. M. A. Hossain, and M. Lachemi. “Methods to control efflorescence in alkali-activated cement-based materials.” In Handbook of alkali-activated cements, mortars and concretes, pp. 463-483. Woodhead Publishing, 2015.
[22] Joshi, Sumit, Shweta Goyal, Abhijit Mukherjee, and M. Sudhakara Reddy. “Protection of concrete structures under

sulfate environments by using calcifying bacteria." Construction and Building Materials 209 (2019): 156-166.

[23] Granneman, Sanne JC, Barbara Lubelli, and Rob PJ van Hees. "Mitigating salt damage in building materials by the use of crystallization modifiers–a review and outlook." Journal of Cultural Heritage 40 (2019): 183-194.

[24] Ashish, Deepankar K., Bhupinder Singh, and Surender K. Verma. "The effect of attack of chloride and sulphate on ground granulated blast furnace slag concrete." Advances in concrete construction 4, no. 2 (2016): 107.

[25] Glasser, Fredrik P., Jacques Marchand, and Eric Samson. "Durability of concrete—Degradation phenomena involving detrimental chemical reactions." Cement and Concrete Research 38, no. 2 (2008): 226-246.