Review Article

INVESTIGATION OF CHLORIDE DIFFUSION INTO CONCRETE WITH JOINT

Abstract

Because volume changes cause stress on concrete, construction joints are intentionally incorporated to ensure efficient construction and crack control in mass concrete structures. Growing concerns about the progressive salinization of concrete are creating pressure to refine the diffusion models currently used for predictions. Their dependability for natural structures presents challenges because of oversimplified presumptions or unknown inputs for the current building materials. This paper seeks to review on the investigation of chloride diffusion into concrete with joint. For an effective study of the topic, various cement specimens were grouped under different categories, D, E, and Fto evaluate the effects of uniaxial sustained and biaxial sustained compressive loads on chloride intrusion, respectively. Categories D and E were used. Non-loading was applied to Category F. The experimental study on the effects of various sustained compressive stresses on the chloride ion diffusivity of concrete in chloride ion solution is presented in this work, together with information on the effects of water/cement ratio and chloride diffusivity. To assess the chloride diffusion properties of concrete materials, the chloride concentration distribution of concrete under uniaxial and biaxial continuous compressive stress was measured. However, the results of this paper shows that, the transport of chloride ions from the environment into concrete is altered by the presence of continuous compressive stress.

Introduction

Concrete cracks as a result of the stress brought on by volume changes, hence construction joints are built on purpose to ensure effective construction and crack control in mass concrete structures.[1, 2] On the other hand, there are numerous engineering benefits which exist for concrete, including cost-benefit analysis, great durability, exceptional fire resistance, building efficiency, and a reliable supply chain.[3, 4] However, due of its weak tensile strength, it permits cracks in the area that is under tensile stress. The tensile zone is where steel reinforcement is most frequently utilized, and it is made to withstand tensile stress. [5, 6] According to some studies, the high alkali content and inadequate oxygen in concrete prevent steel from corrosion, but corrosion is easily caused when RC structures are exposed to a chloride environment. [7] Due to a drastic drop in bonding strength and useful steel area, durability issues might develop into structural issues with corrosion. [8, 9, 10]

Construction joints are typically used for mass concrete structures,[11, 12] such as RC columns for bridges and wall structures, to reduce cracking and ensure that concrete is placed efficiently within a certain amount of time.[13,14] One of the key variables affecting concrete durability and shortening a building's lifespan is chloride diffusion. The composition of the concrete and its porosity are just two of the many variables that affect chloride diffusion.[15, 16] Since aggregates make up around 75% of the volume of common concrete mixtures, aggregate characteristics have a big impact on chloride dispersion and the resilience of concrete structures.[17, 18] In order to estimate the service life of given buildings with known mixes and materials, multiple researchers have studied the problem of chloride diffusion and developed various chloride prediction and service life models.[19 ,20 ,21] A helpful foundation for constructing reinforced concrete structures in salt-contaminated settings has been created [22]. Accordingly, adding silica fume (SF) and other materials boost the concrete's durability,[23] like fly ash (FA) and GGBS, at specific percentages can significantly improve concrete's durability.[24]Quantitative data is needed to specify the boundary condition at the exposed surface, the effective chloride transport coefficient, and the corrosion initiation threshold level of chloride as specified by the applicable code in order for the model to function.

A variety of experimental findings on the diffusion of acid-soluble chloride in various concrete mixtures have been presented by some studies.[25,26] They have demonstrated that the length of time concrete is exposed to a chloride environment has a significant impact on the effective chloride transport coefficient. A mathematical model for chloride penetration in saturated concrete has been developed [27,28] taking into account the w/c ratio, cement type, aggregate content, curing time, temperature, and surface chloride iron concentration. However, it has been noted that the main elements that affect concrete longevity are the near-surface concrete's permeability and the numerous transport systems that control chloride penetration.[29, 30] For determining how long concrete would last, they performed tests on air permeability, freeze-thaw/salt scaling resistance, and an accelerated carbonation test. They came to the conclusion that a higher fraction of bigger aggregate reduces durability.

In addition to, the effects of cement, water, curing conditions, and microsilica content on chloride diffusion characteristics were examined.[31,32] They discovered that there is a relationship between w/c ratio and chloride diffusion, and that this relationship varies depending on the different microsilica compositions. They came to the conclusion that the influence of high w/c ratios on chloride ingress is significantly more noticeable in mixes with low microsilica content and that cement content has no effect on chloride ingress in mixes with high microsilica content. [33] Additionally, they found that when the w/c ratio of the mixes is held constant, the influence of microsilica content on the diffusion coefficient, Dc, is less pronounced. A series of studies have investigated the carbonation of concrete subjected to a hot, arid climate like that of the United Arab Emirates.[34,35,36] Their findings demonstrated that the usage of surface coating, the water/cement ratio, the water-curing time, and the season in which the concrete was initially cast and exposed were the most important variables influencing concrete carbonation. They also came to the conclusion that a lower water/cement ratio and a longer water-curing time led to less carbonation in concrete.

It is clear that research on concrete durability has captured the interest of several scientists across the globe, including those in the Arabian Gulf. Without sufficient research on the effects of chloride exposure, the usage of concrete has expanded in the UAE, which is a significant long-term concern for this region. [37, 38] When employing local materials in the harsh environment of the UAE, where the building sector is growing at an unprecedented rate, the authors believe that this study is crucial for this region. This study is the first stage in an ambitious plan to investigate the chloride diffusion into concrete with joint in various parts of the globe considering the difference environmental and climatic conditions.

Furthermore, the effectiveness of chloride diffusion under prolonged load has been covered in some research. According to these studies, the diffusion of chloride ions will not always be hampered by an increase in sustained compressive stress.[39,40] The experimental findings demonstrate that when the sustained compressive stress is greater than $0.3f_c$ (for example, f_c = prism compressive strength at 28 days), the chloride diffusion coefficient increases.[41, 42] However, biaxial sustained stress will also have an impact on the diffusion of chloride ions in concrete.[43, 44, 45] By employing additive concrete under biaxial sustained pressure stress, Xingcai Wei, [?] investigated the permeability of chloride ions and discovered that this process is not always inhibited by an increase in compressive stress. In the experiments mentioned above, the link between stress level and chloride content of concrete with various w/c (i.e., water/cement) ratios was not thoroughly explored. The chloride diffusion characteristics of several types of w/c concrete under biaxial sustained compressive stress are rarely studied. The diffusion of chloride in concrete structures with various w/c ratios under biaxial sustained compressive stress must therefore be studied. The purpose of this study is to examine the diffusion law of chloride ions in concrete under various compressive stress circumstances in light of the brief discussion that has gone before. In this study, concrete is subjected to a number of chloride ion penetration tests under uniaxial and biaxial sustained compressive stress, and the variation law of chloride concentration in concrete is examined. The apparent chloride diffusion coefficient under stress condition is then calculated using Fick's second law diffusion equation, and its variation under prolonged uniaxial and biaxial compressive stress is examined. The models for chloride diffusion under various stress situations are developed. The experimental evidence from the published literature confirms the applicability of the diffusion models.

A Test-Based Program

Preparation of Materials and Specimens

The following materials were needed to make concrete. Three categories—categories D, categories E, and categories F—were used to group concrete specimens. To evaluate the effects of uniaxial sustained and biaxial sustained compressive loads on chloride intrusion, respectively, Categories D and E were used. Non-loading was applied to Category F. Portland cement supplied by Changsha and meeting GB 175-2007 standards had a characteristic compressive strength of 42.5 MPa. Table 1 illustrates the cement's chemical makeup. As coarse aggregate, gravel with a maximum size of 20 mm and a density of 1550 kg/m3 that is accessible in Liu yang City, Hunan Province, China is used. The fine aggregate used was naturally occurring river sand, with a fineness modulus of 2.3 to 3.1. Poly carboxylic ethers superplasticizer (SP), created by Shandong Huawei Yinkai Building Materials Science and Technology Co., Ltd., was applied to all concrete sample. In Table 2, the concrete mix ratio is displayed. Following their creation, these specimens were cured for 28 days in a curing room at a temperature of 20 2 °C and a relative humidity of 90 5%. When the compressive strength of several concrete specimens was tested, the measured values were 47.21 MPa, 52.68 MPa, and 56.78 MPa, respectively, for concrete with w/c ratios of 0.44, 0.40, and 0.36. In the chloride diffusion experiment, the remaining concrete specimens were continuously compressed.

Table 1. Chemical composition of cement.

Ingredients	**SiO_2**	**Al_2O_3**	**CaO**	**MgO**	SO_2	Loss on ignition
Mass percent (%)	21.53	5.55	62.29	3.52	3.17	1.78

Table 2. Mix ratio of concrete test block.

Unit Content (kg/m^3)						
Type	w/c	Water	Cement	Fine Aggregate	Coarse Aggregate	SP
C45	O.45	181	408.07	542.26	1267.65	3.39
C50	0.40	181	450.00	531.00	1239.10	3.14
C54	0.36	181	500.00	516.00	1204.00	3

Test and experimental arrangements

For proper analysis, the one-dimensional diffusion law of chloride in concrete under sustained pressure stress,[46,47] we coated the other five surfaces of the specimens with epoxy resin apart from the penetration surface.To lessen the impact of the concrete boundary on the chloride diffusion process, the 100 mm central area of the concrete specimen's upper surface was chosen as the chloride ions penetration surface, and the upper surface was treated with wear reduction before the concrete specimens with various w/c ratios were put into the loading device for the loading test. The concrete specimen's long and short sides' stresses were denoted by the letters cx and cy, respectively. The concrete specimens are arranged neatly in the axial direction of the loading device for categories D (one-dimensional loading), and the compressive stress was tracked and managed by the screw jack's pressure measurements, as illustrated in Figure 1. Each concrete specimen for categories E (two-dimensional loading) is equipped with a force transfer plate on the lateral side, as illustrated in Figure 2, with the exception that the axial direction is consistent with that of categories D. On the force transfer plate is a compressive ring that is the same size as the side length of the concrete specimen. The pressure ring was put on one side of the loading plate, and the screw jack put in contact with the other. The numerical values of the three pressure rings were equal and reached the stress design value after adjusting the screw jack to manage the pressure rings' numerical values. Researchers have discovered that the characteristics of concrete materials change significantly when the biaxial compressive stress ratio is between 1:1 and 1:25. Concrete specimens in Category F, the control group, were not stressed. The parameters Fd0, Fe0, and Ff0, respectively, were used to represent the concrete with w/c ratios of 0.44, 0.4, and 0.36. In the same loading apparatus, concrete specimens received the same amount of compressive stress.

Figure 1: Uniaxial loading.

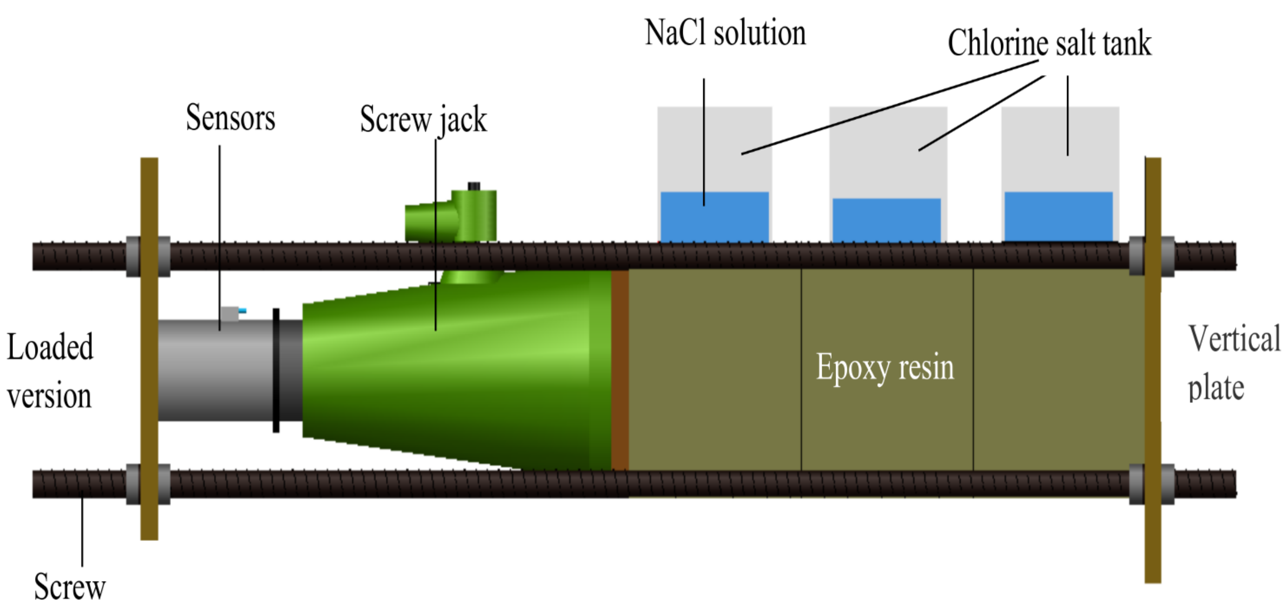
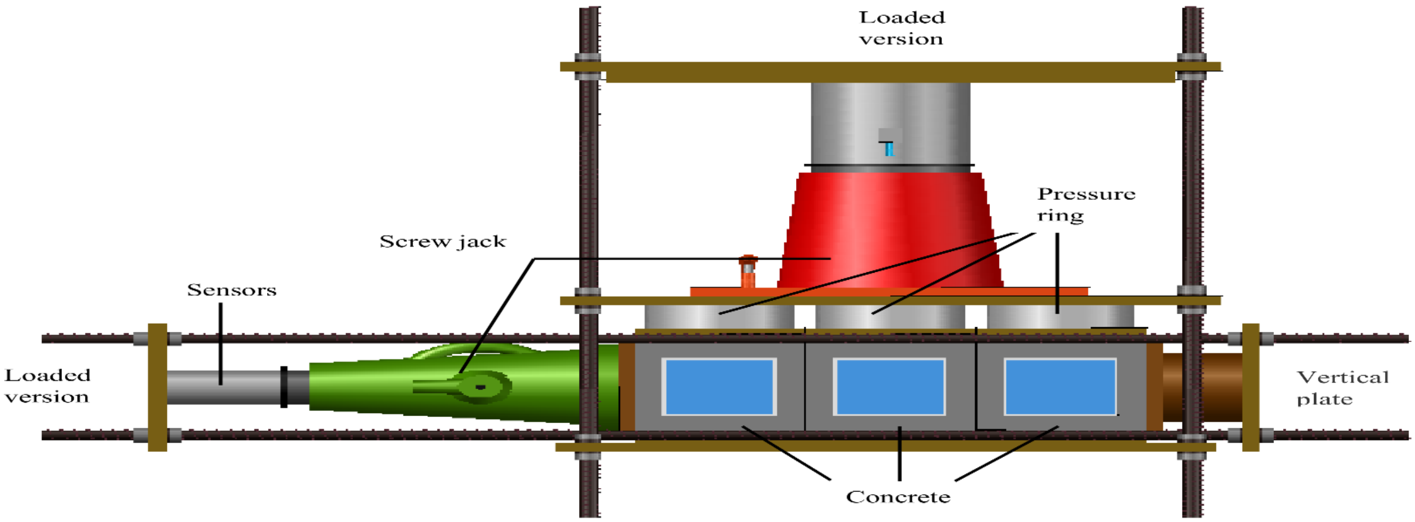


Figure 2: Biaxial loading.



Experiment with Diffusion and Measurement of Chloride Concentration

The prefabricated chloride trough was positioned on the concrete permeable surface and bonded to the concrete sample by the adhesive after the compressive stress was stabilized. With the aid of a beaker, the 3.5% NaCl solution was inverted in the chloride trough. The temperature of the artificial climate simulation box where the chloride ions penetration experiment was conducted was set between 20 and 22 °C. Concrete samples were exposed to chlorine salt for two months. To prevent precipitation and maintain a consistent chloride concentration, the solution in the chlorine salt trough was changed every week. [48] Following that, concrete specimens must be sampled in accordance with JTS/T 236-2019 standard. Vertical to the concrete-permeated surface was the drilling rig. Six measuring locations with distances of 0–5 mm, 5–10 mm, 10-15 mm, 20–25 mm, and 25–30 mm from the penetrated surface were produced by boring holes inward to collect powder. Three data points for the drilling depth of the same stratum were collected to reduce the impact of mistakes. The powders were dried in an oven at 105 °C for two hours, and then they were cooled to room temperature in a desiccator. Following that, a sample of concrete powder was tested for chloride concentration in accordance with JTS/T 236-2019 standards.

Test Findings and Analysis

Chloride Concentration Distribution under Various Axial Compressive Stresses

Figure 3 displays the distributions of chloride in the concrete specimens under uniaxial sustained compressive stress (categories D) and zero stress (categories F). Consider the numbers for the chloride concentration at a depth of 7.5 mm. As shown in Figure 3a, the chloride concentration values of the DCd1, DCd2, DCd3, and DCd4 specimens are, respectively, 21.05%, 34.58%, 29.41%, and 10.85% less than those of the Fd0 specimens in the same stratum. Figure 3b demonstrates that the chloride concentrations of the DCe1, DCe2, DCe3, and DCe4 specimens in the same stratum are 16.83%, 33.75%, 27.84%, and 6.92% lower than those of the Fe0 specimens. As shown in Figure 3c, the chloride concentration values of the DCf1, DCf2, DCf3, and DCf4 specimens are lower than those of the Ff0 specimens in the same stratum by 14.23%, 28.93%, 23.43%, and 4.90%, respectively. According to Figure 3, when compared to Fd0, Fe0, and Ff0 specimens, the average chloride concentration values of DCd2, DCe2, and DCf2 specimens are, respectively, reduced by 35.04%, 30.21%, and 22.23%. With an increase in sustained compressive stress, the chloride concentration values of DCd3, DCe3, and DCf3 specimens are, on average, 1.20 times, 1.17 times, and 1.13 times higher than those of DCd2, DCe2, and DCf2 specimens. Similar to how DCd4, DCe4, and DCf4 specimens have much greater chloride concentrations than DCd3, DCe3, and DCf3 specimens. According to the results of the aforementioned tests, concrete with a high w/c ratio was more vulnerable to external prolonged compressive stress, and C45 concretes performed better in diffusing chloride than C55 concretes did. Concrete sample' chloride concentration drops and their ability to diffuse chloride ions is hampered when the applied sustained compressive stress is less than or equal to 0.3 fc. Concrete sample' chloride ion diffusion would be encouraged if a sustained compressive stress larger than 0.3 fc was applied.

Figure:3 Chloride concentration distribution of concrete with three *w/c* ratios under uniaxial sustained stress: (**a**) *w/c* = 0.44; (**b**) *w/c* = 0.4; (**c**) *w/c* = 0.36.

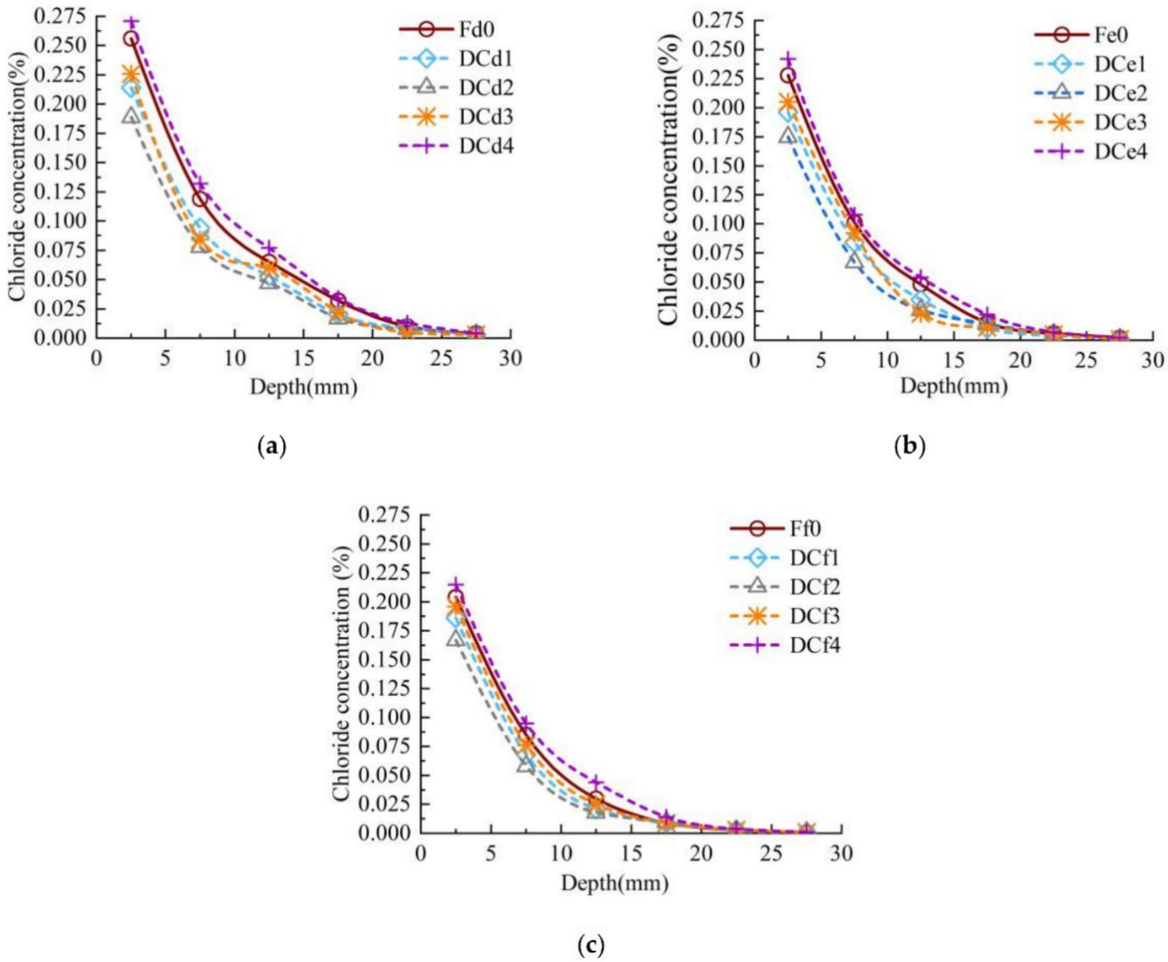
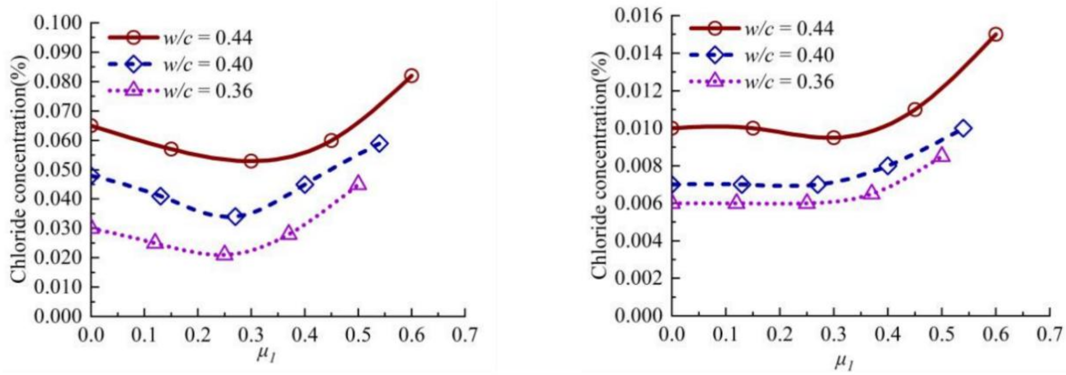


Figure 4 depicts the variations in chloride concentration with stress level 1 at diffusion depths of 12.5 mm and 22.5 mm in concrete. Figure 4a shows that as the stress level rises, the chloride content in concrete initially declines somewhat before rising quickly. The chloride concentration in concrete with various water/cement ratios drops when values of level 1 are close to 0.3. As seen in Figure 4b, the chloride content of concrete is unaltered. When the stresslevel 1 is less than or equal to 0.3, the impact of compressive force on chloride concentration is seen at great depths. When the stresslevel 1 is more than 0.3, as seen in Figure 4a, b, the chloride concentration in concrete rises. The chloride concentration of the C45 concrete specimens is higher than that of the C55 concrete specimens under the same prolonged compressive stress.



(a) (b)

Fig 4 : variations in chloride concentration with stress level 1 at diffusion depths of 12.5 mm and 22.5 mm in concrete

Conclusion and Remarks

Systematic experiments and numerical investigations are conducted on regular concrete exposed to one-dimensional chlorine salt erosion under various prolonged compressive stress settings in order to describe the diffusivity of concrete under sustained compressive stress. The experimental study on the effects of various sustained compressive stresses on the chloride ion diffusivity of concrete in chloride ion solution is presented in this work, together with information on the effects of water/cement ratio and chloride diffusivity. To assess the chloride diffusion properties of concrete materials, the chloride concentration distribution of concrete under uniaxial and biaxial continuous compressive stress was measured. The chloride ion diffusion coefficient was then calculated to examine the effects of various sustained compressive stress states on the chloride ion diffusion process. The chloride diffusion coefficient is then used to develop chloride diffusion models under various stress situations. The results of the experiment lead to the following deductions.

1. The transport of chloride ions from the environment into concrete is altered by the presence of continuous compressive stress. It is discovered that concrete specimens under axially sustained compressive stress of 0.3 fc have a maximum chloride content that is approximately 35% lower than those under no stress. The greatest chlorine content in the concretes with the axial and lateral sustained compressive stress of 0.3 fc and 0.15 fc is decreased by approximately 50% in comparison to those without stress. In addition, when the sustained compressive stress is more than 0.3fc, the diffusion process and concentration of chloride ions will increase. When the lateral sustained compressive stress is greater than 0.15 fc in biaxial concrete, the chloride concentration distribution is 1.27–1.1 times that of the lateral sustained compressive stress. The diffusion of chloride ions will be further improved as the level of prolonged compressive stress rises.
2. The chloride content of C45 concrete specimens is higher than that of C54 concrete specimens under the same sustained compressive stress. This is done because a higher w/c ratio results in inferior quality concrete, which makes the structure less dense and more sensitive to the effects of long-term compressive stress. As a result, concrete samples with higher w/c ratios had greater permeability. The created chloride diffusion coefficient model takes into account the impact of concrete's sustained uniaxial and biaxial compressive stress. The model is useful for estimating how long concrete constructions will last in environments with a lot of chlorine.
3. It is advised that future study measure concrete cracks under continuous stress conditions throughout the experiment. the fracture depth and concrete's pore size distribution under sustained load in order to potentially expand and enhance the model.

References

1. Jędrzejewska, A., Kanavaris, F., Zych, M., Schlicke, D., & Azenha, M. (2020, October). Experiences on early age cracking of wall-on-slab concrete structures. In *Structures* (Vol. 27, pp. 2520-2549). Elsevier.
2. Liu, J., Tian, Q., Wang, Y., Li, H., & Xu, W. (2021). Evaluation method and mitigation strategies for shrinkage cracking of modern concrete. *Engineering*, *7*(3), 348-357.
3. Bleyl, J. W., Bareit, M., Casas, M. A., Chatterjee, S., Coolen, J., Hulshoff, A., ... & Ürge-Vorsatz, D. (2019). Office building deep energy retrofit: Life cycle cost benefit analyses using cash flow analysis and multiple benefits on project level. *Energy Efficiency*, *12*, 261-279.
4. Navaratnam, S., Selvaranjan, K., Jayasooriya, D., Rajeev, P., & Sanjayan, J. (2023). Applications of natural and synthetic fiber reinforced polymer in infrastructure: a suitability assessment. *Journal of Building Engineering*, 105835.
5. Abid, S. R., Gunasekaran, M., Ali, S. H., Kadhum, A. L., Al-Gasham, T. S., Fediuk, R., ... & Karelina, M. (2021). Impact performance of steel fiber-reinforced self-compacting concrete against repeated drop weight impact. *Crystals*, *11*(2), 91.
6. Siddika, A., Al Mamun, M. A., Alyousef, R., & Amran, Y. M. (2019). Strengthening of reinforced concrete beams by using fiber-reinforced polymer composites: A review. *Journal of Building Engineering*, *25*, 100798.
7. Melchers, R. E. (2020). Long-term durability of marine reinforced concrete structures. *Journal of Marine Science and Engineering*, *8*(4), 290.

8. Haghdadi, N., Laleh, M., Moyle, M., & Primig, S. (2021). Additive manufacturing of steels: a review of achievements and challenges. *Journal of Materials Science*, *56*, 64-107.

9. Krishnan, A., Krishnan, A. V., Ajith, A., & Shibli, S. M. A. (2021). Influence of materials and fabrication strategies in tailoring the anticorrosive property of superhydrophobic coatings. *Surfaces and Interfaces*, *25*, 101238.

10. Broomfield, J. P. (2023). *Corrosion of steel in concrete: understanding, investigation and repair*. Crc Press.

11. Holly, I., & Abrahoim, I. (2020). Connections and joints in precast concrete structures. *Slovak Journal of Civil Engineering*, *28*(1), 49-56.

12. Wang, C., Chen, Y., Zhou, M., & Chen, F. (2022). Control of Early-Age Cracking in Super-Long Mass Concrete Structures. *Sustainability*, *14*(7), 3809.

13. Bischof, P., Mata-Falcon, J., & Kaufmann, W. (2022). Fostering innovative and sustainable mass-market construction using digital fabrication with concrete. *Cement and Concrete Research*, *161*, 106948.

14. Gkournelos, P. D., Triantafillou, T. C., & Bournas, D. A. (2021). Seismic upgrading of existing reinforced concrete buildings: A state-of-the-art review. *Engineering Structures*, *240*, 112273.

15. Shafikhani, M., & Chidiac, S. E. (2019). Quantification of concrete chloride diffusion coefficient–A critical review. *Cement and Concrete Composites*, *99*, 225-250.

16. Zhang, J., Bian, F., Zhang, Y., Fang, Z., Fu, C., & Guo, J. (2018). Effect of pore structures on gas permeability and chloride diffusivity of concrete. *Construction and Building Materials*, *163*, 402-413.

17. Wang, Y., Zhang, S., Niu, D., Su, L., & Luo, D. (2020). Strength and chloride ion distribution brought by aggregate of basalt fiber reinforced coral aggregate concrete. *Construction and Building Materials*, *234*, 117390.

18. Mohammed, H., Giuntini, F., Sadique, M., Shaw, A., & Bras, A. (2022). Polymer modified concrete impact on the durability of infrastructure exposed to chloride environments. *Construction and Building Materials*, *317*, 125771.

19. Athibaranan, S., Karthikeyan, J., & Rawat, S. (2022). Investigation on service life prediction models of reinforced concrete structures exposed to chloride laden environment. *Journal of Building Pathology and Rehabilitation*, *7*, 1-15.

20. Alexander, M., & Beushausen, H. (2019). Durability, service life prediction, and modelling for reinforced concrete structures–review and critique. *Cement and Concrete Research*, *122*, 17-29.

21. Taffese, W. Z., & Espinosa-Leal, L. (2022). Prediction of chloride resistance level of concrete using machine learning for durability and service life assessment of building structures. *Journal of Building Engineering*, *60*, 105146.

22. Mao, H., Meng, Q., Li, S., Ren, P., Wang, J., & Santamouris, M. (2022). Convection heat transfer coefficient of building glasses under salt deposition conditions. *Building and Environment*, *224*, 109571.

23. Qureshi, L. A., Ali, B., & Ali, A. (2020). Combined effects of supplementary cementitious materials (silica fume, GGBS, fly ash and rice husk ash) and steel fiber on the hardened properties of recycled aggregate concrete. *Construction and Building Materials*, *263*, 120636.

24. Amin, M., Zeyad, A. M., Tayeh, B. A., & Agwa, I. S. (2022). Effect of ferrosilicon and silica fume on mechanical, durability, and microstructure characteristics of ultra high-performance concrete. *Construction and Building Materials*, *320*, 126233.
25. Ben Nakhi, A., & Alhumoud, J. M. (2019). Effects of recycled aggregate on concrete mix and exposure to chloride. *Advances in Materials Science and Engineering*, *2019*.
26. Jafari Azad, V., Erbektas, A. R., Qiao, C., Isgor, O. B., & Weiss, W. J. (2019). Relating the formation factor and chloride binding parameters to the apparent chloride diffusion coefficient of concrete. *Journal of Materials in Civil Engineering*, *31*(2), 04018392.
27. Sánchez-Pérez, J. F., Hidalgo, P., & Alhama, F. (2022). Concrelife: A Software to Solve the Chloride Penetration in Saturated and Unsaturated Reinforced Concrete. *Mathematics*, *10*(24), 4810.
28. Sánchez-Pérez, J. F., & Alhama, I. (2020). Universal curves for the solution of chlorides penetration in reinforced concrete, water-saturated structures with bound chloride. *Communications in Nonlinear Science and Numerical Simulation*, *84*, 105201.
29. Beushausen, H., Torrent, R., & Alexander, M. G. (2019). Performance-based approaches for concrete durability: State of the art and future research needs. *Cement and Concrete Research*, *119*, 11-20.
30. Milla, J., Cavalline, T. L., Rupnow, T. D., Melugiri-Shankaramurthy, B., Wang, K., & Lomboy, G. (2021). Methods of test for concrete permeability: a critical review. *Advances in Civil Engineering Materials*, *10*(1), 172-209.
31. Ahmad, S., Al-Amoudi, O. S. B., Khan, S. M., & Maslehuddin, M. (2022). Effect of silica fume inclusion on the strength, shrinkage and durability characteristics of natural pozzolan-based cement concrete. *Case Studies in Construction Materials*, *17*, e01255.

32. Khatib, J. M., & Mangat, P. S. (2002). Influence of high-temperature and low-humidity curing on chloride penetration in blended cement concrete. *Cement and concrete research*, *32*(11), 1743-1753.

33. Jain, S., & Pradhan, B. (2019). Effect of cement type on hydration, microstructure and thermo-gravimetric behaviour of chloride admixed self-compacting concrete. *Construction and Building Materials*, *212*, 304-316.

34. Khartabil, A., & Al Martini, S. (2019). Carbonation Resistance of Sustainable Concrete Using Recycled Aggregate and Supplementary Cementitious Materials. *Key Engineering Materials*, *803*, 246-252.

35. Saleh, H. M., El-Saied, F. A., Salaheldin, T. A., & Hezo, A. A. (2019). Influence of severe climatic variability on the structural, mechanical and chemical stability of cement kiln dust-slag-nanosilica composite used for radwaste solidification. *Construction and Building Materials*, *218*, 556-567.

36. Khan, M. F. (2022). *Assessment of Structural Elements Deteriorated in Semi-Arid Environmental Conditions* (Doctoral dissertation, The British University in Dubai).

37. Zhou, Q., Lu, C., Wang, W., Wei, S., Lu, C., & Hao, M. (2020). Effect of fly ash and sustained uniaxial compressive loading on chloride diffusion in concrete. *Journal of Building Engineering*, *31*, 101394.

38. Albattah, M., Shibeika, A., & Sami Ur Rehman, M. (2021). Understanding the hiring issues of the craft workers in the UAE’s construction labor market: project managers perspective. *Buildings*, *12*(1), 26.

39. Locke, J., Dsilva, J., & Zarmukhambetova, S. (2023). Decarbonization strategies in the UAE built environment: An evidence-based analysis using COP26 and COP27 recommendations. *Sustainability*, *15*(15), 11603.

40. Ying, J., Huang, J., & Xiao, J. (2022). Test and theoretical prediction of chloride ion diffusion in recycled fine aggregate mortar under uniaxial compression. *Construction and Building Materials*, *321*, 126384.

41. Huang, M., Zhao, Y., Wang, H., & Lin, S. (2021). Mechanical properties test and strength prediction on basalt fiber reinforced recycled concrete. *Advances in Civil Engineering*, *2021*, 1-10.

42. Mohammad Momeen, U. I. (2015). *Feasibility study of ground palm oil fuel ash as partial cement replacement material in oil palm shell lightweight concrete/Mohammad Momeen Ul Islam* (Doctoral dissertation, University of Malaya).

43. Cheng, X., Peng, J., Cai, C. S., & Zhang, J. (2020). Experimental study on chloride ion diffusion in concrete under uniaxial and biaxial sustained stress. *Materials*, *13*(24), 5717.

44. Ying, J., Xie, Z., Chen, B., Xiao, J., & Pan, C. (2023). Chloride ion diffusion and distribution characteristics in recycled coarse aggregate concrete under uniaxial and biaxial pressure. *Journal of Building Engineering*, *77*, 107469.

45. Ying, J., Huang, J., & Xiao, J. (2022). Test and theoretical prediction of chloride ion diffusion in recycled fine aggregate mortar under uniaxial compression. *Construction and Building Materials*, *321*, 126384.

46. Cheng, X., Peng, J., Cai, C. S., & Zhang, J. (2020). Experimental study on chloride ion diffusion in concrete under uniaxial and biaxial sustained stress. *Materials*, *13*(24), 5717.

47. Xiao, L., Chen, D., Jiang, M., Xiao, L., & Mei, G. (2021). Experimental and numerical analysis of chloride transport in finite concrete under reverse water pressure. *Construction and Building Materials*, *304*, 124576.

48. Bae, Y., Pasteris, J. D., & Giammar, D. E. (2019). The ability of phosphate to prevent lead release from pipe scale when switching from free chlorine to monochloramine. *Environmental Science & Technology*, *54*(2), 879-888.

49. Chen, D., Feng, Y., Shen, J., Sun, G., & Shi, J. (2022, September). Experimental and simulation study on chloride diffusion in unsaturated concrete under the coupled effect of carbonation and loading. In *Structures* (Vol. 43, pp. 1356-1368). Elsevier.

50. Kurley, J. M., Halstenberg, P. W., McAlister, A., Raiman, S., Dai, S., & Mayes, R. T. (2019). Enabling chloride salts for thermal energy storage: implications of salt purity. *RSC advances*, *9*(44), 25602-25608.