

## Parametric effects of nano titanium dioxide on chloride diffusivity of cement mortar via taguchi grey relational analysis

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**Abstract.** This investigation aims to improve the durability of cement mortar in aggressive environments by examining the impact of Nano Titanium Dioxide (NT) on the chloride ion diffusivity. Over time, the effective diffusivity coefficients (Deff) of anolyte and catholyte for mortar mixtures containing 0-3% NT were determined. According to the results, NT's filler effect and microstructural refinement considerably lower chloride migration. The ideal replacement level was determined to be 3% NT through optimization using Taguchi-based Grey Relational Analysis (GRA), which attained the lowest Deff ( $0.0242 \times 10^{-13} \text{ cm}^2/\text{s}$ ) and conductivity (0.322 mS/cm) at 15 minutes.

### Introduction

Chloride-induced steel corrosion deteriorates reinforced concrete structures. Designing and developing marine buildings must include chloride permeability individually due to its importance [1,2]. Water ion transport, capillary suction, and absorption add chlorides to concrete. In prolonged infiltration, chloride ions may accumulate on reinforcing steel [3]. Cyclical exercise worsens durability issues because concrete is sensitive to movement and hazardous component accumulation [4,5,6]. Fine fillers speed cement hydration [7]. At a 15% cement substitution, small particles of silica fume, limestone, and powdered fly ash accelerate cement hydration [8].

Fine fillers shrink and impact the dimensional stability of cement mix [9,10]. Tiny cement paste fillers increased chemical shrinkage, researchers discovered [11]. Compared to OPC mixes, "coarse" cement paste particles did not reduce chemical shrinkage [12]. Thus, cement filler particle size can be adjusted to hasten hydration without affecting dimensional stability [13,14].

Given the increased interest in additives like titanium dioxide (TiO<sub>2</sub>), a study on the impact of chemically inert fillers on cement hydration is needed. Because their different shapes may make concrete stronger, more durable, and better, nano-particles have grown in popularity [15,16]. The smaller the pore size, the higher the photocatalytic activity [17,18]. Several studies [15,16,19] have added TiO<sub>2</sub> nano-particles (NT) to cement or asphalt-based concrete to improve its durability or characteristics. Cement products using NT are popular [20]. However, admitting its effects on cement-based materials was insufficient. Chlorides can penetrate deeper into near-surface unsaturated concrete due to their high concentration [21]. Absorption is the principal mode of chlorine transfer. Because of this, chloride ions are mostly diffused at depth. Concrete chloride intrusion resistance can be assessed in many ways. The procedures produce chloride ion diffusion coefficients or concrete penetration resistance indexes [22], diffusion cells or solution immersion test mortar for diffusivity.

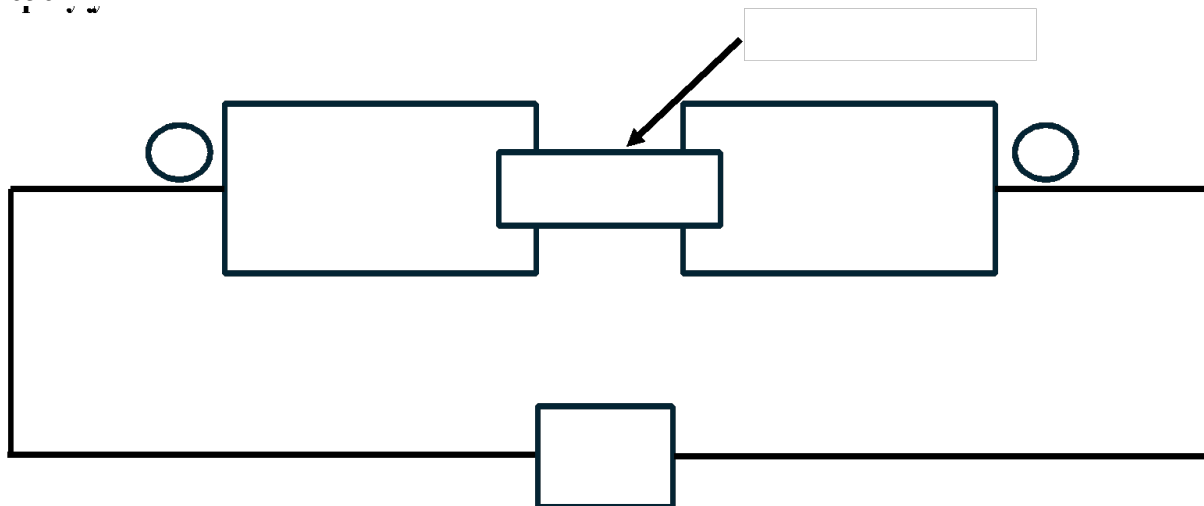
According to Fick's first or second laws, this evaluation assumes steady-state migration of chloride ions through the cement paste or mortar samples [4]. Non-steady state diffusion describes how long it takes for chloride ions to move through concrete and attach to cement phases. On the other hand, steady state diffusion denotes continuous flow [23]. The recommended methods can take months or years, especially for high-performance concretes. Electricity speeds chloride ion



transit, eliminating the time problem. This cut testing time from months to hours [24]. Many studies have tested concrete chloride ion resistance using migration experiments [25,26,27]. According to ASTM C 1202/1992 [28] and Andrade [26], under steady-state circumstances, these experiments evaluated penetration using the estimated diffusion coefficient and total penetrated load. Tests met both goals. Diffusion coefficients have recently been computed from migration studies in non-steady-state scenarios [29,30,31]. All these experiments create ion mobility under an external electric field, although their technique and parameters vary by goal [24,32].

### Experimental Method

Cement mortars were placed into 25 mm x 50 mm cylinder molds. Each combination required three samples. The cylinder mold was removed after 24 hours, and the specimens were cured in water at  $23 \pm 2$  °C for 28 days. The Cl-ion diffusivity coefficient cell schematic is presented in Fig. 1. Such as ASTM C-1202 [28], AASHTO T277 [33], Nord Test NT Build 492 [34], and numerous other studies [26,27,29]. The study potential was 9V, low enough to avoid overheating, high enough to accelerate. A voltage decrease over the liquid in the two compartments is not assumed. The anolyte chamber employed 0.3 M NaOH, and the catholyte 0.1 M NaCl. Andrade 1994, [29] and Whiting [1] advised this. Chamber solutions stayed at 200 ml. Andrade et al. [29] say any solute concentration is feasible. Because diluted solutions have less driving power and cause errors, concentrated solute solutions limit activity [26]. The activity coefficient for 0.3M NaCl was 0.656 this time.



*Fig. 1 Test Set-up*

All tests used IS 2386-1963(Revision 2016) [35] Ordinary Portland Cement (OPC). In order to create 1: 3 mortars with a w/b ratio of 0.45, standardised sand was utilised. Each test (0%, 0.5%, 1%, 1.5%, 2.0%, 2.5% and 3% NT) used three duplicate samples that were cast and cured for 28 days at 25°C and average values are examined in this work. We used Zone III sand that met IS: 383-2016 [36]. Measurement mortar specimens are 2.5 cm wide. All experiments use a 5 cm specimen length to achieve non-steady state. For analysis study Parametric Effects of Nano Titanium Dioxide on Chloride Diffusivity in Cement Mortar Via a Grey Relational Analysis Approach [37,38].

### Results and Discussion

Fig. 2 displays the  $D_{eff}$  vs. time  $t$  in anolyte and catholyte during two similar migration tests. Naturally, control mix anolyte and catholyte diffusivity coefficients are larger ( $10-13 \text{ cm}^2/\text{s}$ ) [39]. As the NT percentage rises, the filler action and enhanced microstructure minimise mortar holes, limiting the flow of Cl-ions [24]. At 15 minutes, the diffusivity of the control mix and mortar containing NT 1 and NT 2 and NT 1 and NT 3 is reduced by 33.18% and 22.14%, respectively.

The experiment ends at 105 min with 43.82 and 20.3%. Time decreases the  $Deff$  for all samples. 2% and 3% NT samples have 10-14 (cm<sup>2</sup>/s) lower diffusivity coefficients.

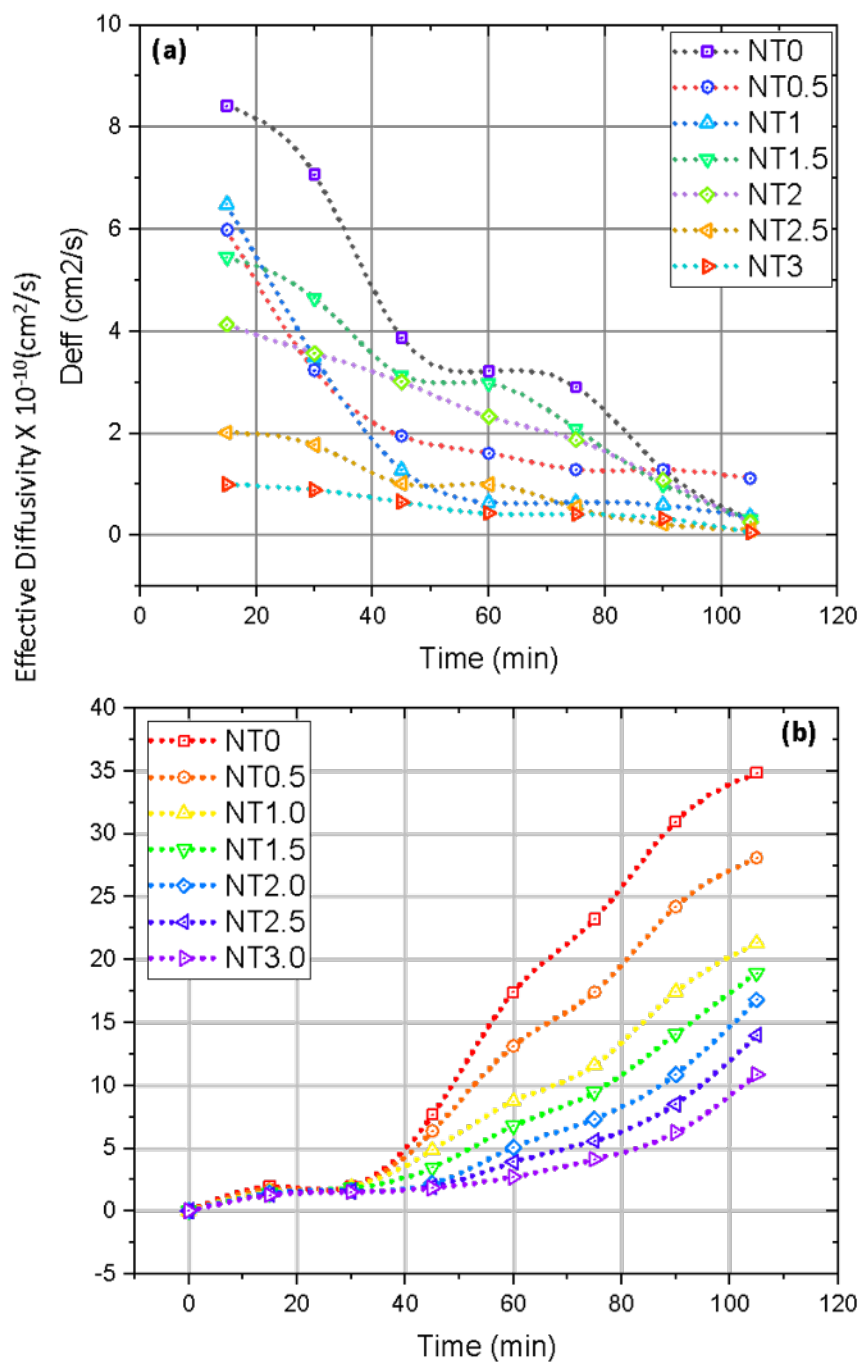


Fig. 2  $Deff$  vs time for (a) Anolyte and (b) Catholyte

*Table 1 Relational Calculations in Taguchi Grey*

| NT % | Duration (min) | Sequence of Deviations | Relational Coeff. in Grey | The Grey Rank | Average Grey Rank Value | Ultimate Grey Rank |
|------|----------------|------------------------|---------------------------|---------------|-------------------------|--------------------|
| 0    | 15             | 1                      | 0.333                     | 25            | 39                      | VII                |
| 0    | 30             | 0.960                  | 0.343                     | 34            |                         |                    |
| 0    | 45             | 0.617                  | 0.448                     | 35            |                         |                    |
| 0    | 60             | 0.596                  | 0.456                     | 42            |                         |                    |
| 0    | 75             | 0.471                  | 0.515                     | 43            |                         |                    |
| 0    | 90             | 0.412                  | 0.548                     | 44            |                         |                    |
| 0    | 105            | 0.401                  | 0.555                     | 47            |                         |                    |
| 0.5  | 15             | 0.892                  | 0.359                     | 23            | 38                      | VI                 |
| 0.5  | 30             | 0.758                  | 0.398                     | 30            |                         |                    |
| 0.5  | 45             | 0.686                  | 0.422                     | 37            |                         |                    |
| 0.5  | 60             | 0.572                  | 0.467                     | 41            |                         |                    |
| 0.5  | 75             | 0.445                  | 0.529                     | 40            |                         |                    |
| 0.5  | 90             | 0.417                  | 0.545                     | 45            |                         |                    |
| 0.5  | 105            | 0.412                  | 0.548                     | 48            |                         |                    |
| 1    | 15             | 0.721                  | 0.409                     | 18            | 34                      | V                  |
| 1    | 30             | 0.616                  | 0.448                     | 27            |                         |                    |
| 1    | 45             | 0.567                  | 0.469                     | 33            |                         |                    |
| 1    | 60             | 0.485                  | 0.508                     | 36            |                         |                    |
| 1    | 75             | 0.384                  | 0.565                     | 38            |                         |                    |
| 1    | 90             | 0.362                  | 0.580                     | 39            |                         |                    |
| 1    | 105            | 0.361                  | 0.581                     | 46            |                         |                    |
| 1.5  | 15             | 0.471                  | 0.515                     | 13            | 26                      | IV                 |
| 1.5  | 30             | 0.364                  | 0.578                     | 24            |                         |                    |
| 1.5  | 45             | 0.317                  | 0.612                     | 26            |                         |                    |
| 1.5  | 60             | 0.249                  | 0.668                     | 28            |                         |                    |
| 1.5  | 75             | 0.216                  | 0.698                     | 29            |                         |                    |
| 1.5  | 90             | 0.189                  | 0.726                     | 31            |                         |                    |
| 1.5  | 105            | 0.186                  | 0.729                     | 32            |                         |                    |

|     |     |       |       |    |    |     |
|-----|-----|-------|-------|----|----|-----|
| 2   | 15  | 0.202 | 0.712 | 4  | 15 | III |
| 2   | 30  | 0.268 | 0.651 | 17 |    |     |
| 2   | 45  | 0.065 | 0.885 | 12 |    |     |
| 2   | 60  | 0.024 | 0.954 | 14 |    |     |
| 2   | 75  | 0.027 | 0.949 | 16 |    |     |
| 2   | 90  | 0.029 | 0.946 | 20 |    |     |
| 2   | 105 | 0.028 | 0.947 | 22 |    |     |
| 2.5 | 15  | 0.029 | 0.944 | 2  | 11 | II  |
| 2.5 | 30  | 0.065 | 0.884 | 5  |    |     |
| 2.5 | 45  | 0.053 | 0.905 | 8  |    |     |
| 2.5 | 60  | 0.040 | 0.926 | 11 |    |     |
| 2.5 | 75  | 0.000 | 1.000 | 10 |    |     |
| 2.5 | 90  | 0.065 | 0.884 | 19 |    |     |
| 2.5 | 105 | 0.064 | 0.886 | 21 |    |     |
| 3   | 15  | 0.024 | 0.954 | 1  | 7  | I   |
| 3   | 30  | 0.036 | 0.933 | 3  |    |     |
| 3   | 45  | 0.065 | 0.885 | 6  |    |     |
| 3   | 60  | 0.080 | 0.863 | 7  |    |     |
| 3   | 75  | 0.078 | 0.866 | 9  |    |     |
| 3   | 90  | 0.106 | 0.825 | 15 |    |     |

## Conclusions

This study demonstrates that adding NT to cement mortar effectively lowers the diffusivity of chloride ions. At 15 minutes, adding 1% NT and 2% NT decreased diffusivity by 33.18%, while adding 1% NT and 3% NT resulted in a 22.14% reduction. The diffusivity coefficient of the control mix was roughly  $10^{-13}$  cm<sup>2</sup>/s. These decreases increased to 43.82% and 20.3%, respectively, by 105 minutes. Diffusion values were consistently lower in samples containing 2% and 3% NT, at about  $10^{-14}$  cm<sup>2</sup>/s, suggesting improved microstructural densification. 3% of NT was found to be the highest-performing mix by optimisation using Grey Relational Analysis (GRA). It had the lowest effective diffusivity of  $0.0242 \times 10^{-13}$  cm<sup>2</sup>/s, the lowest conductivity of 0.322 mS/cm, and the best performance at 15 minutes. The study found that higher NT content significantly reduced conductivity and chloride penetration, with 3% NT proving to be the optimal concentration for boosting durability. This suggests that increasing NT levels enhances resistance to chloride ingress, making it an effective approach for improving cement mortar performance in challenging environments.

## Nomenclature

NT Nano Titanium Dioxide  
Deff Effective diffusivity coefficients  
GRA Grey Relational Analysis  
Avg. Average

OPC Ordinary portland cement

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