The Effect of Nanographene and Nano Titanium Dioxide on the Mechanical Properties and Chloride Ion Penetration in Concrete

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ABSTRACT

Reinforced concrete marine structures located in coastal and corrosive environments are subjected to the attack of destructive chloride ions. In addition, sea waves and coastal storms impose significant stresses on the concrete, resulting in corrosion, abrasion, repeated cycles of wetting and drying, and chemical reactions involving chloride and sulfate ions. One of the main challenges for concrete structures near the shore is their high permeability to moisture and water, which leads to issues such as deterioration and cracking throughout the concrete. In particular, chloride and sulfate ions, which are among the primary causes of corrosion in reinforced concrete, can easily penetrate the structure due to high permeability and cause extensive damage. Therefore, it is essential to employ methods to minimize the permeability of concrete. In this study, with the aim of reducing concrete permeability and improving its durability against chloride ion penetration, a combination of nanographene and nano titanium dioxide was used in the concrete mix. The tests conducted in this study included slump, compressive strength at different ages, water absorption in hardened concrete, and durability against chloride ion penetration using the RCMT method. The results demonstrated that the use of the nanographene and nano titanium dioxide combination did not significantly affect the concrete slump, but the addition of nanographene negatively impacted the cement hydration reaction and reduced the compressive strength of the concrete. Specifically, the addition of 1.5% nanographene decreased the 90-day compressive strength by up to 22.5%. However, this amount of nanographene reduced the chloride ion penetration area in the concrete by up to 47%.

KEYWORDS

Chloride ion penetration, RCMT method, nanographene, nano titanium dioxide, marine structures.

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1. Introduction

Marine concrete structures such as docks, breakwaters, and infrastructures related to the oil and gas industry are of great importance for coastal regions, especially in southern Iran. These structures, due to constant exposure to seawater, aggressive ions like chloride and sulfate, high humidity, and temperature fluctuations, are highly susceptible to corrosion, reduced durability, and substantial maintenance costs. In recent years, the use of nanotechnology and the incorporation of various nanoparticles have emerged as advanced solutions for improving the properties of concrete and enhancing its resistance to environmental threats. This research evaluates the effectiveness of graphene oxide nanocolloid and nano titanium dioxide in increasing the durability and reducing the permeability of marine concrete.

2. Methodology

In this study, local sand and gravel, type II cement, and a superplasticizer were employed to produce concrete samples. High-purity (above 99%) nano titanium dioxide with nanometric dimensions and single-layer graphene oxide nanocolloid with a 70% concentration were used. To ensure uniform distribution of nanoparticles within the concrete mixture, these materials were first mixed with the superplasticizer and then added to the fresh concrete to secure homogeneous dispersion. To assess the performance of concrete containing nano-materials, six different mix designs were developed and a total of 66 laboratory samples were prepared. The main experiments included slump (workability of fresh concrete), compressive strength at 7, 28, and 90 days, water absorption, and chloride ion penetration. In the various mixes, nano titanium dioxide was used at 0.4% by cement weight and graphene oxide nanocolloid was tested at dosages from 0.25% to 1.5% by water weight.

Table 1 Mixing plan and weight values of materials for making each cubic meter of concrete

Nano colloid Graphene	Nano TiO_3	Water	Superplasticizer	Sand	Gravel	Cement	Name
kg/m³	kg/m³	kg/m³	kg/m³	kg/m³	kg/m³	kg/m³	
0	2	160	4	1200	600	400	G-T-C
0.4	2	160	4	1200	600	400	G-T-1
0.8	2	160	4	1200	600	400	G-T-2
1.2	2	160	4	1200	600	400	G-T-3
1.6	2	160	4	1200	600	400	G-T-4
2.4	2	160	4	1200	600	400	G-T-5

3. Results and Discussion

In this study, the results of concrete testing using nano titanium dioxide and graphene oxide nanocolloid were investigated. The findings showed that as the amount of liquid graphene oxide nanocolloid in the concrete increases, the compressive strength decreases. This is due to the fact that graphene oxide nanocolloid hinders the formation of calcium and ettringite in the cement within concrete, thereby interfering with the cement hydration reaction. In contrast, previous studies using solid graphene nanoparticles in powder form

Laboratory results indicated that although the use of graphene oxide nanocolloid led to a relative decrease in compressive strength, it significantly reduced water absorption and chloride ion permeability of concrete. Maximum reduction in permeability and absorption occurred at the highest dosage of nanocolloid; however, increasing beyond this did not further improve performance and in fact, resulted in a more pronounced drop in compressive strength. The reduction in strength was attributed to interference with cement hydration reactions and a decrease in the formation of essential cementitious phases. The simultaneous use of nano titanium dioxide and graphene oxide nanocolloid also had a remarkable positive effect on improving the watertightness and durability of the resulting concrete, so that their combined application led to substantial improvements compared to ordinary concrete.

Overall, the findings showed that the controlled and targeted use of graphene oxide nanocolloid and nano titanium dioxide can considerably decrease permeability, water absorption, and the passage of harmful ions such as chloride in marine concretes, thereby increasing the durability and lifespan of these structures. However, excessive use of graphene oxide nanocolloid leads to a notable reduction in compressive strength, and it is crucial that the quantities of these nano-materials be optimized and kept balanced in concrete design.

demonstrated increases in both compressive and flexural strength. It appears that the graphene used in this research, due to its higher photocatalytic activity compared to cementitious materials and the increased electrical conductivity from the presence of graphene sheets, generates semiconductor electrons in the material, which inhibits the cement hydration reaction. Moreover, apart from the form in which graphene oxide nanocolloid is used, it seems that the type of material based on the manufacturer can also be a determining factor in the results.

On the other hand, the graphene oxide nanocolloid used in this study has effectively prevented the penetration of harmful chloride ions into the concrete and also significantly reduced the water absorption of the concrete. Thanks to its long, continuous chains, graphene creates a protective layer that, as long as the concrete is not subjected to extreme or heavy loads, can effectively maintain its hydrophobicity and impermeability. Therefore, it would be a good idea to develop a solution combining graphene oxide nanocolloid and nano titanium to be used for repairing and strengthening concrete surfaces, in order to create a hydrophobic, impermeable, and abrasion-resistant surface.

4. Conclusions

1. The use of graphene oxide nanocolloid and nano titanium dioxide has no significant effect on the slump of concrete and does not cause any changes in it.

2. The use of nano titanium dioxide and graphene oxide nanocolloid leads to a reduction in the compressive strength of concrete. Specifically, the addition of 0.25%, 0.5%, 0.75%, 1% and 1.5% results in a decrease in the final compressive strength (at 90 days) of concrete by 2.8%, 7.4%, 11.7%, 16.5%, and 22.5%, respectively.

3. The use of nano titanium dioxide and graphene oxide nanocolloid reduces the water absorption of concrete. In particular, adding 0.25%, 0.5%, 0.75%, 1% and 1.5% liquid graphene oxide nanocolloid into the concrete decreases the initial water absorption (at 30 minutes) by 1.05%, 0.99%, 0.76%, 0.53%, and 0.24%, respectively, and the final water absorption (after 72 hours) by 2.68%, 2.29%, 1.97%, 1.28%, and 0.86%, respectively.

4. The use of nano titanium dioxide and graphene oxide nanocolloid can reduce the chloride ion penetration in concrete. Specifically, adding 0.25%, 0.5%, 0.75%, 1% and 1.5% liquid graphene oxide nanocolloid decreases the chloride ion penetration area by 14%, 23%, 39%, 45%, and 47%, respectively.

5. References

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