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Experimental study on salt-freezing performance of nano-SiO_2 bridge concrete

X. Dong, L. Zhou, Muhammad Aqeel Ashraf

ZheJiang Industry Polytechnic College, ShaoXing, 312000, China
China University of Geosciences, Wuhan 430079 China

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The anti-salt performance of nano-SiO2 bridge concrete was tested. The results show that after a certain number of salt freeze tests, the anti-salt and denudation performance of a certain amount of nano-SiO_2 concrete is better than that of blank concrete. The total mass per unit area of the exfoliated material and the relative dynamic elastic modulus of the ultrasonic wave are lower than that of the blank concrete, and the anti-salt performance is greatly improved. After 32 times of freeze-thaw cycles of nano-SiO_2 with 1.0% and 2.0% nano-SiO_2, the total mass of the surface exfoliation of the unit surface is less than 1500 g/m^2, and the relative dynamic elastic modulus of the ultrasonic wave is more than 80%, which meets the requirements of anti-salt index.
Keywords: Nano-SiO_2, bridge concrete, anti-salt performance

Исследованы противосолевые характеристики наноструктурированного бетона на основе SiO_2. Показано, что после определенного количества испытаний с замораживанием соли, характеристики защиты от соли и денудации бетона с нано-SiO_2 лучше, чем у чистого бетона. Общая масса на единицу площади отслаивающегося материала и относительный динамический модуль упругости ультразвуковой волны ниже, чем у чистого бетона и противосолевые характеристики значительно улучшаются. После 32-х циклов замораживания-оттаивания нано-SiO_2 с 1,0% и 2,0% нано-SiO_2 общая масса поверхностного отслаивания единичной поверхности составляет менее 1500 г/м^2, а относительный динамический модуль упругости ультразвуковой волны составляет более 80%, что соответствует требованиям антисолевого индекса.

Експериментальне дослідження солевозаморажівающіх властивостей наноструктурованого бетону. *Х. Донг, Л. Чжоу*

Досліджено протисольові характеристики наноструктурованого бетону на основі SiO_2. Показано, що після певної кількості випробувань із заморожуванням солі, характеристики захисту від солі і денудації бетону з нано-SiO_2 краще, ніж у чистого бетону. Загальна маса на одиницю площі відшаровується матеріалу і відносний динамічний модуль пружності ультразвукової хвилі нижче, ніж у чистого бетону і протисольові характеристики значно поліпшуються. Після 32-х циклів заморожування-відтавання нано-SiO_2 з 1,0% і 2,0% нано-SiO_2 загальна маса поверхневого відшаровування одиничної поверхні становить менше 1500 г/м^2, а відносний динамічний модуль пружності ультразвукової хвилі становить понад 80%, що відповідає вимогам антісолевого індексу.

1. Introduction

In recent years, with the continuous development of nano-materials, the introduction of nano-materials into the field of civil engineering has gradually become a hot trend in the civil engineering field, especially in the field of civil engineering materials. Some scholars have begun to study the use of microscopic materials such as nanomaterials in concrete, traditional civil engineering material to improve their performance. At present, some studies have shown that nanomaterials are applied to concrete, which can improve the strength and durability of concrete. Therefore, the application of nanomaterials in concrete research has great significance and broad prospects. The salt damage of concrete mainly occurs in concrete structures such as concrete bridge structures, roads and airport runways in winter et al. In cold regions, due to snowfall in winter, in order to ensure normal operation, deicing salt is often used on roads and bridge decks. Due to the use of deicing salt, the subcooled solution containing deicing salt flows through the joints of the beam and bridges, salt damage is more serious than ordinary freezing and thawing [1]. There are three ways in which water migrates through the material: capillary action, diffusion, and penetration under pressure gradients [2]. In concrete, capillary action is the main mode of water penetration [3], providing conditions for salt damage. There are many measures to improve the anti-salt performance of concrete. This paper studies the anti-salty performance of concrete by adding nano-materials. Nanomaterial refers to an ultrafine material having a particle size on the order of nanometers (1 to 100nm, 1nm = 10-9 m) in a transition region where atomic clusters and macroscopic objects meet. Due to the small size of nanomaterials, it has many peculiar features that are not available in macroscopic and microscopic objects in terms of structure, physical properties and chemical properties [4]. After the snow melts and the ice melts, water dissolves the salt, forming a solution, and the freezing point drops [5]. Concrete will absorb these solutions until they are saturated. After using the anti-icing salt, concrete will be thawed more often than when anti-icing salt is not used. A study [6] showed that the damage was most severe when the concrete was exposed to a salt solution at a concentration of 2% to 4% compared to other concentrations. Salt will absorb a large amount of heat when the ice on the concrete surface melts, causing a sudden drop in the subsurface temperature of the concrete, resulting in a large temperature difference between the inside and the outside of the concrete, and the temperature stress [7]. Avtors [8] believes that increasing the gas content of concrete will reduce the quality of the peeling after freezing, but if the gas content is too large, continuous pores will be produced, which will increase the water absorption of concrete. After freezing and thawing, the peeling quality of concrete will increase sharply. In [9] proved that in Na_2SO_4 and NaCl salt solutions, aerated concrete with only fly ash or mixed with silica fume and fly ash has higher salt-freeze resistance than aerated concrete without admixtures. In [10] compared the frost resistance of self-compacting concrete mixed with metakaolin and silica fume. Calcium silicate gel becomes the main structure of the nanopowder [11], which makes concrete more compact, reduces the penetration of corrosive media and improves the freezing properties of bridge concrete.

The innovation of this paper is that nanomaterials are added to pavement concrete using nanopowders and nano-sized hydrated CSH gels.

2. Experimental method

2.1 Raw material

The P·O42.5 grade ordinary Portland cement was selected for the experimental study. The 3d compressive strength and flexural strength were 27.3MPa and 4.0MPa respectively. The 28d compressive strength and flexural strength were 47.6MPa and 7.3MPa respectively, and the other indexes met the requirements of general Portland cement.

The fly ash is dry-discharged. The fineness is 15% in the 45μm square hole sieve, the loss on ignition is 6.5%, and the water requirement is 103%, which meets the requirement of Class II fly ash.

Nanomaterials: Nano-silica, white powder, SiO_2 content greater than 99.9% and specific surface area of 213 m^2/g.

Admixture: Polycarboxylate superplasticizer is used, and the water reduction rate is 15%.

Sand: The sand fineness modulus is 2.3, the gradation meets the requirements of Zone II, and other indicators meet the requirements of Class II.

Gravel: Gravel selected the two specifications are 16~31.5 mm, 5~16 mm, the two kinds of gravel are matched with 5:31.5 mm continuous grading according to 7:3, the nominal maximum particle size is 31.5mm.

2.2 Concrete mix ratio

In this test, C40 blank concrete, fly ash concrete and nano-SiO_2 concrete were prepared respectively. The fly ash content was 20%, the amount of nano-silica is 0.5%, 1.0%, 2.0%, 3.0% of the amount of cement, respectively, equal replacement of cement.

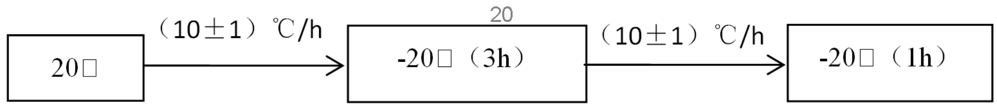

Fig. 1. Freezing-thawing cycle process

2.3 Nano-concrete mechanical strength test

A 150 mm × 150 mm × 150 mm cube test piece was formed according to the aforementioned mixing ratio, and the compressive strength was measured by standard conditions (20±2)°, relative humidity 95% or more for 7 day, 28 day, and 56 day, respectively.

2.4 Single-sided freeze-thaw test

For forming and curing single-sided freeze-thaw test. The sealed test piece is placed in a laboratory at a temperature of (20±2)° and a relative humidity of (65±5)%. Prepare for the test is 28 day.

The test solution is a salt solution prepared by mass ratio of 97% distilled water and 3% NaCl. The test piece was placed in the solution of the single-sided freeze-thaw test chamber, and the freeze-thaw cycle process is shown in Fig.1.

Due to the extremely small size of nanomaterials, their specific surface area is large, and their surface energy is high. To reduce surface energy and therefore stably exist in the environment, nanomaterials tend to agglomerate when used. Particles of the agglomerated nanomaterial tend to form defects in concrete, there by reducing the strength and durability of concrete. Therefore, it is necessary to find an efficient method for dispersing nanomaterials suitable for application to concrete, and then obtain a relatively complete process for preparing nano-modified concrete.

3. Experimental results

3.1 Nano-concrete mechanical strength test results

Test piece numbers (H0, HF, HS1, HS2, HS2, HS3, HS4) are different sample numbers, H0 represent initial samples, HF for final while S1,2,3,4 represent different intermediator samples for testing. These are only related to a concrete mixture tested before in the initial test [EN 206]. A new concrete mixture has to be tested based on the initial test requirements. These include much more than 3 cubes for a compressive strength test. Minimum 3 specimen manufactured from 3 different batch-mixes.

Table 1. Concrete compressive strength test results (Mpa)

Test piece number	H0.	HF	HS1	HS2	HS3	HS4
7d age	30.0	24.6	36.0	37.5	38.8	40.6
28d age	49.4	48.2	53.2	54.1	54.9	53.7
56d age	52.0	54.6	54.8	55.3	56.0	53.7

Tests show that the replacement of cement with nano-materials to prepare nano-concrete has greatly improved the early strength. The increase is about 20% to 30%, and as the amount of addition increases, the increase also increases. Later strength has also increased, with a small increase. The 28d strength meets the requirements of C40 concrete.

3.2 Appearance damage comparison

In order to evaluate the effect of nano-SiO_2 on the freezing characteristics of the salt of a concrete bridge, 40 freeze-thaw cycles were carried out in this experiment. The surface damage of the test specimen was analyzed, and the freezing and denudation characteristics of the salt solution of a bridge with a SiO_2 nanostructure were qualitatively evaluated.

The test can be stopped if the following conditions occur in the freeze-thaw cycle: upon reaching 28 freeze-thaw cycles; the total mass of the sample surface is more than 1500 g/m^2; when the relative elastic modulus of ultrasound of the test sample is reduced to 80%.

3.3 Test results

After measuring and calculating the N freeze-thaw cycles, the total mass of the surface area of the single test piece was tested. The results of 24, 28, 32, and 40 cycles (the same below) are listed in Table 2. The comparison of ultrasonic propagation time and ultrasonic relative dynamic modulus results is shown in Fig. 2.

3.3 Dynamic elastic modulus of different freeze-thaw cycles

One of the most damaging actions affecting concrete is the abrupt temperature

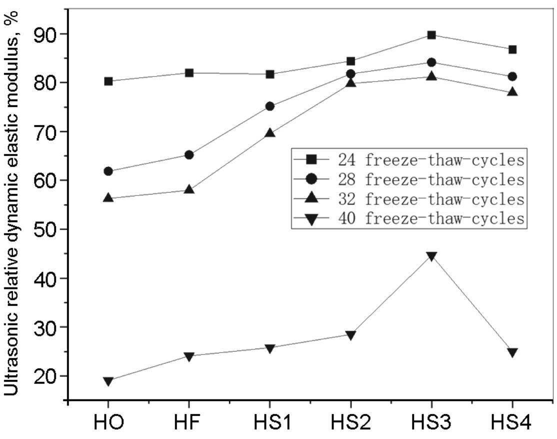

Fig. 2. The relative dynamic elastic modulus of different freeze-thaw cycles

change (freeze-thaw cycles). The types of deterioration of concrete structures by cyclic freeze-thaw can be largely classified into surface scaling (characterized by the weight loss) and internal crack growth (characterized by the loss of dynamic modulus of elasticity). The present study explored the durability of concrete made with air-entraining agent subjected to H0, HF, HS1, HS2, HS2, HS3, HS4 cycles of freeze-thaw. The experimental study of C24, C28, C32, C40 concrete specimens was completed according to "the test method of long-term and durability on ordinary concrete" GB/T 50082-2009. The dynamic modulus of elasticity and weight loss of specimens were measured after different cycles of freeze-thaw. The influence of freeze-thaw cycles on the relative dynamic modulus of elasticity and weight loss was analyzed. The findings showed that the dynamic modulus of elasticity and weight decreased as the freeze-thaw cycles were repeated. The procedure follows the instructions stated in the UNE-EN ISO 12680-1 standard for refractory products although in this study the instructions are applied to standardized RILEM 4x4x16 cm test samples made of lime and cement mortars. The simplicity of the procedure as well as its correlation to other measured variables, suggest that it can be widely applied in studies about the evolution of the physical characteristics in lime mortars, such as mechanical strength, static Young's modulus, carbonation depth, etc.

3.4 Analysis of test results

It can be seen from Fig. 2 that the surface of the H0 specimen is most seriously damaged after 40 freeze-thaw cycles, and the surface damage of the HF specimen is also very serious. The surface of the nano-concrete specimen is still relatively complete, and the nano-SiO_2 content is 2%, the surface of the specimen numbered HS3 was the least damaged. According to the analysis in Table 2 and Figure 2, after the number of single-side freeze-thaw cycles, the total mass of the surface area of the blank concrete is the largest, the ultrasonic relative dynamic modulus is the most, and the salt-free performance is the worst. After 28 freeze-thaw cycles, the total mass of the surface area of the blank concrete and fly ash concrete is more than 1500 g/m^2, and the relative dynamic elastic modulus of the ultrasonic wave is reduced by more than 80%, which cannot meet the requirements. However, since fly ash is a kind of high-quality mixed material with micro-aggregate effect, it can fill the pores of cement slurry and improve the compactness of concrete, so fly ash concrete is slightly better than blank concrete. Nano-ceramics with 1.0%, 2.0%, and 3.0% nano-SiO_2 content meet the requirements. After 32 freeze-thaw cycles, the blank concrete, fly ash concrete, and nano-SiO_2 with 0.5% nano-SiO_2 content have exceeded the above two indexes.

Table 2. Test surface exfoliation total mass $g \cdot m^{-2}$ after freeze-thaw cycle

Test piece number	H0	HF	HS1	HS2	HS3	HS4
24 freeze-thaw cycles	1475	1401	1386	1323	1012	1025
28 freeze-thaw cycles	1582	1504	1452	1337	1025	1066
32 freeze-thaw cycles	1623	1532	1500	1459	1235	1324
40 freeze-thaw cycles	3408	2653	1952	1804	1537	1566

Nano-concrete with 1.0% and 2.0% nano-SiO_2 content still meets the requirements. The number of single-sided freeze-thaw cycles was increased by 8 times. After 40 freeze-thaw cycles, although all proportions of concrete have exceeded the requirements of the index, the loss and reduction of the two indicators of nano-SiO_2 with 1.0% and 2.0% nano-concrete are the lowest, which are lower than blank concrete 47.0%, 54.9.% and 8.6%, 24.0% respectively, the salt-freezing performance of a certain amount of nano-SiO_2 concrete is greatly improved compared with blank concrete. The reason for the analysis is that there are many pores in the interface between aggregate and cement stone in ordinary concrete, and there are a lot of microcracks inside the cement stone, and the interface structure formed is not uniform and is not dense. Ordinary cement itself has a particle size of usually 7 to 200 μm.

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4. Conclusions

The use of nanomaterials in the research of concrete is of great importance and broad prospects. Nanobeton is prepared by replacing cement with an equivalent amount of nano-SiO_2, which significantly improves early strength and increases by about 20-30%. with increasing dosage. Strength also improves in a later period, but the increase is small. The anti-salt and denudation characteristics of the surface with nano-SiO_2 concrete are significantly improved compared to pure concrete.

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