

## Research Article

# Influence of Nanomodified Waterproofing Agent on the Performance of Rigid Waterproof Concrete in Underground Engineering

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Waterproof and impermeable problems seriously affect the safe use, normal structure, and working life of concrete projects. The waterproof performance of concrete can be improved by mixing with a proper amount of waterproofing agent; nevertheless, the early strength of concrete will be seriously affected. With the development of complex structures such as large spans in soil and water engineering and the increasingly complex engineering environment, people have put forward higher requirements for the working performance, strength, impermeability, durability, and intelligence of cement-based materials required. This article compares the changes in compressive strength, fluidity, and water permeability of mixed concrete by controlling the two variables of waterproofing agent and nanosilica. Combining the results of XRD microstructure analysis, the influence of nanosilica and waterproofing agent on the performance of concrete is explored. Moreover, it is hoped that other excellent properties of concrete can be improved, and a waterproof material with good opacity can be found. The test results show that after adding waterproofing agent alone, the 3 d compressive strength of concrete is decreased by 14.81%, the water permeability is reduced by 71.6%, and the depth of carbonic acid molecules at 28 d is also decreased by 37.3%. On the other hand, compared with concrete using waterproof coating alone, after adding in nanosilica, the 3 d compressive strength is increased by about 30%, and the water immersion height is decreased. The results show that the addition of polymer has a great influence on the compressive strength and carbonic acid resistance of concrete.

## 1. Introduction

Nanowaterproofing agent is a high-quality waterproofing agent that can maintain water resistance for a long time, with the functions of antimigration, water reduction, and performance improvement; this is a new generation of high-energy environmentally friendly products. Concrete can play a certain waterproof role in building structures, so it is widely used in waterproof buildings. However, in many engineering projects, concrete has not achieved the expected waterproof effect, resulting in serious water leakage in many building structures, which brings great inconvenience to production and life.

Because of the special properties of nanoparticles, some properties of the material can be changed after the addition of the nanoparticles, which can endow the material with special property required by the user, or make the special performance of the material more excellent [1]. At the same time, it can also help to open up the research road of material modification theory. Manufacturers and users of nanomodified materials put forward new requirements for material properties, such as stronger waterproof performance [2]. Frequent maintenance and leak repairs increase the economic expenditure and may not receive good results. With the development of modern society, the utilization of underground space has become popular, and the

requirements for waterproof technology are getting higher and higher.

Regarding the performance of concrete, relevant scientists have done a lot of research. Tanaka et al. had challenged the development of innovative asphalt mixtures, in view of the fact that the water stranded on the concrete deck of the highway bridge would significantly deteriorate and aggravate its damage. This asphalt mixture could ensure sufficient water resistance even during the limited time for concrete bridge repairs. After years of basic laboratory tests, a specially designed modified asphalt was developed, the performance of the mixture was specified, and its durability was checked using APT equipment, thereby obtaining a prototype mixture. Through the staged field test, the best construction method was finally obtained [3].

Sanytsky et al. were committed to the development of nanomodified cement-based composite materials in the field of self-cleaning building materials. The particle size distribution of the main components of multicomponent cement such as ultrafine zeolite and limestone, titanium dioxide, and kaolin additives was given. The interface degree of active surface in Portland cement and auxiliary cementing material was calculated. Studies had shown that due to the synergistic effect, anatase and rutile mixtures could be added to cement-based composite materials to improve the performance of self-cleaning gypsum. The mathematical programming method was used to study the effect of titanium dioxide and kaolin additives on the mechanical properties of nanomodified multicomponent cement. The results obtained by XRD and SEM methods showed that the addition of  $\text{TiO}_2$  nanoparticles with a high specific surface area to the cement paste would result in the formation of a denser microstructure in the cemented matrix [4].

The purpose of Pacheco-Torres et al. is to evaluate the effect of surface roughness and bond strength between steel and concrete surfaces in two different ways. In this study, push-out tests were performed to evaluate the interface behavior between steel and concrete bonded using epoxy resin. Roughness is obtained by forming grooves on the surface of the specimen. From this study, it can be concluded that the epoxy resin used in the study can be safely used as an adhesive between steel sections and concrete bridge decks with a compressive strength of less than 50 MPa [5].

Regarding nanomodified materials, related scientists have done a lot of research. Li et al. studied the influence of nanosilica and silicone oil paraffin emulsion mixed with flue gas desulfurization gypsum on its water resistance. They mixed nanosilica with desulfurized gypsum, explored how the waterproof and mechanical properties of desulfurized gypsum were affected by the particle size and content of nanosilica, and analyzed its waterproof mechanism. They combined with the microscopic morphology analysis of the gypsum sample, the appropriate size of nanosilica filled the crystal pores and reduced the porosity, and this changed the structure and morphology of the gypsum crystals to a certain extent. The dense oil-hydrophobic film and nanosilica produced a compact gypsum structure, which prevented water molecules from entering the gyp-

sum, thereby improving the performance of FGD gypsum [6]. Xu et al. incorporated nano- $\text{ZrO}_2$  concentrate into phenolic epoxy resin to prepare a nanomodified coating system. They used a combination of electrochemical methods and surface characterization methods and evaluated the corrosion performance of the coating in a hot mixed acid solution, focused on the extent to which the corrosion performance of the coating was affected by the content of nano- $\text{ZrO}_2$ . The results showed that the addition of 1% and 3% of nano- $\text{ZrO}_2$  could effectively improve the corrosion resistance of the coating, while the addition of 5% of nano- $\text{ZrO}_2$  reduced the corrosion resistance of the coating. The coating containing 3% nanometer  $\text{ZrO}_2$  showed the smallest species diffusion, the lowest average roughness (5.94 nm), and the highest C/O ratio (4.55) and coating resistance and showed the best corrosion performance in the coating samples [7]. Liao et al. prepared aliphatic amine-modified layered silicate clay by n-octadecylamine intercalation method. It was an organically modified clay, which was a new type of phase change material. Through the ion exchange reaction, when the equivalent ratio of ODA-HCl to  $\text{Na}^+$ -MMT was 1, and measured by X-ray diffraction (XRD) analysis, the inter-layer corridor of the silicate-layered structure extended from 12 Å to 28 Å. The obtained organoclay could be used as a good heat storage and phase change material [8]. Irshidat and Al-Saleh studied the thermal and fire resistance properties of nanoclay-modified cement mortar. To prepare the modified mortar mixture, they replaced part of the cement with montmorillonite nanoclay (0-2% of the cement weight). The fire resistance was evaluated by comparing the residual mechanical strength of the heated sample and the control sample. Through XRD and SEM tests, the effects of nanoclay on the chemical composition and microstructure of the thermally damaged samples were evaluated, respectively. The experimental results showed that the nanoclay-modified cement mortar had higher compressive, tensile, and flexural strength than the control sample, especially at higher temperatures. Due to high-temperature exposure, the addition of nanoclay significantly reduced the degradation of the tensile and flexural strength of the cement mortar. SEM images showed that due to high-temperature exposure, the presence of nanoclay reduced the density and width of fine-line cracks that appeared along the cement matrix [9]. These methods provide some references for our research.

This article sets up a control group experiment, by controlling one variable unchanged and changing another variable; a comparative analysis study is carried out; and comparisons are made between groups. The changes in the cement-related properties after mixing various materials are studied, and the changes in the microanalysis of the cement are observed. By analyzing the crystal structure and chemical composition of concrete, the principles and laws of concrete performance affected by different components are summarized. The novelty of this experiment lies in the addition of new research content and research methods, while verifying the existing experimental results.

## 2. Methods for the Performance of Rigid Waterproof Concrete

**2.1. Concrete Waterproofing Agent.** Among the many chemical admixtures, there is a concrete waterproofing agent that can fill the capillary channels inside the concrete. And it has the ability to reduce the material's ability to attract water and the ability of water to penetrate concrete under hydrostatic pressure [10, 11]. Waterproofing agent can significantly improve the ability of concrete to repel water, so as to achieve the purpose of improving the durability of concrete [12].

Water-repellent active materials have a waterproof effect, reduce plasticity and surface tension, and reduce harmful holes that concrete can easily allow water to penetrate [13]. In the presence of colloids or other ingredients, use waterproof media to block and fill the pores, and the cement concrete will remain in the pores after hardening. Because the road blocking the pores is blocked, the way for water to penetrate into the concrete is reduced, so as to achieve the purpose of waterproofing [14]. Cutting the pores promotes the airflow in the waterproofing medium to be evenly distributed in the concrete, generating closed small bubbles, blocking the capillary channels, and increasing the density of the concrete. This makes the concrete from hydrophilic to hydrophobic [15]. There are active hydrophobic ingredients in the watertight area. After adding concrete, a hydrophobic layer can be formed on the capillary wall. This weakens the capillary adsorption and reduces the water absorption rate of concrete. This hydrophobic effect can effectively prevent water vapor and nonpressurized water from entering the concrete. From the research results of hydration products, after adding waterproof materials, almost no new hydration products are formed, and some new products formed by water-resistant active substances that may be colloids are formed [16].

The functions of concrete waterproofing agent include effectively enhancing the waterproof function and antiseepage function of concrete. Incorporating a watertight medium into the concrete promotes changes in the pore structure of the concrete and releases gel at the same time. The gel fills the internal pores of concrete, and the density is 6-9 times that of unimpregnated concrete [17]. It significantly improved the performance of mortar and reduced bleeding rate. It can replace limestone to a certain extent, overcome hollowing and scaling, reduce soil ash, save work, and improve efficiency; it can delay the heat release rate of cement and effectively prevent the fracture of concrete; it is also possible to store cement while maintaining the same strength and decline as the reference concrete [18-19].

The use of waterproofing agent has certain functions of water reduction, plasticization, and surface tension reduction, which can reduce the harmful pores in the concrete that easily seep water and at the same time make the concrete uniform and dense, thereby improving the ability of concrete to resist pressure water.

In the waterproofing agent, there are components that form colloid or other blocking and filling capillary pores. After the cement concrete hardens, it stays in the capillary

pores, cuts off the capillary pores, and makes it difficult for water to enter, so as to achieve the purpose of waterproofing.

The air-entraining component in the waterproof profile produces some small and uniform closed air bubbles in the concrete, which blocks the capillary passage and improves the impermeability of the concrete.

Make concrete from hydrophilic to hydrophobic. There are active hydrophobic components in the waterproof profile. After adding concrete, a hydrophobic layer can be formed on the wall of the capillary, which weakens the adsorption of the capillary, thereby reducing the water absorption of the concrete. This hydrophobic effect is effective in preventing water vapor and unpressurized water from entering the concrete but has little effect on preventing the penetration of pressurized water.

**2.2. The Impact of Nanomaterials on Concrete.** Because of the special properties of nanomaterials, the mixing of nanomaterials into concrete will change some of the properties of the concrete. The specific performance is in the following important aspects:

- (1) Cement stone is mainly composed of three parts: cement that has not reacted with water, the reaction product after the reaction between cement and water, and pores. Pores are the spaces that can be filled by the other two parts in the cement stone [20]. The strength of cement stone is inversely proportional to the number of pores and directly proportional to the density of cement stone. Adding nanomaterials to concrete can fill the remaining pores in the cement, making the overall structure of the concrete denser and stronger [21]
- (2) Nanomaterials have the characteristics of small size, large surface, and high chemical activity. The addition of nanomaterials to the cement matrix not only directly involves the hydration process of the cement but also promotes the hydration process of the cement through the secondary hydration reaction with the hydration product. Especially, it improves the strength of concrete [22, 23]
- (3) Nanomaterials accelerate the hydration reaction of cement and act as a catalyst, and the faster hydration of cement is beneficial to increase the initial strength of concrete. There are many chemical bonds on the surface of nanomaterials, and these chemical bonds are also very active, so there is no need to form a stable C-S-H phase during the hydration process [24]. The C-S-H phase is formed directly on the surface of the nanomaterial, and the loose hydrated cinematic acid gel is transformed into a lattice structure centered on the nanoparticle. Thus, a general, uniform, and dense secondary interface can be formed in a good state [25, 26]
- (4) Nanomaterials can significantly reduce the dense distribution and directional arrangement of calcium hydroxide at the interface between concrete cement

slurry and aggregate, which helps to improve the comprehensive performance of the interface, thereby improving the strength and durability of cement-based materials

Due to its special physical and chemical characteristics, nanomaterials have the following important roles in concrete: cement stone is composed of unhydrated cement particles, hydration products, and capillary pores. Capillary pores are the spaces in the cement stone that are not filled by cement particles and hydration products. The fewer the capillary pores, the denser the cement stone and the higher the strength. Nanomaterials can fill the capillary pores inside cement-based materials, making the internal structure of concrete more compact. Cement particles are equivalent to coarse aggregates, and nanomaterials play a good role in filling, which can reduce the total porosity in cement-based materials, effectively refine pores, and reduce critical pore size, thereby improving the compactness and durability of cement-based materials. Nanomaterials are smaller in size, are larger in surface energy, and have great chemical activity. The addition of nanomaterials to cement-based materials can not only directly participate in the cement hydration process but also promote the process of cement hydration through secondary hydration reactions with hydration products, thereby improving the strength of concrete, especially cement-based materials' early strength.

**2.3. Concrete Performance.** Concrete has the following basic properties:

- (1) **Impermeability:** the ability and performance of concrete materials to resist pressure penetration by water and oil not only reflect the ability of concrete to resist water flow. It also affects concrete performance, carbonization, and chloride ion penetration [27]
- (2) **Frost resistance:** under the conditions of water adsorption and continuous low temperature, the concrete material has experienced multifrozen soil cycle, retaining its original properties or not significantly reducing the original properties
- (3) **Corrosion resistance:** the ability to resist the corrosive and destructive effects of the surrounding environment is called corrosion resistance
- (4) **Fluidity:** the concrete mixture flows under its own weight or mechanical vibration, and the mechanical vibration can flow evenly and densely on the formwork. It reflects the dilution consistency of the concrete mixture and the ability to fill the form [28]
- (5) **Compressive strength:** when concrete is subjected to continuous and slowly increasing external pressure, the limit of pressure that the concrete can withstand per unit area at the critical point of destruction

From the research results of hydration products, few new hydration products formed crystals after the incorporation

of water repellent. The new products formed by some water repellents are likely to be colloids.

### 3. Experiments on the Performance of Rigid Waterproof Concrete

**3.1. Preparation before the Experiment.** Some raw materials that need to be prepared before starting the experiment:

- (1) **Cement.** Use the data in Table 1 as a technical standard to ensure that the cement used in the experiment meets the standard
- (2) **Water repellent.** For example, Table 2 is used as the performance standard of waterproofing agent, and the materials used in the study are all waterproofing agents with a cement content of 2%
- (3) **Nanomaterials.** For example, Table 3 is used as the technical standard for nanomaterials

Trial mixing is carried out in the laboratory, and the mixed ingredients, proportions, and test mixing are obtained, such as the concrete materials shown in Table 4.

In order to better mix the concrete, the mixing process shown in Figure 1 is used in the lubrication process: first, wet the mixing drum of the concrete mixer, pour all the coarse aggregates during the mixing process, then pour the half sand, and then pour the cement (according to the test requirements, add different amounts of anticorrosion and hydrophobic substances). After the mixing is completed, reduce the amount of water and water pouring, and mix horizontally. Turn off the machine after the mixing is complete. If you find that the fluidity of the concrete is obviously low, add an appropriate amount of water-reducing agent and mix horizontally until the flow rate meets the requirements. Then, determine the amount of water-reducing agent, quickly load the mixed concrete into the test shell, and swing it firmly.

#### 3.2. Experimental Process

**3.2.1. Liquidity Test Experiment.** To quantitatively analyze the fluidity of concrete, it is necessary to use the index of slump. According to the "Standard for Test Methods of Performance of Ordinary Concrete Mixtures," the experimental procedures and precautions for concrete test experiments are formulated. Before the test, take a clean water source and use a brush to moisten the inner wall of the slump cylinder and the tamping rod, and put a funnel of appropriate size on the top of the cylinder. Put it on the iron plate, step on the pedal with your feet, and slowly adjust and fix it. The mixed concrete is taken out and divided equally into three parts, and the three layers of space in the cylinder are filled with concrete, respectively. The height of each layer is set to 1/3 of the cylinder height, and the plug is inserted about

TABLE 1: GB175-2007 quality standard for ordinary Portland cement.

Insoluble matter (%)		≤0.75
Insoluble matter (%)		≤5.0
Sulfur trioxide (%)		≤3.5
Loss on ignition (%)		≤5.0
Chloride ion (%)		≤0.06
Fineness (%)		≤10.0
Setting time	Initial setting (h:min)	≥0:45
	Final coagulation (h:min)	≤10:00
Flexural strength	Three days (MPa)	≥3.5
	Twenty-eight days (MPa)	≥6.5
Compressive strength	Three days (MPa)	≥16
	Twenty-eight days (MPa)	≥42.5
Stability		Qualified

TABLE 2: KIM waterproof agent technical form.

Physical property		
Inspection items	Measured results	
Appearance	Light gray powder	
Particle size ( $\mu\text{m}$ )	40-150	
Bulk density ( $\text{g}/\text{cm}^3$ )	~1.4	
Proportion	~2.8	
Curing properties		
Curing properties	Test method	Detection result
Permeability	Taywood/Valenta	-70%
Shrinkage cracking	BS 1881-5	-25%
Freeze thaw resistance	BS 5075-2	-87%
Compressive strength	BS EN12390-3	+8%
Flexural strength	BS EN12390-5	+7%
Elastic modulus	BS 1881-122	+16%

TABLE 3: Test report of nanocinnamon dioxide.

Inspection items	Quality standard	Measured results
Appearance	White powder	Compliant
Average particle size (nm)	$50 \pm 5$	50
Specific surface area ( $\text{m}^2/\text{g}$ )	$200 \pm 30$	200
Content (%)	≥90.5	99.7
pH value	5-7	6.8
Surface treatment section	Nothing	Nothing
Loss on ignition (%) 950 × 2 h	≤6.0	0.5
Arsenic	1.0	Qualified
Lead	1.0	Qualified

25 times in each layer. The stopper is injected into a spiral shape from the outside, and each penetration detection point is distributed as evenly as possible on the surface. Especially when printing the bottom, the tip of the knife must pene-

trate the entire depth. When lightly impacting the second layer and the previous layer, the tip of the knife must penetrate the surface of the next layer. When inserting and punching the upper layer, make sure that the concrete of the upper layer is poured and lift it higher or with the top layer of the caving drum. After completion of cementing, the concrete is wiped with a knife. After removing the concrete on the floor by the side of the drum, the foldable pipe rises vertically and firmly. At this time, check the difference between the upper body point and the height of the cylinder, which is the slump.

**3.2.2. Compressive Strength Test.** When determining the compressive strength of concrete, strictly refer to the “Standard for Test Methods for Mechanical Properties of Ordinary Concrete.” The main equipment includes the pressure tester, ruler, and brush as shown in Figure 2.

The specific steps of the experiment are as follows:

- (1) Dry the test piece taken out from the curing site and the water on the upper and lower bearing plates, and start the experiment immediately
- (2) The sample should be placed under the pressure plate or backing plate of the testing machine. If a sample is formed, the upper surface should be perpendicular to the storage area of the sample. The center of the sample should correspond to the center of the pressure plate under the testing machine. In the test mode or worksheet, adjust the ball position and adjust the contact balance
- (3) When the specimen begins to deform, pay attention to it. When the specimen deforms sharply and reaches the critical point of being destroyed, stop adjusting the throttle, and record the load value when the specimen is broken
- (4) Use the following formula to calculate the compressive strength of the test piece:

$$X_{CC} = \frac{M}{N}, \quad (1)$$

where  $X_{CC}$  is the compressive strength of test piece (MPa),  $M$  the destroy load of specimen (N), and  $N$  the pressure-bearing area of the test piece ( $\text{mm}^2$ ).

**3.2.3. Water Penetration Test.** Based on the Standard for Test Methods of Long-term Performance and Durability of Ordinary Concrete, the water penetration test is carried out after preparing the materials required for the experiment. To quantify the water penetration resistance of concrete, the water penetration resistance of concrete is expressed by measuring the average water penetration height under constant water pressure. The water penetration testing machine used is shown in Figure 3.

The specific method of the test is as follows:

TABLE 4: Composition and proportion of each sample of concrete.

Group	Composition and proportion of admixture
P1	Ordinary concrete
P2	Ordinary concrete + 2%waterproof agent
P3	Ordinary concrete + 2%waterproof agent + 1%nanosilica
P4	Ordinary concrete + 2%waterproof agent + 1.5%nanosilica
P5	Ordinary concrete + 2%waterproof agent + 2%nanosilica
P6	Ordinary concrete + 2%waterproof agent + 1%nanosilica + 0.01%PowderA
P7	Ordinary concrete + 1.5%nanosilica + 0.01%PowderA

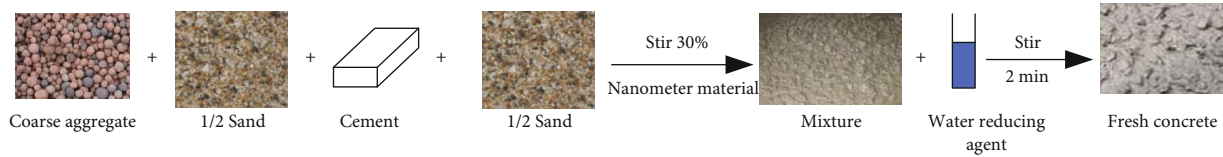


FIGURE 1: Schematic diagram of concrete pulling and mixing sequence.



FIGURE 2: Pressure testing machine.

- (1) Take out the test piece one day before the curing time of the test piece is reached, and wipe it with a clean damp cloth. Air-dry the test piece or use other methods to dry it, and seal it after the surface of the test piece is completely dry
- (2) Coat the side of the sample with a layer of molten paraffin containing a small amount of resin, and then, preheat the sample with a spiral pressure heating furnace or an electric furnace. In order to fix the sample on the bottom of the test model, release the pressure after the test model is completely cooled, and touch the test model with paraffin on the side of the test piece. When the paraffin slowly melts but does not flow, it indicates that the preheating temperature of the test model has reached the standard
- (3) When the test piece meets the test standard, start the water penetration tester. Open the valve at the test position to make all the water seeping from the hole flow into the test pit. After the test pit is filled with water, close the gate and install the sealed test piece on the impermeability instrument
- (4) After the test piece is installed, immediately open the valve under the test position to constantly control the water pressure in each time period, and control the pressurization time to no more than five minutes. When a stable pressure is reached, record this time as the start time of the experiment. Before the pressure reaches a stable level, always pay attention to the penetration of water on the end surface of the test piece. When water immersion occurs on the end face of the test block, the test block stops the test, the time is recorded as the end of the experiment, and the height of the test block is taken as the water penetration height of the test block. If the end surface of the test piece is not immersed in water, the test is terminated after the test is completed, and the test piece is taken out. During the test, when water is found to seep out from around the test piece, it must be sealed again
- (5) Place the test piece taken out of the impermeable meter on the pressure plate. Diameter steel buffer sheets are arranged in the center of the upper and lower end surfaces of the test piece in the diameter direction, and check whether they are in the same vertical plane. Then, start pressing and divide the specimen into two halves along the longitudinal area. After dividing the test block, use the waterproof mark to trace the watermark
- (6) The trapezoid plate is placed on the dividing surface of the test piece, and the water inlet height of each measuring point is measured at equal intervals along the water bottle with a steel ruler for accurate reading. When reading, if the measurement point is blocked with aggregate, the water penetration height near the two ends of the aggregate is measured and the average value is taken. The average value can be



FIGURE 3: Water penetration resistance testing machine.

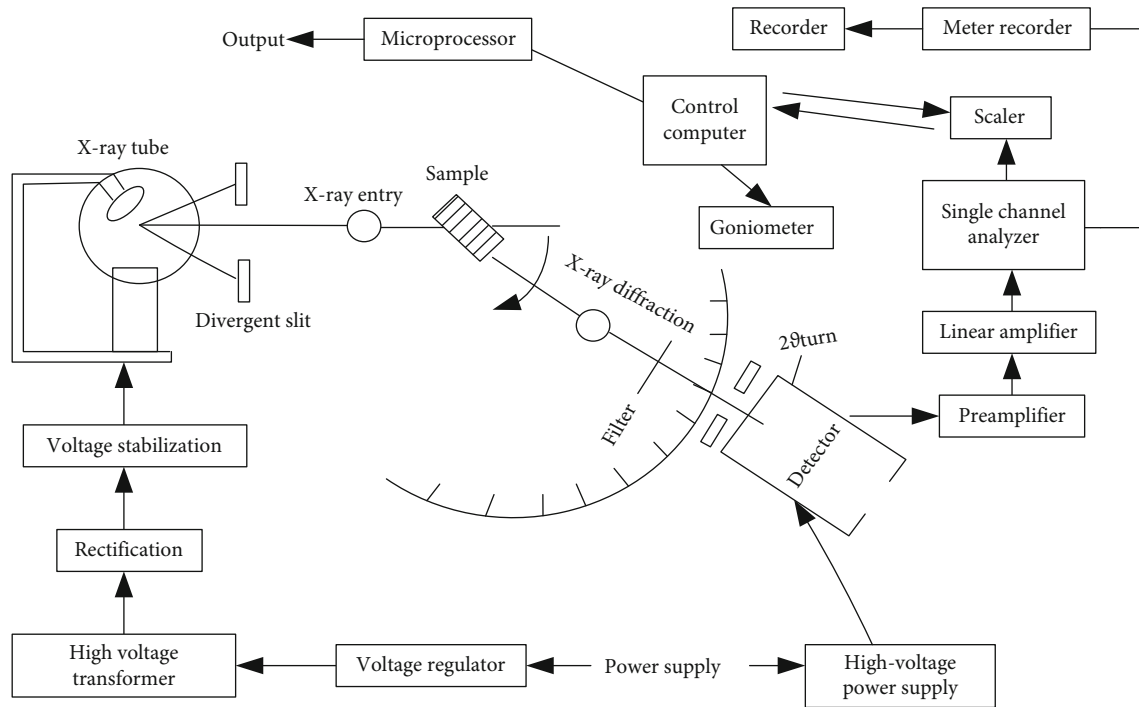


FIGURE 4: Block diagram of diffractometer composition.

used as the water immersion height of the measurement point

**3.2.4. Phase Analysis-X-Ray Diffraction Analysis.** XRD is the abbreviation of X-ray diffraction. The material is diffracted by light to cause the transformation of atoms in the atomic layer and obtain a diffraction pattern. X-rays are a type of short-wavelength electromagnetic waves that can penetrate quite thick objects. Light crystals formed by electron transfer in the inner layer of X-ray molecules under the irradiation of high-speed moving electrons can act as photons. The coherent scattering formed by multiple atoms or ionic molecules causes an impact on the light, which in turn affects the intensity of the scattered rays. The maximum intensity of light formed by the overlapping of divergent waves from several molecules is called diffracted light of light. It can be obtained by the following formula:

$$2M \sin \theta = \alpha, \quad (2)$$

where  $M$  is the plane distance and  $\alpha$  is the wavelength.

The measurement angle is based on rays of known wavelengths, and then, the crystal plane distance is calculated, which is mainly used for X-ray structure analysis. Another way to determine the angle is to use a known metal crystal to calculate the wavelength of the characteristic X-ray. The calculated characteristic X-ray wavelength can also be used to find the elements contained in the sample from existing data. Figure 4 is a block diagram of the diffractometer.

Prepare the test sample: after testing the compressive strength, take a specific test block, dismantle it, and put it in absolute ethanol to stop the final water. Before the test, use the mortar to mash the powder. After passing through the 80 square-hole sieve, it is double-sealed with a sealed bag and stored for later use.

**3.2.5. Pore Structure Analysis.** In this test, a pressure system test is used to test the hole structure. The pump will not penetrate most pressure materials. The pump can be forced into the pores of the porous solid under the action of only external force. Generally speaking, the pressurized pressure is

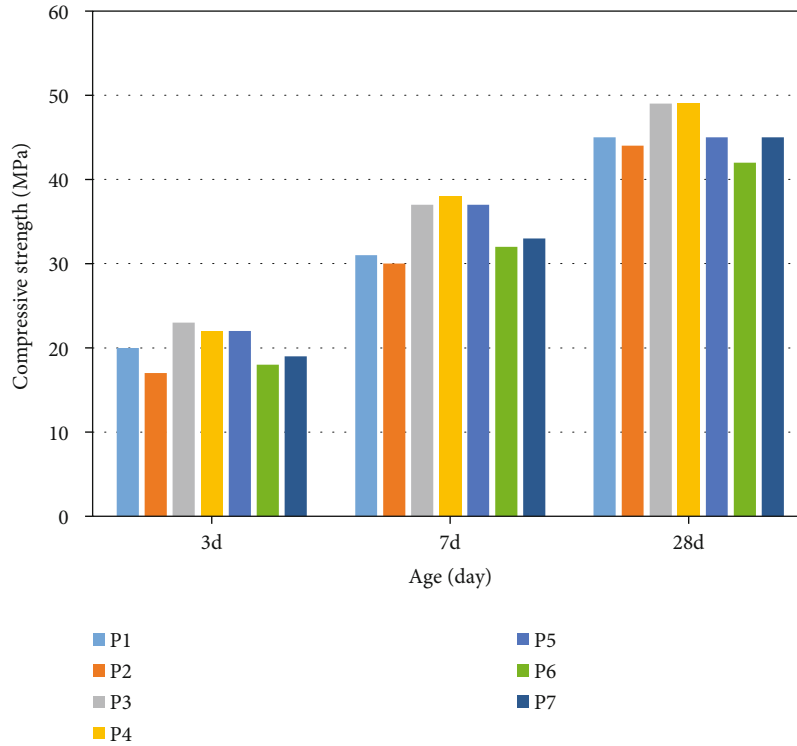


FIGURE 5: Comparison diagram of compressive strength and concrete compressive strength.

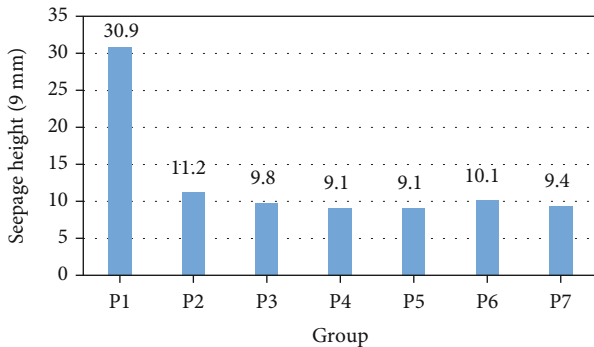


FIGURE 6: Comparison diagram of water penetration height of each sample.

equal to the surface tension of the capillary orifice pump. The relationship between hole radius and external pressure is as follows:

$$M = -\frac{2m \cos \alpha}{N}, \tag{3}$$

where  $M$  is the capillary pore radius,  $N$  is the pressure applied to the pump,  $\alpha$  is the wetting angle of the pump to the solid, and  $m$  is the surface tension of the pump.

#### 4. Experimental Analysis of Waterproof Concrete Performance

4.1. *Concrete Fluidity.* In this test, different amounts of water-reducing agent are added to control the slump to

remain basically the same. During the mixing process, it can be clearly observed that after adding nanometers, the fluidity of the concrete is obviously affected, and the content of the required water-reducing agent increases. Finally, the slump of each test group is basically maintained at between, which meets the specification requirements.

4.2. *Compressive Strength of Concrete.* The compressive strength of each sample concrete is shown in Figure 5.

Through the analysis of the above data, it can be seen that the mixing of water-repellent agent seriously affects the early strength of concrete. This is because the fluidity of concrete is improved by the addition of organic water-repellent agent and has a retarding effect. The incorporation of nanomaterials solves the problem of low strength in the early stage, and the compressive strength in the later stage is also greater than that of the benchmark group. The incorporation of PowderA has an effect on the strength of concrete, and the early decrease is obvious. This is also because PowderA is an organic material, which is not good for the early strength.

In the compressive strength test, the 3 d strength of the P7 group concrete after adding KIM waterproofing agent decreased by 14.81%, and by 28d, it only decreased by 3.94% with the P1 group. The strength of P3, P4, and P5 added with nanosilica increases significantly, especially the 3 d strength which increases by about 30%. However, the strength of the specimens doped with different amounts of nanosilica differed by less than 3%. Because nanosilica fills and refines a large number of pores in the concrete, it makes the apparent structure of the concrete denser, thereby



TABLE 5: Comparison of concrete impermeability test results.

Group	P2	P3	P4	P5	P6	P7
Reduction rate of each group relative to P1 group	71.6%	75.1%	76.9%	76.9%	74.4%	76.1%

TABLE 6: Peak value of main substances.

Sample	Crystal plane/crystal								
	(001)/CH			(101)/CH			C <sub>3</sub> S		
	3 d	7 d	28 d	3 d	7 d	28 d	3 d	7 d	28 d
P1	946	1199	1099	692	870	812	490	490	332
P2	988	978	1140	756	886	869	460	328	571
P3	1116	1150	640	700	717	645	480	339	307
P4	804	546	993	714	652	650	521	541	416
P5	753	822	862	677	708	578	578	348	340
P6	474	427	967	606	682	620	377	302	453
P7	586	604	736	649	653	749	541	374	683

promoting the development of concrete strength. The specimens with PowderA have lower early strength, reaching the level of P1 group by 28 d.

The incorporation of nanosilica will cause the loss of concrete slump. With the increase of nanosilica content, the slump drops sharply, and the fluidity of the concrete mixture will gradually decrease. In order to make up for the slump loss, the required water-reducing agent content increases. The specific surface area of nanomaterials is very large. Although their incorporation reduces part of the filling water, it greatly increases the surface adsorption water, which greatly increases the water consumption of standard cement consistency.

**4.3. Concrete Anti-Water Penetration Test.** The water penetration test was carried out after 28 days of curing of the specimen. The test result is shown in Figure 6.

By calculating the reduction rate of the permeable height in each group of samples relative to the P1 group, the effects of various composite waterproofing agents on the water permeation resistance of concrete were analyzed. The results are shown in Table 5.

From the above test data analysis, it can be seen that after adding KIM waterproofing agent, the ability of concrete to resist water penetration is greatly improved. On this basis, the density of concrete added with nanosilica is improved, and the water penetration resistance is further strengthened. In PowderA, a small amount of air will be introduced, so the impermeability of concrete will be slightly reduced. The combination of nanosilica and KIM waterproofing agent and the combination of nanosilica and PowderA have roughly the same waterproof penetration effect, but the combined effect of the three has a certain degree of impermeability.

**4.4. X-Ray Diffraction Analysis.** By analyzing the results of X-ray diffraction, it can be seen that the XRD diffraction spectra of each group are basically the same. Among them, 29.4° is selected, and 18.1° and 39.4° are selected as the characteristic peaks of calcium hydroxide. By comparing the

characteristic peaks, a semiquantitative method is used to determine the amount of the corresponding substance. The main substance peaks obtained by ray diffraction analysis are shown in Table 6.

First, analyze the content of C<sub>3</sub>S, which can be seen from Table 6:

- (1) Compare the P7 group with the P1 group; the content of C<sub>3</sub>S in the sample was similar at 3 d; the content of P1 group was more than that of P7 at 7 d, and the content of the P7 group was more than that of the P1 group at 28 d
- (2) Compare the P3, P4, and P5 groups; the content of *c* in the samples showed a decreasing trend at 3 d, 7 d, and 28 d, and the cement hydration continued to be uniform
- (3) Compare the P6 group with the P4 group; the P6 group showed fluctuations similar to that of the P7 group. The content increased significantly at 28 d, even exceeding the content at 3 d, and it was quite low at 7 d

## 5. Conclusion

The effect of nanomodified waterproofing agent on the performance of underground rigid waterproof concrete was studied by designing the impermeability durability test of concrete with different proportions. Comparing with the case of adding the waterproofing agent only, the early strength of concrete was significantly improved by adding nanomodified waterproofing agent. The concrete modified by nano-SiO<sub>2</sub> showed good improvement in water resistance, seepage resistance, and chloride ion penetration resistance, nearly double the water resistance and seepage resistance of ordinary concrete; in addition, the chloride ion penetration resistance was better than that of single water repellent. There are still many deficiencies in this paper, such as the lack of analysis of the reasons for the influence of nanomodified materials on concrete and the incomplete perspective on the influence of nanomodified materials on concrete. Nanomaterials are the new materials of the century. They exhibit unique properties in physics, chemistry, structure, etc., which lead to their research and applications in various fields. In the field of construction engineering, researchers add nanomaterials to traditional building materials to improve the performance of traditional building materials and give new application value. More comprehensive research should be done on the specific influence and mechanism of nanomaterials on concrete properties, and all research results should be combined to classify the types of nanomaterials and the influence of nanomaterial dosage on concrete and formulate

corresponding standards, so as to provide a theoretical basis for the target concrete to select the corresponding nanomaterials and dosage according to the required performance index.

### Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

### Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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