buildings

Review

The Effects of Nano-Based Bio-Carbonates in Superhydrophobic Concrete—A Review

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Abstract: Concrete must be a hydrophilic compound that is easily fabricated by nature. At the nanoscale, mechanical and chemical reactions alter the quality of cement-based substances. Continuous sprinkling of nano-silica solution synthesised with minimal surface solvents has been used to create a superhydrophobic (SH) concrete surface while similarly modifying the surface's chemical composition and dynamical intrinsic structure. In this study, we examine the impacts of admixtures in SH concrete including nano-based bio-carbonate. The fundamental characteristics and dispersal techniques of nanoparticles often employed in cement-based compounds are reviewed initially in this paper. Investigations of the large contact angle, small slide angle, and carbonated thickness have been employed to analyze the impacts of admixtures. Additionally, the industry and uses of nanoparticles for concrete substances are addressed, and the expense is inventively represented by a survey questionnaire. Finally, this article identifies the obstacles that now occur in the field of research and offers appropriate future viewpoints.

Keywords: admixtures; bio-carbonates; concrete; dispersal techniques; hydrophilic compound; nanoparticles; nano-silica solution; superhydrophobic (SH) concrete

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1. Introduction

The biggest and most frequently utilised construction material on the globe is cement. Concrete is the substance that people are consuming second only to water. As an amorphous hydrophilic substance, concrete is subject to water infiltration and forceful ion movement within the porous microstructure, which are the major factors affecting its longevity [1]. Water serves as a forceful ion transport medium during all of these activities. Hence, preventing moisture transfer within a concrete block is the most efficient technique to enhance its longevity and expand its serviceability. There are two major groups of widely used techniques to control wetness transfer [2]. The initial step involves enhancing the concrete's density by adjusting the water–cement proportion, adding a water-reducing agent, and mixing in admixtures. The next strategy involves using a coating to prevent water from contact with the concrete. Ionic varnishes, edge varnishes, and ground varnishes are mostly included [3]. The design of concrete products as well as the causes of hybrid cracking have been the focus of the bulk of nano-research in building projects. With the use of innovative, sophisticated tools, it is now possible to examine the molecular structure of materials and evaluate their capacity, toughness, and other fundamental attributes [4]. The use of nano-scale assessment to comprehend nano-scale mechanisms in cement concrete has made significant advancements over the past decade. Gaining more insight into the nanoscale structure of substances may have a significant impact on key manufacturing and use-related phenomena such as workability, cracking, rusting, and the creation of novel capabilities [5].

Figure 1 demonstrates the process of SH concrete. The benefits of superhydrophobic materials in different identities and anti-icing purposes have gained widespread interest [6]. SH materials were developed by the inspiration from living creatures. Surfaces of non-wetting animals and plants often include hydrophobic compounds [7]. By coating concrete with siloxane-based aqueous solutions, either with an incorporated hierarchy organization or an integrating micro-texture, extremely hydrophobic concrete blocks were produced. Such techniques cannot be used on building systems since, during the combination process, a new micro-roughness is created [8]. SH concrete was additionally produced using a top-down multilevel molding process. In SH concrete, an epoxy pre-sprayed adhesive surface was constructed on top of a water phase [9]. In this article, we surveyed the effects of admixtures on nano-based bio-carbonates in SH concrete.

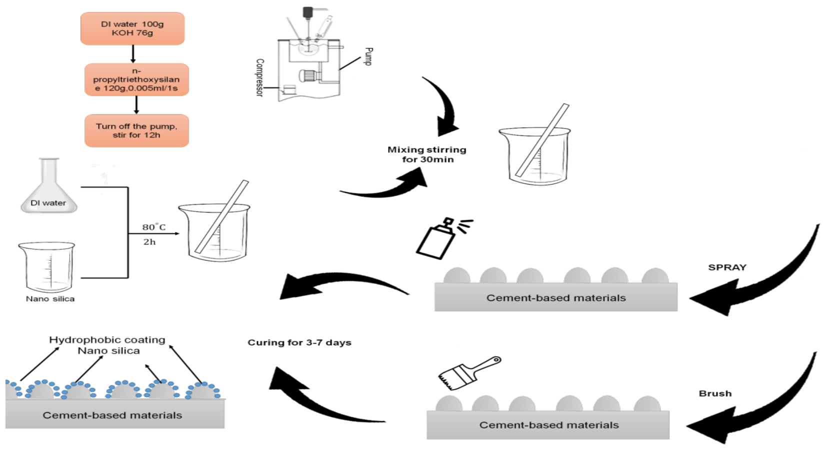

Figure 1. SH concrete process [5].

2. Techniques for Dispersing Nanoparticles

Poor dispersion is the primary obstacle that must be overcome in order to successfully incorporate nanomaterials into cement-based materials. This problem leads to a high amount of damage inside the composite, limits the effectiveness of the nanomaterials in the matrices, and raises the price of nanomaterials. Because the nanoparticles are not efficiently disseminated within the cement matrix, the incorporation of these nanomaterials has a detrimental impact not only on the performance of cement-based products but also on the process of cement hydration and the subsequent development of strength. Hence, proper dispersion of nanomaterials is a crucial stage in the process of successfully applying engineering [10]. The dispersion techniques that have been investigated thus far include physical dispersion, electric field induction, surfactant modification, surface modification, and hybrids of these and other techniques [11].

2.1. Method of Physical Dispersion

The mechanical and ultrasonic dispersal methods fall under the umbrella of the material dispersion method. This method can introduce mechanical power into nanoparticle agglomeration by high-speed and ultrasonic shearing to disrupt the bond among nanoparticles to the greatest extent possible. The agitated frequency, the agitator's shape and dimensions, and the agitation technique can affect the way particles and powders disperse in liquid [12,13]. Mechanical agitation is the method that is typically used to disperse particles and powders in liquid. In an ultrasonic processor, the electricity from an electrical source is transformed into mechanical vibrations. The process of cavitation produces millions of shock waves and releases a significant amount of energy, both of which contribute to the dispersion of nanomaterials throughout the liquid. It is generally agreed that the ultrasonic dispersion method is one of the more successful dispersion methods. However, if mechanical energy is used in the dispersion process, it can potentially harm the structure of the nanomaterials; for example, by significantly lowering the aspect ratio of CNT [14,15].

2.2. Surfactant Modification Method

The addition of surfactants to nanomaterials can physically affect their surface properties, stabilising their dispersion. This process is referred to as surfactant modification. For instance, this method does not impair the structure of CNTs, nor does it diminish the CNTs' mechanical qualities; nevertheless, it does cause damage to the electronic system of CNTs. It is possible to classify molecules as either ionic or non-ionic. Two types of dispersants are commonly used to scatter nanoparticles in water: (1) ionic surfactants, which use a hydroxyl group in which the exterior of the nanoparticles absorbs the water-insoluble tail of the dispersant, and the hydrophilic head of the dispersant is obligated with liquid to disintegrate; and (2) non-ionic emulsifiers, which use an adsorption capability in which the tail and head of the emulsifier are conditioned. The modification of surfactants is simple to employ. However, one must consider the dispersion price and the nanomaterials' connectivity inside the cementitious matrix [16,17].

2.3. Covalent Functionalization Method

This is the most prevalent method, which is utilized for enhancing nanomaterials' dispersion in water. This method can graft functional groups onto nanomaterials via a covalent link. These functional groups can then combine with nanomaterials using the covalent bond to provide a modification effect. However, it requires additional chemical reagents, sophisticated synthesis, and post-processing methods, thereby increasing the cost. To increase the dispersity of silicon-based materials such as silicon dioxide in acrylic resins, methacryloxypropyltrimethoxysilane can be distributed onto the surface of nano-SiO_2 particles. Methacryloxypropyltrimethoxysilane was developed for silicon-based materials such as nano-SiO_2. Using silylated PCE superplasticiser and colloidal nano-SiO_2 as the raw materials, the core-shell nanoparticles of nano-SiO_2 polycarboxylate (PCE) superplasticizers are synthesized with high dispersity. The plasma technique is another method that is thought to be effective for increasing the dispersity of carbon nanotubes (CNTs). This method boosts the surface charge density of CNTs, ultimately resulting in a more significant zeta potential for the treated CNTs. They have spread evenly throughout the aqueous solution thanks to the powerful repulsive force between the treated CNTs. Moreover, this treatment can potentially alter the hydrophobic character of CNTs, which is necessary for forming surface functional groups. It can prevent sedimentation in the dispersed treated CNT solution for an extended period. According to recent research, the hydrophobicity of coated concrete is being improved through the covalent alteration of nano-SiO_2 and nano-TiO_2. Silane, as coupling agent, can be efficiently used to convert nano-SiO_2 and nano-TiO_2 from hydrophilicity into hydrophobicity. Inorganic film coverings can be guaranteed to have a stable dispersion of nanoparticles [18,19].

2.4. Cement Admixture Modification Method

The polycarboxylic acid-based (COOH) superplasticiser is the additive utilised most frequently for distributing nanomaterials such as CNTs inside the cement matrix. The utilisation of PCE resulted in an excellent dispersion of MWCNT both in water and in the cement paste that had already been set. The production of the carboxylic acid group on the surfaces of CNTs was achieved by using a solution which contained both H_2SO_4 and HNO_3. The carboxylic acid and the hydration products, either C-S-H or Ca (OH_2), are reactants in the chemical processes. Because of the contact, a high covalent force is exerted on the interface between the carbon nanotubes and the composite matrix, which increases the nanocomposites' compressive and bending strengths [20,21].

2.5. Electric Field Induction Method

To create a thin liquid surface with a condensed cross-section region, carbon nanotubes and carbon nanofibers are mixed with just an extraction liquid in a process referred to as electric fields inducing [22,23]. The thin layer is then covered with a metal mesh or foil to function as a two-terminal electrode within the solution layer. The electrode is subjected to a direct or alternating current to induce electrical polarisation in the CNTs and CNFs and transform them into electric dipoles [24,25]. CNTs and CNFs will generate regular movements when subjected to the influence of an electric field. Particles will also have the propensity to expand along electromagnetic field lines, leading to their equal distribution in conclusion [26,27].

3. Survey on the Fundamental Properties of Concrete with Nanomaterials

Organic or inorganic substances, having several dimensions on the nanometer scale (1–100 nm), greater than atomic clustering but less than tiny powder particles, are often referred to as nanoparticles [28]. Instead, in frameworks, aggregates, or categories comprised of nano-based particles or microparticles, its diameters could be approximately within one hundred nm, preserving the nanoscale features [29]. The spaces between natural compounds are filled with a nano-binder that contains a nano-dispersed concrete material. Emulsion processing of Conventional concrete-generated topo-chemical responses may also produce the nano-sized concrete mixture material [30].

The rapid hydrolysis is significantly accelerated when calcium silicate hydrate (C-S-H) is added in tiny quantities to tricalcium silicate (C3S) glue and Portland cement. The initial services for the dissolution of hydration products from the pore water were said to be provided by C-S-H. Figure 2 illustrates the integration of particles within a concrete mixture [31].

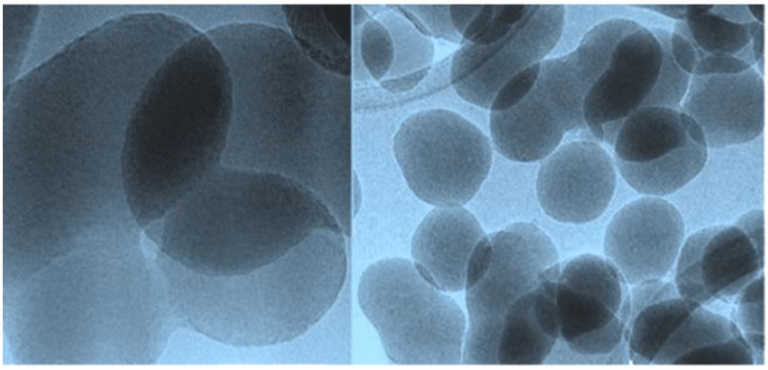

Figure 2. Particles in the concrete mixture [31].

3.1. Significance of Carbon Materials in the Concrete Process

The construction sector prefers carbon-based particles such as graphene oxide, carbon nanotubes (CNT), or graphene over certain types of nanoparticles. CNTs are the ideal compound for enhancing the tensile flexibility and strength of a hyper-quality concrete mixture compound [32]. Calcium carbonate, nanostructure particles formed when CO_2 reacts to the cement's Ca^{2+} ions, is incorporated into the concrete. This thickness in the cement also reduces the amount of carbon dioxide released into the atmosphere, while strengthening the cement [33]. Concrete's tensile properties can be improved with the inclusion of calcium carbonate. Additionally, it stimulates the self-compacting qualities of cement and improves it by packing particles and spacing impact [34]. The tensile strength of concrete using carbon materials is depicted in Figure 3.

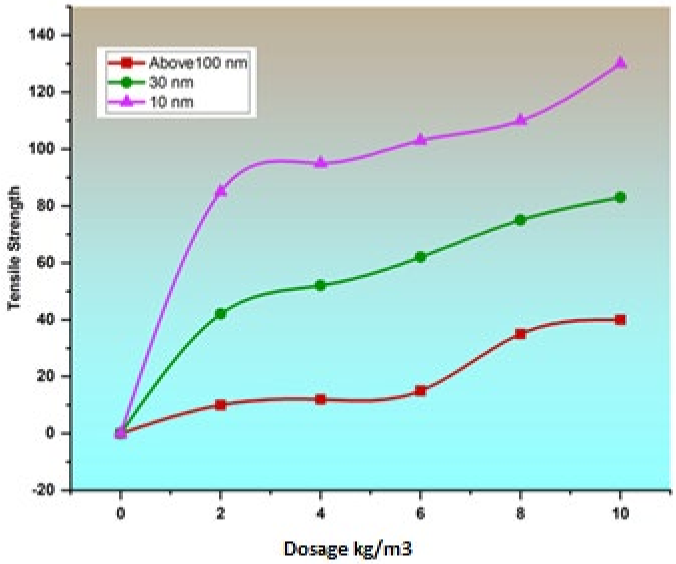

Figure 3. Tensile strength [34].

3.2. Significance of Calcium Carbonate and Silicon Dioxide

Using nano-$CaCO_3$ (calcium carbonate) and nano-SiO_2 (silicon dioxide) particles improves the mechanical characteristics and strength of concrete by increasing packing. The amount of nano-silica in concrete rises with increasing compressive strength. Cementitious reactivity is extremely strong in nano-silica [35]. The filling intensity of nano-silica has a significant impact on the pore building's development. The wettability and durability of the concrete are improved by the nanocrystal capacity to fit the cement concrete's microscopic holes. The compressive strength of the SH while using the nano-$CaCO_3$ and nano-SiO_2 [10] is indicated in Figure 4.

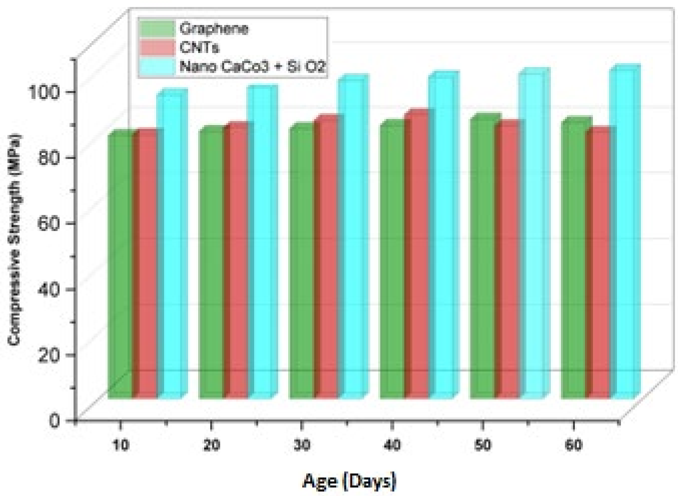

Figure 4. Compressive strength [10].

3.2.1. Calcium Carbonate

The hyper nature of nano-$CaCO_3$ particles causes changes in the crystalline lattice and outer layer electrons structures, resulting in quantum confinement, tiny dimension, impact on surfaces, and massive impacts which were not present in regular $CaCO_3$ [36]. Given that the edge structure of the nano-$CaCO_3$ calcite crystal is comparable to that of C-S-H, it has clear implications for an acceleration of hydration for concrete materials. Nano-$CaCO_3$ has been more reasonably priced when compared to other materials [37]. To increase the hydrophobicity of the concrete surface, calcium carbonate can be used as a surface treatment. A hydrophobic substance, such as a silane-based solution containing calcium carbonate, can be applied to the surface of the concrete. The calcium carbonate particles will aid in generating a rougher, water-repellant surface. As an addition, calcium carbonate may be included in the concrete mixture. It can aid in lowering the concrete's porosity and enhancing its water-repellent qualities. Additionally, it can be used to improve the concrete's compressive strength. To create extremely hydrophobic concrete, calcium carbonate can be utilised as a filler ingredient. It may be used in the mixture together with other components such as cement, sand, and water to create a concrete that is highly durable and hydrophobic.

3.2.2. Macro-Calcium Carbonate

Rough calcium stones and dust are examples of macro-calcium carbonate, a term referring to $CaCO_3$ with molecular weights in the range > 1 mm. At this scale, the chemical and physical impacts of $CaCO_3$ on the hydrolysis reaction are negligible; hence, macro-$CaCO_3$ has little influence on the process [38]. Moreover, the moisture content, particle density, as well as constitution of macro-$CaCO_3$ stones have a major impact on the workability, mechanical properties, and endurance of cement materials. It can be used in the concrete mix as a filler ingredient to strengthen the concrete and lessen porosity. To achieve optimum effectiveness, choose a macro-calcium carbonate of excellent quality and low moisture content. The required qualities of the concrete should guide your choice of particle size. To make sure the macro-calcium carbonate is dispersed uniformly throughout the concrete mix, choose an appropriate mixing technique.

3.2.3. Micro-Calcium Carbonate

Micro-$CaCO_3$ in the form of limestone powder and limestone dust is often used as a blended or underground material in cement manufacture [39]. When smaller than one micrometer, calcium carbonate particles are referred to as micro-calcium carbonate. It is used as an addition in concrete mix to increase the hydrophobicity of the concrete surface. Despite its lack of pozzolanic activity and inability to react with alkaline substances such as $Ca(OH)_2$ and calcium oxide (CaO), the inclusion of micro-$CaCO_3$ in cement can have biological and chemical impacts on the hydrolysis reaction, the properties of which include the essential and material performance of hardcore brands [40]. Although micro-$CaCO_3$ has a smaller particle size than cement grains and may be found in ternary and quaternary mixes with SCMs such as fly ash and metakaolin [41], it is incorrect to classify micro-$CaCO_3$ as an innocuous substitute. The hydration rates and morphology of the cement may be affected by the presence of micro-$CaCO_3$ under these conditions. Last but not least, the mechanical characteristics and durability will also be involved [42]. To increase the hydrophobicity of the concrete surface, taking everything into account, employing a surface treatment which contains micro-calcium carbonate is useful.

3.2.4. Hydration Process

Hydrated lime, a kind of macro-$CaCO_3$ has a much larger specific area and surface energy than macro-$CaCO_3$ [43]. As a function, the various particle size contents and microstructures of micro-$CaCO_3$ have a far more substantial impact on the effects of hydrated lime on total combined moist temperature, the flow velocity of gelatinisation warmth, as well as the consequent condensing of concrete material. Hence, the structure of macro-$CaCO_3$ is more crystalline [8]. A crucial element in the hydration of concrete is the ratio of water to cement. It is critical to use less water in the mix to minimize porosity and improve the strength of ultra hydrophobic concrete. To retain the concrete's hydrophobicity, a lower water-to-cement ratio also helps to reduce the quantity of water that is accessible to react with the hydrophobic substance. It is possible to produce high-strength, long-lasting, and hydrophobic concrete that is appropriate for a variety of applications by carefully controlling the hydration process in superhydrophobic concrete.

3.2.5. Particle Size

Micro-calcium carbonate's physical and chemical effects are influenced by its particle size [44,45]. The filling effect of larger met kaolin is the main activity in cement materials [46]. Because of its low surface energy and limited solubility in a highly alkaline environment, Portland cement plays a minor role in the hydrolysis reaction of concrete and is typically used to fill the voids among particles such as silt and admixtures [47,48]. Nevertheless, when little limestone dust is introduced to cement materials, there are notable differences in the accumulation of hydrating heat, the pace at which hydration heat is dissipated, and the mineral admixtures [49]. The findings may be intriguing in terms of micro-calcium carbonate's chemical impact. Three different grades of limestone powder were utilised to compare the effects of particle size on cement hydration. The hydrophobicity of calcium oxide is accelerated, and the hydration peak is raised due to the deposition impact, which occurs when finer cementitious materials offer more macropores for the synthesis and growth of the calcium silicate hydrate (C-S-H) [50,51]. The production of additional hydration of cement, such as calcium hemicarboaluminate and monocarboaluminate, is facilitated by using 0.7 m hydrated lime, recognised as the hydrolysis of hydrated calcium [52]. Several other researchers have also backed up the creation of carboaluminates. Calcium hemicarboaluminate, on the other hand, is not thermostable and only occurs for the first seven days of hydration before progressively changing into monocarboaluminate, and significantly less $CaCO_3$ than is present in limestone powder is involved in the synthesis of carboaluminate [53,54]. Micro-calcium carbonate is a measure of formation of hemi- and monocarboaluminate at higher pH levels [55]. Thus, the carboaluminates inside the X-ray diffraction (XRD) signal are weaker and harder to distinguish than others [56]. While $CaCO_3$ has its calcium iron supply, an additional source from limestone powder may account for the growing second hydration maximum in concrete fine stone dust [57]. The secondary hydrolysis phase of cement made with varying fineness of hydrated lime was identical in all cases [58]. It is possible to improve the particle packing density and lower the porosity of the concrete by using a variety of particle sizes in the concrete mix. As a result, the end product may be stronger and more hydrophobic. The performance of the finished product can also be impacted by the particle size of the hydrophobic ingredient used in the concrete mix. For instance, smaller particles could be more efficient in filling up the gaps in the concrete and improving the surface's hydrophobicity. The particle size of the concrete may be tailored to the required attributes of the finished product with regular testing and monitoring. Concrete performance may be evaluated using testing techniques including compressive strength tests and water contact angle measurements.

3.2.6. Silicon Dioxide

A white crystalline powder with a sphere-like structure, nano-SiO_2 represents one of the early nanoparticles employed in concrete materials. It retains excellent toughness and strength even at extreme heat and has a quantum confinement impact and unique optical and electrochemical performanc [59]. Additionally, nano-SiO_2 has a significant benefit over other nanomaterials in that it increases the synthesis of hydration of cement $Ca[OH]_2$,has quicker cementitious properties, and has an enhancing influence on the hydration process [60]. Superhydrophobic concrete may be made using silicon dioxide as a filler ingredient. It may be used in the mixture together with other components such as cement, sand, and water to create a concrete that is highly durable and hydrophobic. The hydrophobicity of the concrete surface can be improved by treating it with silicon dioxide. A hydrophobic substance, such as a silicon di-oxide containing silane-based solution, can be applied to the surface of the concrete. The silicon dioxide particles will aid in producing a surface that is rougher and deters water.

3.3. Significance of Nano Calcium Silicon Hydrate in the Concrete Process

Calcium silicon hydrate particles are a new possible hydrated cement acceleration that has garnered significant attention in recent years. Calcium silicon hydrate particles formed artificially are very similar in structure to the Calcium silicon hydrate produced naturally during the hydration of cement. The synthetic Calcium silicon hydrate particle can considerably increase the early hydration of tricalcium silicate, which, in turn, increases the substance's initial strength by a significant amount. The C/S ratio of the Calcium silicon hydrate seed appears to be a crucial element that has a considerable impact on both the mechanical qualities of the cement paste that has been hardened and the accelerating effect of the hydration of cement, even though the response mechanism is still not fully understood. Co-precipitation of calcium salt and silicate and hydrothermal processes are the most common ways to produce nano-Calcium silicon hydrate seeds. Examples of these seeds are xonotlite-type and tobermorite-type Calcium silicon hydrate seeds [61].

3.4. Aspects Involving Improved Carbon Nanoparticles Made of Cement-Based Composites (CN-CBCs)

Improved hydrating mechanisms, morphology, mechanical qualities, endurance, conductivity, as well as properties [62,63] are only some of the ways in which CN-CBCs benefit the environment. First of all, when done properly, adding carbon nanoparticles to composites may lower their cement content while retaining their technical qualities [64]. Secondly, since innovative structures are anticipated to have longer service lives, their greater durability results in a reduction in the average yearly cement usage [65]. Last but not least, recent technical developments in the manufacture of nanostructured materials, and particularly in nanoparticles, have started to use atoms of carbon for gases such as carbon dioxide, which might also help in reducing atmospheric carbon dioxide levels [66]. The widespread usage of CN-CBCs in the civil engineering sector would provide a means of achieving this goal [67]. Nonetheless, there are still certain issues with the widespread use of CN-CBCs.

As ultra-sonication treatments take so long and are so hard to control, improvements and streamlining are needed initially in the pretreatment phase [68]. Preparing electrolytes of nanostructured materials may take several hours, and mixing the suspensions with cement can lead to reagglomeration of the nanoparticles [69,70]. One method proposed to deal with the issue of dispersion of CNTs and CNFs is to manufacture CNFs and CNTs along with the cement/mineral admixture [71,72]. In this method, the CNTs and CNFs are grown directly on the concrete particles. These nano-hybrids have been used as OPC alternatives [73] because of their ability to produce great CNF or CNT distribution with strong CNF/CNT-cement binding for improvement. Fly ash grains and silica fume particles might possibly be suitable substrates for CNT growth. Due to their reduced surface energy, nano-hybrids may be pre-mixed with cement powders before the pozzolanic reaction takes place, resulting in the independent distribution of CNFs and CNTs throughout the matrix [74].

Second, despite the hope for a solution to the production issue, the high price of commercially available nanostructure materials is cause for concern. Its costs are unaffordable because of the novelty, complexity, and machinery required in synthesizing carbon nanoparticles [33]. The output of nanotechnology is increasing with the development of methods for mass production, it is anticipated that the cost of nanotechnology will decrease in the next years [75]. Carbon nanomaterials will most likely be employed in attractive applications even with a significant price drop. Thus, one of the key purposes of research should be to reduce costs [36].

Lastly, before utilising CNCBCs on construction sites, particularly for monitoring reasons, as cement concrete systems are often exposed to a wide range of challenging environments, it is required that a number of field tests be conducted [76]. Understanding how factors such as moisture, heat, the presence of nanostructures, and even the morphology, the size and form, of the concrete structures impact the reliability of the data available, is crucial for achieving accurate calibration of the equipment. An appropriate smart tracking system needs to be constructed in order to take advantage of the CN-CBCs' identity capacity. Lastly, there is much discussion over how nanomaterials will affect the environment [77]. Thus, further analysis and applied work are needed in the fields of smart planning and development to forestall future environmental damage.

4. Survey on the Analyses of the Production of Superhydrophobic Concrete

Substances comprise n-Propyltriethoxysilane (nP), Isobutyl-triethoxy-silane (Its), NanoSiO_2 (NSi), and some others. Minimal surface energy material called nP is employed. SiO_2 nanoparticles have a 25 nm size distribution [78]. Different chemical substances such as deionized water and potassium hydroxide are examples of analytical reagent (AR) grades. Its quality is 99% and serves as the experimental group. Sand with a refinement factor of 2.55 and a maximal diameter of 4.75 mm was chosen [79]. The material used was a sedimentary rock with a maximum diameter of 20 mm. It was decided to use deionized water as the scattering agent. The Portland cement used was rated 52.5 P II according to Chinese standards. To make mortars and create a concrete sample, common sand with total particle sizes of 4.75 mm was combined with water from the tap. Figure 5 illustrates a structured view of the production process [80].

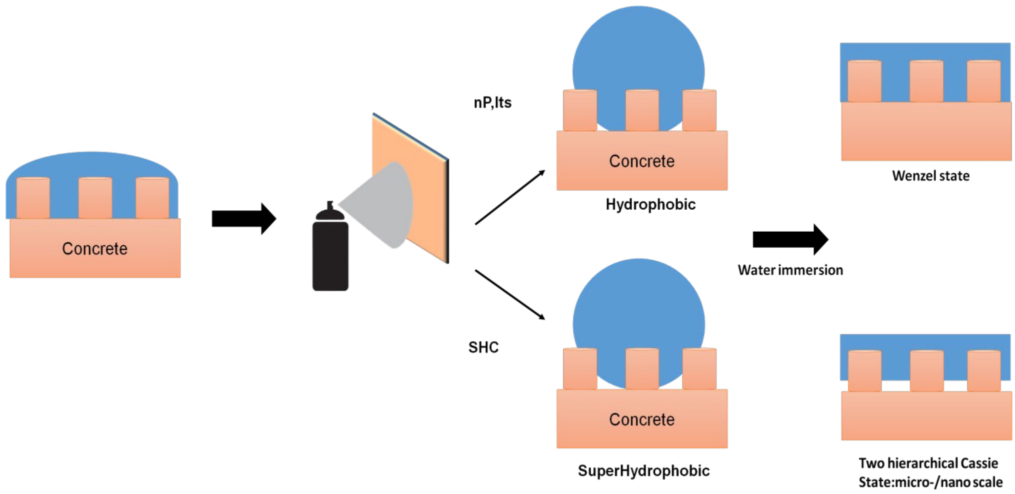

Figure 5. A structured view of the production process [80].

4.1. Concrete Surface Fabrication with an SH Coating

For the X-ray diffraction (XRD), Mercury intrusion porosimetry (MIP), and nanoindentation experiments, a concrete mixture specimen with a water–cement ratio (w/c) of 0.5 was made and molded into 20 mm × 20 mm × 80 mm [81]. A cement specimen was then produced and molded in molds approximately 102 mm × 102 mm × 102 mm for macroscopic studies such as moisture content, moisture intake rate, and resilience tests. Additionally, all specimens underwent a 24 h and a 27 day demolding process at a state of 21 ± 3 °C and humidity levels of 97 ± 3% [82]. The concrete mixture specimen and the cement sample were divided into smaller portions that measured 40 mm × 40 mm × 30 mm and 10 mm × 10 mm, respectively, before the coating process. The sliced surfaces were then polished for 5 min and ultrasonically cleaned for 20 min [83]. The specimen was then vacuumed at 50 °C for 18 h, coated with the coatings for 40 s, and allowed to cure for seven days at typical curing temperatures of 21°C and 75% humidity [29].

4.2. Characterization Techniques

A DSA25 Contact Angle Meter was employed to determine the average contact angle, which represented the average of six distinct places on a single specimen. The basic and changed surfaces' elemental composition was examined using an X-ray diffractometer. Using a Fourier infrared spectrometer, variations in the chemical reactions between the coatings and the substrate were examined [84]. Then, it was possible to see the structure of the coating formation. The surface's hardness and textural characteristics were examined. MIP, which has a measurement range from 5 nm to 300 µm, was used to determine the permeability of the surfaces. Additionally, a Nano Test Vantage system was used to assess the changed surface's nanoscale characteristics. Contact angle measurements are an important characterization technique to evaluate the superhydrophicity of concrete incorporating nano-based bio-carbonates. Surface tension is a measure of the cohesive forces between molecules at a liquid's surface, which works to reduce the surface area of the liquid. Superhydrophobic concrete made with nano-based bio-carbonates has a close relationship between the contact angle and the surface tension. The relationship between contact angle and surface tension is important for understanding the wetting behaviour of water droplets on the surface of superhydrophobic concrete incorporating nano-based bio-carbonates. By optimizing the surface properties of the concrete, including the surface tension and contact angle, it is possible to design concrete with improved durability and performance in harsh environmental conditions. In the proposed method if the value of the contact angle increases, the surface tension also rises. Figure 6 depicts the contact angle [38].

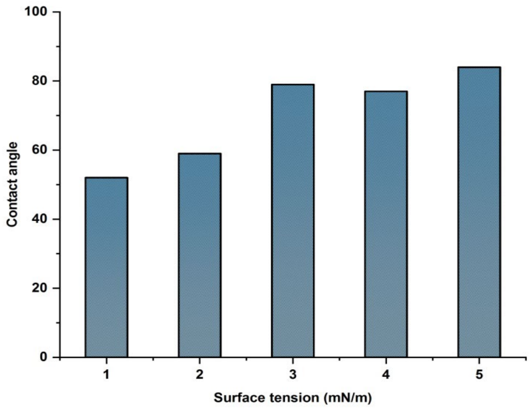

Figure 6. Contact angle [38].

4.2.1. Wettability

A contact angle test method depending on the chemical deposition technique was used to assess the wettability of test samples at 20 °C. Using high-purity, deionized water, the mean of six experimental measurements collected at various locations on the surface was calculated to estimate the contact angle and slide angle [39].

4.2.2. Analysis of Mechanical Stability

The mechanical resilience of the SH surface may be characterized by performing a tape peeling test since this causes the largest damage to the morphology. Three M610 sticky tapes were tested, each having an adhesiveness of 47 N/100 mm [40]. Following application, the tapes were softly cleaned by an eraser to ensure complete interaction with the surface test and then peeled off at a perfect angle. After every peeling cycle, the phase contact angle was monitored till a total of 100 peel events had been performed [41].

4.2.3. Absorption of Water

The concrete's capacity to take up water through capillary suction had also been measured using the standard ASTM C1585 capillaries moisture absorption test. The specimen was dehydrated and then immersed in water so that one of its surfaces may rehydrate [42]. The weight of absorbing water was determined by weighing the specimen before and after immersing and by recording the weights of the cubes at periodic intervals of ten minutes on the initial day and after each day for all experimental days (approximately thirty days) [43]. Conductivity (C) is measured as the slope of the straight matching curves and is calculated by dividing the volume of water taken by the cross-sectional area by the square root of the interval, as shown in Equation (1) [8].

$$k = C\sqrt{t} \tag{1}$$

4.2.4. Resilience Test

When comparing surfaces and materials, the tape peeling experiment is one of the easiest methods for gauging coating adherence and structural integrity. An SH surface's structure may be damaged during the withdrawal of the tape [44]. Moisture qualities after every peeling cycle were examined to assess the longevity of the surface area, using a 3M 610 clear gauze fabric tape with an adhesive strength of 47 N/100 mm.

4.2.5. Carbonation Test

Materials underwent the industry-standard accelerated carbonation test. Following 3, 7, 14, and 28 days of carbonation, phenolphthalein reagents were employed to determine the degree of carbonation [45]. The extent to which the coatings were destroyed by exposure to sunlight was determined using a photo aging test. Carbonization testing can also be performed to assess the efficacy of coatings and surface treatments for decreasing carbonation rates in concrete. The carbonation test is an effective method for determining how well concrete can withstand carbonation, and the results can be applied to the construction and upkeep of concrete buildings. The graph shows that when time is increased, the carbonation depth level will increase, and the control level is greater than the SH concrete level. Figure 7 indicates the carbonation depth [46].

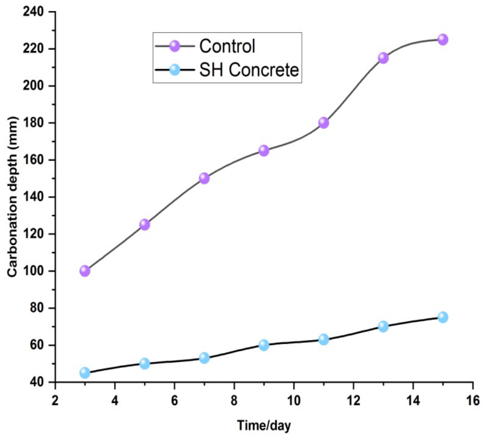

Figure 7. Carbonation depth [46].

5. Discussion

To increase the quality of the physical performance of the cement composites, the modern manufacture of high-strength concrete mix requires the inclusion of numerous expensive additives. Alternative, cheaper admixtures should be developed and researched to reduce the need for mineral and chemical admixture in the long run. In addition, several studies have been conducted on strengthening composites by incorporating natural or superhydrophobic property into cement mortar or concrete [39]. Unfortunately, the limitations and difficulties that the tiny diameters of fibres introduce into the cementation material's mix hinder its workability [40]. The compacting effect during cement mortar mixing is proportional to the micro-size thread added. Nanomaterials have been found to possess strength and flexibility on a much larger scale compared to known strong material.

In consequence, they should weaken the concrete mix. Furthermore, using additives or natural materials in cement paste ensures the durability of the building. Since long-term exposure to the weather will surely cause the material to degrade [41], if the cement is not dense enough, water and air may get inside the building more efficiently, hastening the decay process. As a result, the industries as a whole are in desperate need of re-valuation. It is essential to take precautions early on to ensure that the cementation materials structure is impervious to chemical assault and decay agents such as air and water. Table 1 depicts the summary of some current work.

Table 1. Summary of some existing nano-based bio-carbonates in superhydrophobic concrete.

S. No	Reference	Technique	Advantages	Limitations
1	[33]	Multipronged nanohybrid method	Analysis revealed that nano/micro two hierarchical surface roughness improves non-wettability.	Depending on the system, it might be highly expensive
2	[35]	Biomimetic superhydrophobic surface of concrete	Efficient for fabrication.	Low surface-energy surfactants
3	[36]	In situ biomineralization of inorganic crystals $CaCO_3$	Superhydrophobic surface is anti-corrosion friendly.	It faces difficulties in durability and adaptability
4	[59]	Intelligent processing	Efficient for ecofriendly superhydrophobic coatings.	Low water affinity
5	[60]	White Portland cement (WPC)	The cement-based superhydrophobic coating cannot be made dirty by dust or liquid solutions.	Stability issue
6	[80]	Stainless steel by two-step chemical etching	Effective for fabrication of superhydrophobic surface.	Low surface energy

6. Summary and Perspectives

In numerous technologies, mixes are used to enhance the qualities of cementitious materials that are still soft or hardened. With the effects on water/cement (w/c) decrement, hydrophobic impact pores decrease the densification, and additives have boosted both the tensile strength and endurance of concrete. In this paper, we surveyed the effects of admixture-based bio-carbonates in SH concrete. Initially, the nanoparticles present in SH concrete were surveyed and their results such as compressive strength and tensile strength were analyzed. Due to this, its application in the modern building sector has significantly risen. Admixtures are likely to propel the development of the concrete industry because they provide complicated contemporary buildings with high workability, superior compressive strength, longevity, moisture resistance, wear-resistant, and excellent quality. Further, the superhydrophobic concrete production scheme has been surveyed and the characterization techniques are studied with their approximate results. From this review, it is determined that when a nano-based bio-carbonate is added to the SH concrete, the admixtures seem to be less effective because more carbonation in the concrete leads to damaged construction in the future. New innovative techniques are introduced in future work with more advantages.

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References

1. Qu, L.; Song, W.; Wang, Q.; Xu, S.; Hou, C. Effects of hydrophobically modified fly ash on resistance of chloride corrosion and water penetration of cement mortar in the early hydration stage. *J. Build. Eng.* **2022**, *64*, 105573. [CrossRef]
2. Kravanja, G.; Godec, R.F.; Rozman, M.; Rudolf, R.; Ivanič, A. Biomimetic superhydrophobic concrete with enhanced anticorrosive, freeze-thaw, and deicing resistance. *Adv. Eng. Mater.* **2022**, *24*, 2101445. [CrossRef]
3. Cai, J.; Ran, Q.; Ma, Q.; Zhang, H.; Liu, K.; Zhou, Y.; Mu, S. Influence of a Nano-Hydrophobic Admixture on Concrete Durability and Steel Corrosion. *Materials* **2022**, *15*, 6842. [CrossRef] [PubMed]
4. Garcia-Lodeiro, I.; Gonzalez-Aguza, S.; Zarzuela, R.; Pardos, Y.; Garcia-Navarro, R.; Tébar, A.; Mosquera, M.J.; Blanco-Varela, M.T. Studying the dosage-dependent influence of hydrophobic alkoxysilane/siloxane admixtures on the performance of repair micromortars. *J. Build. Eng.* **2022**, *48*, 103905. [CrossRef]
5. Jahandari, S.Z.; Tao, Z.; Alim, M.A. Effects of different integral hydrophobic admixtures on the properties of concrete. In Proceedings of the 30th Biennial National Conference of the Concrete Institute of Australia, Perth, Australia, 5–8 September 2021.

6. Zhao, J.; Gao, X.; Chen, S.; Lin, H.; Li, Z.; Lin, X. Hydrophobic or superhydrophobic modification of cement-based materials: A systematic review. *Compos. Part B Eng.* **2022**, *243*, 110104. [CrossRef]
7. Wu, Y.; Dong, L.; Shu, X.; Yang, Y.; She, W.; Ran, Q. A review of recent advances in the fabrication and evaluation of superhydrophobic concrete. *Compos. Part B Eng.* **2022**, *237*, 109867. [CrossRef]
8. Fu, Q.; Zhang, Z.; Zhao, X.; Xu, W.; Niu, D. Effect of nano calcium carbonate on hydration characteristics and microstructure of cement-based materials: A review. *J. Build. Eng.* **2022**, *50*, 104220. [CrossRef]
9. Vaghela, A.; Vesmawala, G. DIC analysis of nano concrete using functionalized and dispersed carbon nanotubes. *Mater. Today Proc.* **2022**, *57*, 812–817. [CrossRef]
10. Zhao, Z.; Qi, T.; Zhou, W.; Hui, D.; Xiao, C.; Qi, J.; Zheng, Z.; Zhao, Z. A review on the properties, reinforcing effects, and commercialization of nanomaterials for cement-based materials. *Nanotechnol. Rev.* **2020**, *9*, 303–322. [CrossRef]
11. Zhao, L.; Guo, X.; Song, L.; Song, Y.; Dai, G.; Liu, J. An intensive review on the role of graphene oxide in cement-based materials. *Constr. Build. Mater.* **2020**, *241*, 117939. [CrossRef]
12. Vinchhi, P.; Patel, J.K.; Patel, M.M. High-pressure homogenization techniques for nanoparticles. In *Emerging Technologies for Nanoparticle Manufacturing*; Springer International Publishing: Cham, Switzerland, 2021; pp. 263–285.
13. Velusamy, S.; Subbaiyyan, A.; Ramasamy, K.; Shanmugamoorthi, M.; Vellingiri, V.; Chandrasekaran, Y.; Murugesan, V. Use of Municipal solid waste inert as a powerful replacement of fine aggregate in mortar cube. *Mater. Today Proc.* **2022**, *65*, 549–553. [CrossRef]
14. Hwangbo, S.A.; Kwak, M.; Kim, J.; Lee, T.G. Novel Surfactant-Free Water Dispersion Technique of TiO_2 NPs Using Focused Ultrasound System. *Nanomaterials* **2021**, *11*, 427. [CrossRef] [PubMed]
15. Arunkumar, G.E.; Nirmalkumar, K.; Loganathan, P.; Sampathkumar, V. Concrete Constructed with Recycled Water to Experimental Analysis of the Physical Behavior of Polypropylene Aggregate (PPA). *Glob. Nest J.* **2023**, *25*, 126–135.
16. Sargam, Y.; Wang, K.; Tsyrenova, A.; Liu, F.; Jiang, S. Effects of anionic and nonionic surfactants on the dispersion and stability of nanoSiO_2 in aqueous and cement pore solutions. *Cem. Concr. Res.* **2021**, *144*, 106417. [CrossRef]
17. Krishnaraja, A.R.; Kulanthaivel, P.; Ramshankar, P.; Wilson, V.H.; Palanisamy, P.; Vivek, S.; Sampathkumar, V.; Ganeshan, P.; Sashikkumar, M.C.; Raja, K.; et al. Performance of polyvinyl alcohol and polypropylene fibers under simulated cementitious composites pore solution. *Adv. Mater. Sci. Eng.* **2022**, *2022*, 9669803. [CrossRef]
18. Kowalczyk, D.; Kaminska, I. Effect of pH and surfactants on the electrokinetic properties of nanoparticles dispersions and their application to the PET fibres modification. *J. Mol. Liq.* **2020**, *320*, 114426. [CrossRef]
19. Kumaraswamy, A.S.; Nirmalkumar, K.; Sampathkumar, V.; Karthikeyan, S. Experimental Study on the Usage of Eco-friendly and Recyclable Helical Springs as dampers in Earthquake Resistance Construction. *J. Environ. Prot. Ecol.* **2022**, *23*, 616–623.
20. Zhang, P.; Su, J.; Guo, J.; Hu, S. Influence of carbon nanotube on properties of concrete: A review. *Constr. Build. Mater.* **2023**, *369*, 130388. [CrossRef]
21. Shanmughan, S.; Velusamy, S.; Nallasamy, J.L.; Selvakumar, K.P.; Thirumoorthy, P.; Saravanan, M.M.; Sakthivel, H.; Periyasamy, M.; Kasirajan, R. Critical study on corrosion inhibitors in U-shaped RCC beams. *Adv. Mater. Sci. Eng.* **2022**, *2022*, 4762524. [CrossRef]
22. Barhoum, A.; Pal, K.; Rahier, H.; Uludag, H.; Kim, I.S.; Bechelany, M. Nanofibers as new-generation materials: From spinning and nano-spinning fabrication techniques to emerging applications. *Appl. Mater. Today* **2019**, *17*, 1–35. [CrossRef]
23. Shanmugamoorthy, M.; Velusamy, S.; Subbaiyyan, A.; Yogeswaran, R.; Krishnanbabu, R.; Senthilkumar, R. Obtaining high durability strength using bacteria in light weight concrete. *Mater. Today Proc.* **2022**, *65*, 920–924. [CrossRef]
24. Palanisamy, C.; Velusamy, S.; Krishnaswami, N.; Manickam, K.; Rathinasamy, L.; Annamalai, I. Experimental investigation on self-compacting concrete with waste marble and granite as fine aggregate. *Mater. Today Proc.* **2022**, *65*, 1900–1907. [CrossRef]
25. Krishnaswami, N.; Velusamy, S.; Palanisamy, C.; Govindharajan, G.; Elanchezhiyan, G.; Ravi, G. Experimental studies on recycled E-waste by using coarse aggregate in concrete. *Mater. Today Proc.* **2022**, *65*, 1996–2002. [CrossRef]
26. Sharma, R.; Kar, K.K. Characteristics of carbon nanofibers. In *Handbook of Nanocomposite Supercapacitor Materials I: Characteristics*; Springer: Cham, Switzerland, 2020; pp. 215–245.
27. Nandhini, V.; Ambika, D.; Kumar, V.S.; Priya, S.D.; Poovizhi, G.; Rubini, V.S. An analysis on low cost and energy efficient materials for sustainable housing. *Int. J. Eng. Trends Technol.* **2020**, *68*, 88–96.
28. Kim, H.; Sharma, R.; Pei, J.; Jang, J.G. Effect of carbonation curing on physicochemical properties of mineral admixture blended belite-rich cement. *J. Build. Eng.* **2022**, *56*, 104771. [CrossRef]
29. Liu, S.; Shen, Y.; Wang, Y.; He, H.; Luo, S.; Huang, C. Synergistic use of sodium bicarbonate and aluminum sulfate to enhance the hydration and hardening properties of Portland cement paste. *Constr. Build. Mater.* **2021**, *299*, 124248. [CrossRef]
30. de Souza Oliveira, A.; Gomes, O.D.F.M.; Ferrara, L.; Fairbairn, E.D.M.R.; Toledo Filho, R.D. An overview of a twofold effect of crystalline admixtures in cement-based materials: From permeability-reducers to self-healing stimulators. *J. Build. Eng.* **2021**, *41*, 102400. [CrossRef]
31. Raghav, M.; Park, T.; Yang, H.M.; Lee, S.Y.; Karthick, S.; Lee, H.S. Review of the Effects of Supplementary Cementitious Materials and Chemical Additives on the Physical, Mechanical, and Durability Properties of Hydraulic Concrete. *Materials* **2021**, *14*, 7270. [CrossRef]
32. Carneiro, L.D.R.S.; Houmard, M.; Ludvig, P. Recent Advances and New Discussions on Superhydrophobic Coatings and Admixtures Applied to Cementitious Materials. *Open Constr. Build. Technol. J.* **2020**, *14*, 400–409. [CrossRef]

33. She, W.; Yang, J.; Hong, J.; Sun, D.; Mu, S.; Miao, C. Superhydrophobic concrete with enhanced mechanical robustness: Nanohybrid composites, strengthen mechanism and durability evaluation. *Constr. Build. Mater.* **2020**, *247*, 118563. [CrossRef]
34. Di Mundo, R.; Labianca, C.; Carbone, G.; Notarnicola, M. Recent advances in hydrophobic and icephobic surface treatments of concrete. *Coatings* **2020**, *10*, 449. [CrossRef]
35. She, W.; Wang, X.; Miao, C.; Zhang, Q.; Zhang, Y.; Yang, J.; Hong, J. The biomimetic superhydrophobic surface of concrete: Topographic and chemical modification assembly by direct spray. *Constr. Build. Mater.* **2018**, *181*, 347–357. [CrossRef]
36. Yin, B.; Xu, T.; Hou, D.; Zhao, E.; Hua, X.; Han, K.; Zhang, Y.; Zhang, J. Superhydrophobic anticorrosive coating for concrete through in-situ bionic induction and gradient mineralization. *Constr. Build. Mater.* **2020**, *257*, 119510. [CrossRef]
37. Shaheen, N.; Khushnood, R.A.; Khaliq, W.; Murtaza, H.; Iqbal, R.; Khan, M.H. Synthesis and characterization of bio-immobilized nano/micro inert and reactive additives for feasibility investigation in self-healing concrete. *Constr. Build. Mater.* **2019**, *226*, 492–506. [CrossRef]
38. Liu, H.; Jiang, T.; Wang, F.; Ou, J.; Li, W. Thermochromic superhydrophobic coatings for building energy conservation. *Energy Build.* **2021**, *251*, 111374. [CrossRef]
39. Kazemi, M.; Wang, H.; Fini, E. Bio-based and Nature Inspired Solutions: A Step Toward Carbon-neutral Economy. *J. Road Eng.* **2022**, *2*, 221–242. [CrossRef]
40. Rabajczyk, A.; Zielecka, M.; Klapsa, W.; Dziechciarz, A. Self-Cleaning Coatings and Surfaces of Modern Building Materials for the Removal of Some Air Pollutants. *Materials* **2021**, *14*, 2161. [CrossRef]
41. Zhu, Y.; Li, H.; Zhu, M.; Wang, H.; Li, Z. Dynamic and active anti scaling via scale inhibitor pre-stored superhydrophobic coating. *Chem. Eng. J.* **2021**, *403*, 126467. [CrossRef]
42. Khairuddin, F.M.; Rashid, A.A.; Leo, C.P.; Lim, G.K.; Ahmad, A.L.; Lim, H.M.; Tan, I.C.S. Recent progress in superhydrophobic rubber coatings. *Prog. Org. Coat.* **2022**, *171*, 107024. [CrossRef]
43. Douba, A.; Hou, P.; Kawashima, S. Hydration and mechanical properties of high content nano-coated cements with nano-silica, clay and calcium carbonate. *Cem. Concr. Res.* **2023**, *168*, 107132. [CrossRef]
44. Zajac, M.; Irbe, L.; Bullerjahn, F.; Hilbig, H.; Haha, M.B. Mechanisms of carbonation hydration hardening in Portland cements. *Cem. Concr. Res.* **2022**, *152*, 106687. [CrossRef]
45. Singh, G.; Saini, B. Nanomaterial in cement industry: A brief review. *Innov. Infrastruct. Solut.* **2022**, *7*, 45. [CrossRef]
46. He, B.; Gao, Y.; Qu, L.; Duan, K.; Zhou, W.; Pei, G. Characteristics analysis of self-luminescent cement-based composite materials with self-cleaning effect. *J. Clean. Prod.* **2019**, *225*, 1169–1183. [CrossRef]
47. Sharma, V.; Goyat, M.S.; Hooda, A.; Pandey, J.K.; Kumar, A.; Gupta, R.; Upadhyay, A.K.; Prakash, R.; Kirabira, J.B.; Mandal, P.; et al. Recent progress in nano-oxides and CNTs based corrosion resistant superhydrophobic coatings: A critical review. *Prog. Org. Coat.* **2020**, *140*, 105512. [CrossRef]
48. Bai, W.; Liu, J.; Qi, S. Preparation of Superhydrophobic Coating on Q235 Steel and its Corrosion Resistance in Simulated Concrete Pore Solution. *Int. J. Electrochem. Sci.* **2022**, *17*, 2. [CrossRef]
49. Filippovich, S.Y.; Bachurina, G.P. Antifungal Surfaces. *Appl. Biochem. Microbiol.* **2022**, *58*, 507–517. [CrossRef]
50. Cao, M.; Ming, X.; He, K.; Li, L.; Shen, S. Effect of macro-, micro- and nano-calcium carbonate on properties of cementitious composites—A review. *Materials* **2019**, *12*, 781. [CrossRef]
51. Seifan, M.; Berenjian, A. Microbially induced calcium carbonate precipitation: A widespread phenomenon in the biological world. *Appl. Microbiol. Biotechnol.* **2019**, *103*, 4693–4708. [CrossRef]
52. Li, L.; Cao, M.; Yin, H. Comparative roles between aragonite and calcite calcium carbonate whiskers in the hydration and strength of cement paste. *Cem. Concr. Compos.* **2019**, *104*, 103350. [CrossRef]
53. Mozafari, M.; Banijamali, S.; Baino, F.; Kargozar, S.; Hill, R.G. Calcium carbonate: Adored and ignored in bioactivity assessment. *Acta Biomater.* **2019**, *91*, 35–47. [CrossRef]
54. Cao, M.; Ming, X.; Yin, H.; Li, L. Influence of high temperature on strength, ultrasonic velocity and mass loss of calcium carbonate whisker reinforced cement paste. *Compos. Part B Eng.* **2019**, *163*, 438–446. [CrossRef]
55. d'Amora, M.; Liendo, F.; Deorsola, F.A.; Bensaid, S.; Giordani, S. Toxicological profile of calcium carbonate nanoparticles for industrial applications. *Colloids Surf. B Biointerfaces* **2020**, *190*, 110947. [CrossRef] [PubMed]
56. Li, L.; Cao, M.; Ming, X.; Yin, H.; Sun, Y.N. Microstructure of calcium carbonate whisker reinforced cement paste after elevated temperature exposure. *Constr. Build. Mater.* **2019**, *227*, 116609. [CrossRef]
57. Li, Y.; Mi, T.; Liu, W.; Dong, Z.; Dong, B.; Tang, L.; Xing, F. Chemical and mineralogical characteristics of carbonated and uncarbonated cement pastes subjected to high temperatures. *Compos. Part B Eng.* **2021**, *216*, 108861. [CrossRef]
58. Ming, X.; Cao, M.; Lv, X.; Yin, H.; Li, L.; Liu, Z. Effects of high temperature and post-fire-curing on compressive strength and microstructure of calcium csssarbonate whisker-fly ash-cement system. *Constr. Build. Mater.* **2020**, *244*, 118333. [CrossRef]
59. Bayer, I.S. Superhydrophobic coatings from eco-friendly materials and processes: A review. *Adv. Mater. Interfaces* **2020**, *7*, 2000095. [CrossRef]
60. Wang, F.; Xie, T.; Ou, J.; Xue, M.; Li, W. Cement-based superhydrophobic coating with excellent robustness and solar reflective ability. *J. Alloys Compd.* **2020**, *823*, 153702. [CrossRef]
61. Wang, H.; Lu, Z.; Wang, F.; Li, Y.; Ou, Z.; Jiang, J. A novel strategy to reinforce double network hydrogels with enhanced mechanical strength and swelling ratio by nano cement hydrates. *Polymer* **2023**, *269*, 125725. [CrossRef]

62. Vergara, L.A.; Colorado, H.A. Additive manufacturing of Portland cement pastes with additions of kaolin, superplastificant and calcium carbonate. *Constr. Build. Mater.* **2020**, *248*, 118669. [CrossRef]
63. Cao, M.; Li, L.; Yin, H.; Ming, X. Microstructure and strength of calcium carbonate ($CaCO_3$) whisker reinforced cement paste after exposed to high temperatures. *Fire Technol.* **2019**, *55*, 1983–2003. [CrossRef]
64. Liu, W.; Li, Y.Q.; Tang, L.P.; Dong, Z.J. XRD and 29Si MAS NMR study on carbonated cement paste under accelerated carbonation using different concentration of CO_2. *Mater. Today Commun.* **2019**, *19*, 464–470. [CrossRef]
65. Shilar, F.A.; Ganachari, S.V.; Patil, V.B. Advancement of nano-based construction materials—A review. *Constr. Build. Mater.* **2022**, *359*, 129535. [CrossRef]
66. Allujami, H.M.; Abdulkareem, M.; Jassam, T.M.; Al-Mansob, R.A.; Ng, J.L.; Ibrahim, A. Nanomaterials in recycled aggregates concrete applications: Mechanical properties and durability. A review. *Cogent Eng.* **2022**, *9*, 2122885. [CrossRef]
67. Kumar, S.S.A.; Bashir, S.; Ramesh, K.; Ramesh, S. A comprehensive review: Super hydrophobic graphene nanocomposite coatings for underwater and wet applications to enhance corrosion resistance. *Flat Chem.* **2022**, *31*, 100326. [CrossRef]
68. Okeke, E.S.; Ezeorba, T.P.C.; Mao, G.; Chen, Y.; Feng, W.; Wu, X. Nano-enabled agrochemicals/materials: Potential human health impact, risk assessment, management strategies and future prospects. *Environ. Pollut.* **2022**, *295*, 118722. [CrossRef]
69. Tri, P.N.; Nguyen, T.V. Radically curable nano-based coatings. In *Nanomaterials-Based Coatings*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 339–372.
70. Okoro, E.E.; Josephs, R.; Sanni, S.E.; Nchila, Y. Advances in the use of nanocomposite membranes for carbon capture operations. *Int. J. Chem. Eng.* **2021**, *2021*, 6666242. [CrossRef]
71. Singh, V.; Upadhyay, S. Nanotechnological Revolution: Carbon-Based Nanomaterials Detecting Pollutants. In *Nanotechnology for Environmental Pollution Decontamination*; Apple Academic Press: Palm Bay, FL, USA, 2022; pp. 101–134.
72. Lei, L.; Wang, Q.; Xu, S.; Wang, N.; Zheng, X. Fabrication of superhydrophobic concrete used in marine environment with anti-corrosion and stable mechanical properties. *Constr. Build. Mater.* **2020**, *251*, 118946. [CrossRef]
73. Xu, K.; Ren, S.; Song, J.; Liu, J.; Liu, Z.; Sun, J.; Ling, S. Colorful superhydrophobic concrete coating. *Chem. Eng. J.* **2021**, *403*, 126348. [CrossRef]
74. Xu, S.; Wang, Q.; Wang, N.; Qu, L.; Song, Q. Study of corrosion property and mechanical strength of eco-friendly fabricated superhydrophobic concrete. *J. Clean. Prod.* **2021**, *323*, 129267. [CrossRef]
75. Song, J.; Li, Y.; Xu, W.; Liu, H.; Lu, Y. Inexpensive and non-fluorinated superhydrophobic concrete coating for anti-icing and anti-corrosion. *J. Colloid Interface Sci.* **2019**, *541*, 86–92. [CrossRef]
76. Xiang, T.; Liu, J.; Lv, Z.; Wei, F.; Liu, Q.; Zhang, Y.; Ren, H.; Zhou, S.; Chen, D. The effect of silicon-based waterproof agent on the wettability of superhydrophobic concrete and enhanced corrosion resistance. *Constr. Build. Mater.* **2021**, *313*, 125482. [CrossRef]
77. Zhao, Y.; Lei, L.; Wang, Q.; Li, X. Study of superhydrophobic concrete with integral superhydrophobicity and anti-corrosion property. *Case Stud. Constr. Mater.* **2023**, *18*, 01899. [CrossRef]
78. Fang, Y.; Wang, J.; Wang, X.; Amaral, M.L.D.; Kniffin, H.; Reed, M.; Wang, L.; Qian, X. Bio-Based Admixture (Black Tea Extraction) for Better Performance of Metakaolin Blended Cement Mortars. *Materials* **2022**, *15*, 3994. [CrossRef] [PubMed]
79. Song, Q.; Wang, Q.; Xu, S.; Mao, J.; Li, X.; Zhao, Y. Properties of water-repellent concrete mortar containing superhydrophobic concrete. *Constr. Build. Mater.* **2022**, *337*, 127423. [CrossRef]
80. Zhang, Y.; Zhang, Z.; Yang, J.; Yue, Y.; Zhang, H. Fabrication of superhydrophobic surface on stainless steel by two-step chemical etching. *Chem. Phys. Lett.* **2022**, *797*, 139567. [CrossRef]
81. Procházka, L.; Boháčová, J.; Vojvodíková, B. Effect of Admixtures on Durability and Physical-Mechanical Properties of Alkali-Activated Materials. *Materials* **2022**, *15*, 2010. [CrossRef]
82. Lagouin, M.; Laborel-Préneron, A.; Magniont, C.; Geoffroy, S.; Aubert, J.E. Effects of organic admixtures on the fresh and mechanical properties of earth-based plasters. *J. Build. Eng.* **2021**, *41*, 102379. [CrossRef]
83. Park, B.; Choi, Y.C. Effect of healing products on the self-healing performance of cementitious materials with crystalline admixtures. *Constr. Build. Mater.* **2021**, *270*, 121389. [CrossRef]
84. Nazarenko, O.B.; Amelkovich, Y.A.; Bannov, A.G.; Berdyugina, I.S.; Maniyan, V.P. Thermal Stability and Flammability of Epoxy Composites Filled with Multi-Walled Carbon Nanotubes, Boric Acid, and Sodium Bicarbonate. *Polymers* **2021**, *13*, 638. [CrossRef]