MULTISCIA
JOURNALS PUBLISHERS

FRONTIERS IN CIVIL ENGINEERING AND CONSTRUCTION MATERIALS

ISSN: (3065- 4181)

editor.fcecm@gmail.com

https://multisciajournals.com/journals/index.php/fcecm

Frontiers in Civil Engineering and Construction Materials

Volume 1 Issue 3 2025

REVIEW OF NEW DEVELOPMENTS IN THE INDUSTRY OF CIVIL ENGINEERING MATERIALS

Waqas Mansouri[1], Mehmood[2]
Department of Civil

Article Info

Received: 30-06-2025 Revised:08-09-2025 Accepted:19-09-2025 Published:29-09-2025

Abstract. The aim of this research paper is to address the futuristic construction materials. Relevant data of the developments made during the recent past are also presented. It is believed that nanotechnology is going to play an important role in the development of futuristic building materials. The innovations could be two-fold; one is the modification of classical materials and the other should cover the invention of novel materials. The primary goal of all such materials should be environment friendliness. Secondarily, they should be durable and cost effective. Thirdly, they should address the space shortage. Innovations are needed as man is also plan- ning to colonize moon and other planets. Fourthly, they should have adequate strength to cater the natural and manmade calamities. In short, they should serve the coming generations in the best possible way, which is the sole purpose of an engineering discipline.

INTRODUCTION

The foundation of civil engineering is building materials. With the current human agenda including the colonization of space, they are essential building materials for almost every structure on Earth, as well as for roads, railways, airports, dams, and water reservoirs. They have been in use since ancient times, when people in the forest would construct them to protect themselves from the elements and wild animals. Temporary human dwellings in the past often only lasted a few days or months due to their simplicity. Humans began farming with the intention of creating longer-lasting dwellings for themselves and their livestock. More long-lasting materials such as clay, stone, and wood replaced bio-materials such as leaves, branches, etc., in later stages. The creation of artificial materials such as bricks, mortars, and concretes resulted from the quest for longer-lasting construction materials. metals. In the end, they settled on multi-story and multi-span structures as their ideal. They dreamed of more stronger materials to make their fantasy a reality. A new species evolved specifically to mine these resources for their usefulness in producing goods of the highest quality. The idea of creating a controlled atmosphere inside the structures was also considered in another study. Air quality control encompasses a wide range of functions, including temperature, lighting, noise, humidity, and odor. A global industrial revolution occurred last century. It brought enormous environmental concerns with it, despite the many advantages it gave to humanity. When it comes to civil engineering, the use of synthetic materials such as brick, concrete, metals, and plastics has also contributed to pollution. Developing future construction materials with a careful eye on avoiding adding to human suffering by creating health and environmental hazards is an urgent need.

1. FUTURISTIC MATERIALS

1.1. Nanomaterials

When it comes to particles, nanotechnology is the subfield of materials science that focuses on those with dimensions in the nanometer range (10-9 m). It is well-established that materials exhibit very distinctive properties at such a microscopic scale, distinct from their micro and macro equivalents [1]. While copper is a malleable metal at greater sizes, it becomes an excellently hard substance at the nanoscale [2]. Also, compared to bulk gold's melting point of 1064 °C, Nano Gold's is a much lower 300 °C [3,4]. Engineers and scientists from various walks of life have been drawn to them because of their distinctive qualities, which they hope will be useful in their respective professions. Same thing happened in civil engineering, when professionals were convinced that nanoparticles might provide better results. Cement and supplementary cementitious materials play a crucial role in civil engineering. The foundation of civil engineering is cementitious materials [5]. The most common ones are cement paste, concrete, and mortar. Common examples of SCM include silica fumes, fly ash, ground granulated blast furnace slag, sugar cane bagasse ash, and many industrial waste products. Among the many significant benefits of using SCMs in concrete are the following: It helps concrete achieve certain additional advantages including strength, workability, impermeability, and resistance to chemical assault [5], and it also uses industrial waste to decontaminate the environment. Thanks to the hydration reaction, a chemical process involving cement compounds and water, cementitious materials acquire strength in about one month. Both the primary and secondary cementitious materials' surface-to-volume ratios have a significant role in these well-known tribological processes [6]. The increased hydration that should result in greater initial and end strengths should be caused by the larger surface to volume ratio of nano particles compared to their micro counterparts [7]. Nanoparticles' interactions with concrete have been the subject of much study throughout the last decade. Carbon nano tubes (CNTs), nano-silica, nano-titania, nano-clay, and nano food additives are all now part of the concrete mix. CNTs are intended mainly for strength enhancement and crack arrest, nano-titania for self-cleaning char- acteristics, nano-silica for chemical resistance, nano-clay for enhanced rheological qualities and additions to nano-sized foods to reduce the rate of hostile species diffusion in the pores of concrete [8-12]. Nano building materials operate in two ways: Nanoscale grinding of already-existing materials, such as cement, or direct inclusion into pre-existing materials, such as concrete and paint. The particles of nano cement are only a few nanometers in size. The issue of construction materials' strengths and densities is quite current. Regrettably, increased dead weight is a side effect of increased strength, which is accompanied by increased density. During the past few years, it has been well established that nano materials owing to their higher strength and lower density are very useful for con- struction industry [13]. Coatings and paints are another category of construction materials that might benefit greatly from nanotechnology. Highly durable paints incorporating nanomaterials could be prepared. Paints are basi- cally composed of a few components: Base for giv- ing them a body, vehicle for its flow over surface, binder for sticking to the surface, viscosity adjuster and drier for quick drying [7]. The life of all the paints is limited due to its interactions with the surround- ing environment. Titania or Titanium dioxide is be- ing used since early 1900s for pigmentary purposes. It gives brightness and opacity to paints [14]. Nano titania particles have found to be more stable than its micro and macro matching parts. Moreover, they possess photocatalytic properties [15]. Recent re- search claims that nanotitania-paints are photocata- lytic and possess much longer life span [16].Aggressive elements like chlorides greatly af- fect the durability of reinforced concrete structures. Chlorides penetrate in concrete through its pores via well-know diffusion phenomenon. Beyond some threshold values, they initiate and propagate the rusting of embedded steel, which cost billions of dollars to construction industry each year [17-19]. At National Institute of Standards and Technology (NIST) USA, the engineers have introduced a new technique called Viscosity Enhancers Reducing Diffusion in Concrete Technology (VERDICT). This technique involves the addition of nano-sized food additives inside the pores of concrete, which con- sequently enhances the viscosity of porous solu- tion and therefore, decreases the diffusion rates of the species [20]. Steel, an iron-carbon alloy is the second most important building material after cementitious materials. It has high tensile strength, but its resistance to corrosion and high density are the issues of concern for civil engineers [12]. CNTs possess very high tensile strength, in fact 100 times more than that of an ordinary steel with about six times lesser density [21]. In USA, FHWA, Ameri- can Iron and Steel Institute, and the U.S. Navy de- veloped a new steel by incorporating in it copper nano-particles; the new manufactured steel has considerably higher corrosion-resistance and weldability [22]. MMFX2 is another nano-modified steel having a laminated lath type structure like ply- wood. It is claimed that MMFX2 has enhanced duc- tility, toughness, corrosion resistance [23].

1.2. Biological materials

Crack formation in concrete is a commonly observed phenomenon. As far as micro cracks are concerned, they do not change the structural properties of con- crete significantly, however the ingression of aggres- sive substances due to increased permeability may significantly decrease the durability of structures in long term [24]. This risk is even more when con- crete structures are exposed to the moist environ- ment [25]. With the passage of time, these cracks may enlarge, further increasing the permeability of concrete and causing more damage to the struc- tures [26]. Another risk is the enlargement of these micro cracks to the position of reinforcement; this way not only concrete but embedded reinforcement will also be affected when exposed to the water and oxygen [27].

Methods usually adapted for the remediation of cracks are often based on the usage of synthetic polymers that need to be applied repeatedly and are not environment friendly [28]. Currently, more ecologically friendly methods have been recom- mended and within this framework, bacterial induced carbonate mineralization has been proposed as a novel and environment friendly technique for the healing of cracks: The technique is known as Auto- genic healing [29]. The basic mechanism of auto- genic healing is based on several physical, chemi- cal and mechanical processes. However the forma- tion of calcium carbonate is the most contributing factor in this regard [26,30].

Several bacteria have the ability to heal micro cracks and these bacteria can be traced in soil, sand and several other natural minerals [27]. For this purpose, bacterial spores, calcium lactate and nutrients have been introduced in concrete by em- bedding them in capsules to prevent interaction before the development of cracks. When cracks develop, the spores become active on interaction with water and make limestone out of calcium lac- tate and nutrients. This limestone fills up the cracks and prevents further movement of water in the con- crete [31].

In an experimental study, a two component bio- chemical self healing agent was introduced in con- crete by embedding it in porous clay particles, which replaced a portion of the concrete. Experimental results showed crack-healing of up to 0.46 mm width in bacterial concrete as compared to 0.18 mm in control specimens after 100 days of submersion in water [25]. It is also observed that the treatment of concrete cracks with bacteria results in a very lim- ited change in the chromatic aspect of the concrete surface as opposed to conventional techniques [29]. The viability of bacterial treatment was a question of concern for the researchers. In a study using Bacillus spores, it

was found that the bacteria re- mained viable for up to 4 months. Actually, as set- ting of cement stone paste occurs, pore diameter in concrete decreases considerably; a phenomenon which limits the life span of spores [31]. Tempera- ture dependency of bacterial treatment was another factor widely studied during the past decade. Tests have shown that the efficacy of this technique in- creases with rise in temperature [32].

Concrete porous solution is alkaline in nature
having pH more than 12 [4]. It is observed that an environmental pH value of more than 12 sufficiently reduces the activity of bacterial spores [33]. Fol- lowing that it was argued to introduce the bacteria via exclusively selected carriers. Silica gel and poly- urethane were used as carriers, which provided sat- isfactory results, with silica gel being the superior one [34].

In the recent years, increasing interest towards regain of mechanical properties in healed concrete is seen. No doubt, the self healing mechanism im- proves the mechanical properties of the concrete; for example, the resonance frequency of ultra high strength concrete damaged by freeze-thaw action showed a significant improvement after undergoing self healing mechanism [35]. Moreover, according to Ramachandran et al. microbiologically induced calcium carbonate had been proved to increase the compressive strength of mortar cubes [36]. Similar outcome was achieved in another study where com- pressive strength of mortar samples having bio based agents at 7, 28, and 56 days showed con- siderable improvements. As far as deflection of con- crete is concerned, after cracking and healing the mixtures with bio-based healing agent showed a slightly better recovery of both flexural strength and deflection capacity from control mixtures without bio- based healing agent [37]. Besides the improvement in the physical properties of concrete, biological repair technique is also appealing as microbial ac- tivity is free from pollution; thereby giving a very sus- tainable solution against cracks [38].

Besides, water interaction based healing of con- crete, the filling up of cracks in dry conditions is also essential to be achieved. For this purpose vari- ous techniques are available. One technique is to fill healing agent in hollow plant fibers which have large storage volume for liquids thus act as a reser- voir for a healing agent. Another technique is to in- troduce water filled Super Absorbent Polymers in concrete mix. These polymers form water pockets which are used as hydration of cement and after- wards for self healing of concrete. If all water is con- sumed in hydration of cement, rains on the struc- ture once again fill up these SAPs thus fulfilling the requirement of self healing [37].

1.3. Super hydrophobic coatings

Dampness and leaks are prevalent issues for all kinds of buildings. People often say that water is the building's worst nightmare. It is a major worry because, if left unchecked, it may have catastrophic outcomes. Because of its importance in preventing leaks and moisture, water proofing is a key component in making concrete constructions long-lasting [39]. In order to construct waterproof constructions, many traditional methods are modified. Membranes, paints, polymeric coatings, and admixtures are all part of this category [40,41]. The lack of attraction for water is represented by the material quality known as hydrophobicity. Among the many types of hydrophobic materials are alkanes, oils, lipids, and greasy compounds [42]. Superhydrophobic surfaces, in contrast, are notoriously resistant to water. As an illustration of this point, consider the lotus leaf [43]. A great deal of research and development into ultra hydrophobic coatings has occurred in recent years: These include a wide range of materials, such as nano-silica coatings, precipitated calcium carbonate, nano-composites of manganese oxide and zinc oxide, and carbon nanotube structured coatings. Their durability has been confirmed by testing with aerosol spray. Although polystyrene coatings have many practical uses, they may be somewhat expensive [44]. One possible solution to the problem of moisture sensitivity is to make the surface very water repellent. The rough texture of self-cleaning lotus leaves has been used as a model for the generation of water-repellent surfaces for other materials. Air may be trapped between water droplets and the surface thanks to the structure of the leaves. A highly water-repellent surface may be the result of this, since it contributes to decreased wetting and adhesion of water droplets to the surface [45]. Results have shown that enhanced hydrophobicity may be achieved by combining this surface structure with a hydrophobic outermost molecular layer. Super hydrophobic surfaces were created in various materials using various processes. A low surface energy material's surface roughness induced by oxygen plasma treatment, laser etching, or nano-casting is one of the topics covered in the study. Other research has detailed the idea of a desirable roughness achieved by electrochemical particle deposition or etching, which was then reinforced with a material with a low surface energy [46]. Surface structures like this have been synthesized in a number of investigations using silica nanoparticles, various polymer binders, and hydrophobic agents. Surface roughness and low surface energy may be combined to make something highly hydrophobic [46].A new ultra hydrophobic substance has been created by researchers at BYU in the USA [47]. Their argument is that structure is really contributed to the coating rather than the other way around. The BYU group developed two distinct Teflon surfaces: one with a rib-cavity structure that is a tenth the size of a human hair and another with micro-sized posts. It seems as if a spherical ball of water rests over it. The United States Department of Energy's Brookhaven

National Laboratory also conducts comparable research. Because of their capacity to absorb and disperse water, certain nano cone textures (such the small micro-sized posts mentioned earlier in BYU) are proposed here as a water-proofing material [48]. In addition to cones, additional forms such as columns and fibers are also suggested and evaluated [49]. At MIT USA, a superhydrophobic surface is created by the addi- tion of ridges to silicon surface [50].

1.4. Lunar materials

Several possibilities have been sorted out as to what should be the potential materials to make colonies at moon. Primarily concrete was chosen as the first point of debate. An ordinary concrete is a mixture of cement, sand, gravels and water. In Table 1, the chemical composition of ordinary Portland cement, terrestrial fly ash and lunar dust are given for the sake of reference [51-53].

Table 1. Chemical composition of cement, terrestrial fly ash and moon dust.

Component	Cement (% by mass)	Fly ash (% by mass)	Lunar dust (% by mass)
CaO	64.01	0.37-27.68	10
SiO_2	20.13	27.88-59.40	50
Al_2O_3	5.98	5.23-33.99	15
Fe_2O_3	2.35	1.21-29.63	5-15
MgO	1.19	0.42-8.79	10
SO_3	3.53	0.04-8.79	-
Na_2O	0.11	0.2-6.9	-
K_2O	0.77	0.64-6.68	-
TiO_2	0.37	0.24-1.73	5
LOI	1.63	0.21-28.37	-

It is evident that the chemical composition of lunar dust is much similar to that of fly ash at earth. Fly ash, a supplementary cementitious material, is frequently used as partial replacement of cement up to 15 percent. Thus lunar dust is a potential material for making concrete at the moon. The soils and rocks on moon have been found to possess specific gravities more than 2.6 [54]. This indicates that lunar rocks can be crushed to coarse aggre- gate size. Similarly the lunar soil can be sieved to obtain fine aggregates. So far cement itself is con- cerned, that is a point of concern, keeping in view that an ordinary Portland cement possesses a CaO content of typically 65% by mass whereas the high- est CaO content found in lunar soil is 19%. The last ingredient is water, which can either be sup- plied from the earth or by combining oxygen with hydrogen produced from the lunar soil [55]. There are also some other alternatives like using epoxy or sulfur as binder than cement and water [56].

Process of sulfur concrete manufacture comes under the domain hot technology. The mixed com- ponents are heated at 140-150 °C at which the sul- fur melts and when re-solidified acts as binder in the concrete mix. With sulfur, concretes with strength 60-115 MPa have been prepared, which is quite reasonable [57]. The use of sulfur eliminates the use of water for concrete. Sulfur ranks eleventh in mass abundance among the elements in aver- age lunar rocks about 0.16% to 0.27% [58]. Pres- ently, this amount of sulfur is not so abundant to be used at huge scale, however it might be utilized for first-stage construction at moon with further efforts to exploit more sulfur reserves at the lunar surface.

1.5. Security protective materials

Nanotechnology has also been credited to signifi- cantly revolutionize the issues related to the chemi- cal, biological, explosive and radiological threats. The advancement in the growth of widely ranged insightful nanotechnology-based sensors for chemi- cal, biological and explosive terrorization is in the offing [59]. Efficiency enabled by the nano-scale allows opportunities to integrate the capabilities of the sensors and detect the above threats in a single way. Many concepts for threat detection are still under the phase of commercial development [60]. For biological detection and sensing, it has been revealed that Silver clusters of nano-size when in solution form have different colors, depending on their severance. If appropriately chosen strands of DNA are attached to the clusters, the existence of comple- ments of strands can cause the clusters to be glued together and consequently change the color. A lower detection limit for this system for a 24 base single-stranded target has been demonstrated as 500 pM and for a duplex target nucleotide as 2.5 nM [61,62]. It might be of interest that in analytical chemistry, the lower limit of detection (LOD) is the lowest quan- tity of a substance that can be distinguished from the zero quantity within a certain confidence limit [63,64].

Chemical reactions constantly effect the tech-nology as well as different cycles of life when they occurs at nano-scale. Nano-structured materials are essential building units which are capable of acting as catalyst for chemical reactions by virtue of their adapted surface chemistries, surface areas are highly specific as well as the molecular have unique structures [65]. Recent developments have enabled the snare of nano- structured materials within the high porosity interior carrier networks, which are composed of sinter-locked micron diameter metal fibers. Computational methods for the redesign of the ligand-binding specificity of receptor proteins that can function as fluorescent, electrochemical or cellular biosensors have been developed and experi- mentally tested [66]. The eventual objective is to redesign a binding site for any ligand within a cer- tain molecular weight range, and to apply this ca- pacity to the construction of robust, reagent-less biosensors for the continuous, immediate detection of explosives and chemical and biological warfare agents.

The combined computational and experi- mental methodologies provide a radical potential to design, construct and deploy sensors for newly iden- tified threats within 7-10 days [67,68].

2. CONCLUSIONS

It is worth noting that Nobel laureate Richard Feyman famously said, "There is plenty of room at the bottom," when addressing the future of civil engineering materials [69]. The building sector stands to benefit greatly from the improvements that nanotechnology might bring about. A plethora of novel materials have been developed or are in the works via the use of nanotechnology. High ultra strength concrete and self-cleaning concrete are two fantastic examples of future materials created utilizing nanotechnology. This is because nanosized materials have a better surface to volume ratio than larger ones. These materials may solve many of the design, environmental, and security issues that plague their micro and macro equivalents, according to the reports. Historically, engineering has been thought of as the field that makes use of the hard sciences to create more complex civil engineering materials, but recently, biotechnology has also been used in this field. As they work to create materials for usage beyond Earth, specialists are also trying to reduce the amount of natural resources used. Regardless, research into creating new construction materials is ongoing. It has long been recognized that understanding the smallest details is bringing about massive transformations, which in turn are bringing several economic advantages to the building sector.

REFERENCES

[1] Nanotechnology in Civil Infrastructure, by K. Gopalakrishnan. The Change of a Paradigm (Springer Press, 2011). (Springer, Germany, 2007) by B.D. Fahlman, Materials Chemistry.Rashid Sardar, Alexandra M. Funston, Patrick Mulvaney, and Article published in 2009 by R.W. Murray in Langmuir, volume 25, page 13840. The book "Properties of Concrete" by A.M. Neville was published in 2011 by Pearson Education. [5] Written by A. Khitab, M.T. Arshad, F.M. Awan, and I. Khan // International Journal of Sustainable Volume 4, Issue 33, 2013 of Construction Engineering & Technology. 6. In Applied Mineralogy of Cement and Concrete: Reviews in Mineralogy & Geochemistry 74 (Mineralogical Society of America, 2013), authors M.A.T.M. Broekmans and H. Pöllmann discuss the field. Allied Books, Pakistan, 2012, author A. Khitab, lists construction materials as both classical and novel. Cement & Concrete Composites 32 (2010) 110 by M.S. Konsta-Gdoutos, Z.S. Metaxa, and S.P. Shah [8]. Building and Environment, volume 44, issue 9, pages 2463, by G. Hüsken, M. Hunger, and H.J.H. Brouwers. In: Proceedings of the Twenty-third International Offshore and Polar Engineering (Anchorage, Alaska, USA, 2013), L.V. Kim, V.V. Potapov, A.N. Kashutin, V.A. Gorbach, K.S. Shalaev and D.S. Gorev [10] published. "International Journal of Engineering Research and Applications" (Volume 2, Issue 2, 2012) by K.Patel (1682). In 2009, D.P. Bentz, M.A. Peltz, K.A. Snyder, and J.M. Davis published an article in Concrete International, volume 31, page 31. The authors of the cited article are Z. You, J. Mills-Beale, J.M. Folev, S. Roy, G.M. Odegard, O. Dai, and S.W. Goh. The article was published in Building and Construction Materials in 2011. [14] In Rev. Adv. Mater. Sci. 38 (2014) 181, A. Khitab and M.T. Arshad discuss. The authors of the cited article are Quagliarini, Bondioli, Goffredo, Cordoni, and Munaf, and the publication year is 2012. In their 2009 article "Building and Environment," Chen and Poon cite a source from 1899.The paper "Concrete that cleans itself and the environment" by M. Barbesta and D. Schaffer from 2009 may be accessed online at http://txactive.us/images/ concrete_international.pdf. [18] in (L. Nilsson, 2001) Nordic Mini Seminar and fib TG 5.5 conference, Gothenburg, Sweden.

The modeling of ionic transport in saturated porous media was published in a dissertation by A. Khitab in 2005 by the National Institute of Applied Sciences in Toulouse, France. N. Silva's 2013 dissertation on chloride-induced corrosion of concrete reinforcement steel was completed at Chalmers University of Technology in Gothenburg, Sweden. This information is sourced from the work of M.D. Arafa, C. DeFazio, and B. Balaguru, which was presented at the 2005 Bilbao International Symposium on Nanotechnology in Construction.