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# FUTURE OF CIVIL ENGINEERING MATERIALS: A REVIEW FROM RECENT DEVELOPMENTS

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**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 planning 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.

## 1. INTRODUCTION

Building materials are the backbone of civil engineering. They are used in the construction of buildings, roads, railway lines, airports, dams, water reservoirs in almost all corners of the planet Earth, keeping also in view that mankind is now planning to colonize the upper space. They are in use since prehistoric times, when humans used to build shelters while living in the jungles against natural calamities and the beasts. Earlier human shelters were simple and therefore lasted for a few days or months. When the humans started agriculture, they thought to make more durable structures not only for them but also for the storage of their crops and cattle. At start, bio-materials like leaves, branches etc. were used, which later on changed to more durable materials like clay, stone and timber. The pursue for more durability led to the development of manmade materials like bricks, mortars and concretes, and metals. Then pragmatically, they dreamt for multi-span and multi-storey buildings. To make their dream come true, they thought of even stronger materials. Here, a new race came into being i.e. to exploit the material so that they could be utilized to give greatest benefits. Another research was put forward to make a controlled environment inside the buildings. This includes the regulation of air temperature, light and sound levels, humidity, odor and other elements of human comfort. Last century brought an industrial revolution in the world. Along with its numerous benefits to mankind, it also brought with it enormous environmental problems. So far civil engineering is concerned, all its manmade materials like brick, concrete, metals and plastics have also contributed to the environmental pollution. There is a dire need that the future building materials must be developed with a serious perspective not to add to human miseries by posing environmental and health threats.

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## 2. FUTURISTIC MATERIALS

### 2.1. Nanomaterials

Nanotechnology is a special branch of materials sciences that deals with nano particles: Those ones having at least one of its dimensions in nanometer ($10^{-9}$ m). This fact has been well established that at such a petite size, materials show extremely unique characteristics, which are different from those of their micro and macro counterparts [1]. A Nano copper is a fantastic hard material whereas at larger size, it is a bendable metal [2]. Likewise Nano Gold has a much lower melting point of 300 °C than 1064 °C for bulk gold [3,4]. Their unique characteristics, attracted scientists and engineers from all domains to find its utility in respective fields. And so was the case of civil engineering, where experts were convinced that they could gain superior benefits by using nanomaterials.

In civil engineering, cementitious and supplementary cementitious materials are of paramount importance. Cementitious materials are considered to be the backbone of civil engineering [5]. Primarily, they include concrete, mortar, and cement paste. Supplementary cementitious materials (SCM) include mostly industrial wastes like silica fumes, fly ash, ground granulated blast furnace slag, sugarcane bagasse ash, and many more. The use of SCMs in concrete is very important and has a twofold advantage: Firstly it makes use of industrial waste giving environmental decontamination and secondly, it helps concrete achieving some additional benefits like strength, workability, impermeability and resistance to chemical attack [5].

Cementitious materials gain strength in a period of about one month due to hydration reaction: a chemical reaction between cement compounds and water. These well known reactions are tribological, which greatly depend upon the surface to volume ratio of cementitious and supplementary cementitious materials [6]. Nano particles have larger surface to volume ratio than their micro counterparts and therefore should offer enhanced hydration, leading to higher initial and final strengths [7].

A considerable research has been carried out in the last decade to watch the interaction of nano particles in concrete. Concrete has been incorporated with Carbon Nano Tubes (CNTs), nano-silica, nano-titania, nano-clay and nano food additives. CNTs are intended mainly for strength enhancement and crack arrest, nano-titania for self-cleaning characteristics, nano-silica for chemical resistance, nano-clay for enhanced rheological qualities and nano-food additives to slow down the diffusion of aggressive species in concrete pores [8-12].

Nano building materials operate in two ways: Direct incorporation in existing materials like concretes and paints or grinding of existing materials like cement itself at nano-scale. Nano cement is a cement having its grains as fine as a few nanometers. Strength and densities of the building materials is a hot topic. Unfortunately, the higher strength is also associated with higher density, which considerably increases the dead weight of the structure. 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 construction industry [13].

Paints and coatings are another series of building materials, where nanotechnology could be of immense utility. Highly durable paints incorporating nanomaterials could be prepared. Paints are basically composed of a few components: Base for giving 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 surrounding environment. Titania or Titanium dioxide is being 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 research claims that nanotitania-paints are photocatalytic and possess much longer life span [16].

Aggressive elements like chlorides greatly affect 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 consequently enhances the viscosity of porous solution 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, American Iron and Steel Institute, and the U.S. Navy developed 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 plywood. It is claimed that MMFX2 has enhanced ductility, toughness, corrosion resistance [23].

## 2.2. 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 concrete significantly, however the ingression of aggressive substances due to increased permeability may significantly decrease the durability of structures in long term [24]. This risk is even more when concrete structures are exposed to the moist environment [25]. With the passage of time, these cracks may enlarge, further increasing the permeability of concrete and causing more damage to the structures [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 recommended 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 Autogenic healing [29]. The basic mechanism of autogenic healing is based on several physical, chemical and mechanical processes. However the formation 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 embedding 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 lactate and nutrients. This limestone fills up the cracks and prevents further movement of water in the concrete [31].

In an experimental study, a two component biochemical self healing agent was introduced in concrete 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 limited 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 remained viable for up to 4 months. Actually, as setting of cement stone paste occurs, pore diameter in concrete decreases considerably; a phenomenon which limits the life span of spores [31]. Temperature dependency of bacterial treatment was another factor widely studied during the past decade. Tests have shown that the efficacy of this technique increases 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]. Following that it was argued to introduce the bacteria via exclusively selected carriers. Silica gel and polyurethane were used as carriers, which provided satisfactory 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 improves 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 compressive strength of mortar samples having bio based agents at 7, 28, and 56 days showed considerable improvements. As far as deflection of concrete 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 activity is free from pollution; thereby giving a very sustainable solution against cracks [38].

Besides, water interaction based healing of concrete, the filling up of cracks in dry conditions is also essential to be achieved. For this purpose various 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 reservoir for a healing agent. Another technique is to introduce water filled Super Absorbent Polymers in concrete mix. These polymers form water pockets which are used as hydration of cement and afterwards for self healing of concrete. If all water is consumed in hydration of cement, rains on the structure once again fill up these SAPs thus fulfilling the requirement of self healing [37].

## 2.3. Super hydrophobic coatings

Leaks and dampness is a very common problem of all types of structure. Water is considered to be the phenomenal enemy to the building. If not properly guarded against, it leads towards the disastrous results; making it an extremely important concern. Therefore, water proofing is the major concern and is considered to be one of the most effective parameters to make concrete structures durable by preventing leaks and dampness [39].

Different conventional techniques are adapted to make waterproof structures. These include impregnation and use of admixtures, paints, polymeric coatings and membranes [40,41]. Hydrophobicity is a material property that represents an absence of attraction for water. Alkanes, oils, fats and greasy substances are some examples of hydrophobic materials [42]. On the other hand, superhydrophobic surfaces are extremely difficult to wet. An example given in this regard is that of the leaves of the lotus plant [43].

During the past few years, many super hydrophobic coatings have been made and tested: These include Manganese Oxide Polystyrene nano-composites, Zinc Oxide Polystryrene nano-composite, Precipitated Calcium Carbonate, CNT structured coatings and nano-silica coatings. They have been tested via aerosol spray and have been found to be very durable. However, polystyrene coatings in spite of their utility, are very costly [44].

It is claimed that creating a highly water repellent surface might resolve the issue of moisture sensitivity. Water-repellent surfaces have been generated in many ways for different kinds of materials by mimicking the surface roughness of the self-cleaning lotus leaves. The surface structure of the leaves can empower the entrapment of air between water droplets and the surface. Also, this can contribute to less wetting and adherence between the water droplets, and the surface, consequently forming a highly water repellent surface [45]. The combination of this surface structure and a hydrophobic outermost molecular layer has proven to build super hydrophobicity.

Various techniques were used to produce super hydrophobic surfaces in different kinds of materials. The studies include surface roughness created on a low surface energy material, through oxygen plasma treatment, laser etching or nano-casting. Some other studies have reported the conception of a favorable roughness, through etching or electrochemical deposition of particles, which later on were reinforced with a low surface energy material [46]. Silica nano-particles have been used in many different studies to create these surface structures along with different polymer binders and hydrophobic agents. By the combination of surface roughness and low surface energy, super hydrophobic can be created [46].

At Brigham Young University (BYU) USA, the researchers have made a new super hydrophobic material [47]. What they claim is that, instead of applying coating to the structure, structure itself is added to the coating. The team at the BYU created two types of surfaces made of Teflon; the first is a one tenth the size of a human hair rib-cavity structure and the other consists of tiny micro-sized posts. It was observed that the water sits on top of it like a spherical ball.

Similar research is also made at U.S. Department of Energy's Brookhaven National laboratory. Here some nano cone textures (similar to tiny micro-sized posts as above in BYU) are suggested as water proofing material owing to the fact that they have the ability to roll off the moisture from the surface and prevent it from being wet [48]. Along with cones, various other shapes like columns and fibers are also proposed and tested [49]. At MIT USA, a superhydrophobic surface is created by the addition of ridges to silicon surface [50].

## 2.4. 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 aggregate size. Similarly the lunar soil can be sieved to obtain fine aggregates. So far cement itself is concerned, 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 highest CaO content found in lunar soil is 19%. The last ingredient is water, which can either be supplied 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 components are heated at 140-150 °C at which the sulfur 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 average lunar rocks about 0.16% to 0.27% [58]. Presently, 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.

## 2.5. Security protective materials

Nanotechnology has also been credited to significantly revolutionize the issues related to the chemical, biological, explosive and radiological threats. The advancement in the growth of widely ranged insightful nanotechnology-based sensors for chemical, 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 complements 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 quantity of a substance that can be distinguished from the zero quantity within a certain confidence limit [63,64].

Chemical reactions constantly effect the technology 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 experimentally tested [66]. The eventual objective is to redesign a binding site for any ligand within a certain molecular weight range, and to apply this capacity 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 experimental methodologies provide a radical potential to design, construct and deploy sensors for newly identified threats within 7-10 days [67,68].

## 3. CONCLUSIONS

While discussing the future of civil engineering materials, the famous statement of Nobel Laureate Richard Feyman comes to the mind that there is plenty of room at the bottom [69]. Nanotechnology has tremendous potentials to create innovations for construction industry. A lot of new materials are in hand or in the development stage, using nanotechnology. Some wonderful futuristic materials made using nanotechnology are High Ultra Strength concrete and Self cleaning Concrete: Thanks to the higher surface to volume ratio of nanosized materials. As reported, these materials might address many environmental, design and security concerns associated with their micro and macro counterparts.

Engineering was ever considered to be the application of Mathematics, Physics and Chemistry but now Biotechnology is also being exploited to make more sophisticated civil engineering materials. While developing materials for extra-terrestrial purposes, the experts are exerting efforts to minimize the use of resources from the earth. Nevertheless, the investigation for building up novel building materials continues. It is by now evident that the knowledge of the very small things is creating gigantic changes, with various economic benefits to the construction industry.

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