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Innovation in Construction Materials-A Review

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Abstract. This study was carried out to review different types of available innovative construction materials. It was found that advancement in nanotechnology, use of mineral admixture, glass and plastic, biological materials, wood and other construction materials have contributed significantly to the growth of discovery and production of innovative construction materials. The implementation of some innovative construction materials, meets the requirements for sustainability, durability, reliability, safety, cost reduction, increasing quality, better mechanical and physical characteristics, flexibility in extreme conditions and locations, simple assembly and environmentally friendly. Construction materials used to carry out project consumed about 40% of the entire cost of the project in the construction industry. The success stories were recorded in the area of turning industrial and agricultural wastes to wealth. This reviewed paper will enrich the database for innovative materials entering the construction industry.

Keyword: Construction material, concrete, sustainability, economy

1. Introduction

Construction materials can be described as the mainstay of civil engineering [1]. Construction materials are utilized in structure development, development of streets, railroad tracks, airplane terminals, viaducts, burrows, spans, dams, seawards structures, television towers, water reservoirs and in nearly all spheres of the planet earth, to boost safety, minimize pollution, environment-friendly, user-friendly, aesthetically rich and consequently embraces a healthy atmosphere [2]. Construction materials consumed up to 40% of the entire cost of the project in construction projects [3]. There is a common saying that “Necessity is the mother of Invention.” Quest for better life forced man to create safer and better living conditions that provide reliability, durability, functionality and have some elements of harmony and beauty [4]. Acceptability of innovative construction materials should be based on satisfying some of these requirements such as sustainability, durability, reliability, safety, reduction in cost, improved quality, better mechanical and physical characteristics, extreme condition flexibility, simple assembly and environmentally friendly [3]. Some of the innovative construction materials include 3D printed sandstone, aluminum, foam, and bamboo reinforced concrete, bio-receptive concrete, bricks made from pollutants, plaited microbial cellulose, and super plasticizers [5]. There is also a success story in the area of turning waste to wealth by replacing sand and cement with pond ash/fly ash in concrete production [6]. This results in cost decrease and provide a solution to the issue of transfer of fiery debris coming out of the power plants. The material selection for any construction should be based on the requirements and suitability in the project. Some man-made construction materials such as concrete, metals, brick, ceramics and plastics have also polluted the environment [1]. Construction materials should be widely accepted by the construction industry and the end user. The economic feasibility is significant in the selection and acceptance of any construction



materials. It is imperative to ensure that the new construction materials should be labour-saving at construction sites, and further reductions in construction costs on the project. Modern construction materials should be sustainable and environmentally friendly. One of the main factors affecting acceptance of new construction materials is non-availability and production of new materials locally. The innovative materials should have the potential for further modification, suitable for the requirements at that point in time. The adoption of waste products will save cost and space for their disposal. The innovative materials should have a positive impact on the environment while the inordinate utilization of plastics should be discouraged [7]. Early days of our forefathers, shelters built were simple and thus had shorter life span of some months. Shelters for human and storage of crop products and cattle were built from bio-materials such as leaves, branches, bamboo, twigs [4]. As time goes on construction materials, improved to more durable materials such as timber, clay, rocks, sand and stone. Some years back there was upsurge quest for more durable, reliable and sustainable material that prompted the improvement of man-made materials, such as blocks, mortars and cements, and metals. This study was carried out to review different types of available innovative construction materials.

2. Application of Nano Technology

Nanotechnology is an important aspect of materials science that described nanoparticles. It shows the minimum particle size dimensions in nanometer (10⁻⁹ m). At nanoparticle size, the materials demonstrate extremely unique properties that cannot be compared with their micro and macro counterparts [4, 8, 9]. Nano particles have greater surface to volume ratio than their micro colleagues and thus offer improve hydration and this eventually enhance both the initial and final strengths [4]. The roles of nanomaterials cannot be overemphasized in civil engineering works. Nano materials are good candidates for construction industry due to their special attribute [10]. This makes it an ideal candidate for construction purposes. There are two ways nanomaterials can operate: Direct incorporation of nanomaterials into current materials such as concrete and paints or nanoscale grinding of existing materials such as cement. Cement with grains that are as fine as a few nanometers can be called nano cement. Cementitious and supplementary cementitious materials are important in civil engineering. Cementitious materials are described as the backbone of civil engineering [4]. Cementitious materials contain concrete, mortar and cement paste. While additional cement materials contain major modern waste, such as fly fiery debris, granulated impact heater slag, silica fumes, sugarcane bagasse ash, etc. The application of supplementary cementitious materials in the manufacturing of concrete have the following benefits such as turning industrial wastes to wealth, reduction in environmental contamination and also added values to manufactured concrete such as strength, impermeability, workability and chemical attack resistance [4]. Many researchers have worked on incorporation of nano particles materials in concrete. Some of the nanomaterials incorporated into concrete are Carbon Nano Tubes, Nano silica, Nanotitania and Nano clay [4]. The inclusion of Carbon Nano Tubes into concrete is necessary to improve strength and also to stop cracking. Addition of nano-titania in concrete is to achieve self-cleaning characteristics. Incorporation of Nano silica and Nano clay respectively in concrete is to enhance chemical resistance and rheological qualities respectively [4, 10, 11,12].

3. Use of Mineral Admixture

Recent development has shown the relevance of durable concrete structures; hence concrete composition has undergone changes. Before now, concrete was produced of three or four materials namely; cement, aggregate sand and water, but presently durable concretes combine six or more construction materials. Various researches have been done on mineral admixture [13-21]. Minimizing micro cracks in concrete can be achieved through mixing the concrete with mineral admixtures either in the batching plant or in the bond plant [20], improves the service life of concrete structure in a cost-effective manner. Researches done on mineral admixture include.

3.1 Fly Ash

This is the undesirable fine solid residue by-product in the burning of coal in a power plant. They are produced in large quantities. The disposal of unutilized fly ash has cost implications to power stations resources. Presently, about 120 million tons of fly ash are produced yearly, and not all fly ash produced can be used without processing [23]. Fly ash possesses varied components of which may constitute SiO_2 , Fe_2O_3 , Al_2O_3 and CaO . It has been established that fly ash could be in an amorphous form or various other forms, and when utilized as a filler admixture in concrete it functions as a void content minimizer [19]. In reference to the European concrete code, 35% of it can be used to replace cement in concrete. The cement replacing fly ash was strictly required to be processed in accordance to the code when used in concrete as a mineral admixture. Based on European Concrete Standard, processed fly ash mineral admixture is allowed in concrete, and from the limit that about 35% of cement may be replaced by fly ash in concrete, the actual percentage replacement depends on the outcome of trial mixes. Additionally, work on fly ash and its application on geopolymer is ongoing [19].

3.2 Ground Granulated Blast-Furnace Slag (GGBS)

The GGBS is a concrete admixture formed from a liquid cooling, waste material called slag produced in the blast furnace during iron ore smelting. The mineral admixture in concrete is economical, reliable, and sustainable in construction development [23, 24]. GGBS has been used in various groundbreaking structures with a durable application like Burj Khalifa [22], is used in various countries such as the United States, Japan, Singapore and European countries build durable and improved life span concrete structures. The utilized GGBS improve the concrete workability, reduce the risk of cracking caused due to low early age rise in temperature; reduction in reinforcement corrosion because of its strong resistivity to chloride ingress [25], sustainable benefits [23-26], sulphate attack resistivity [25], could also be used in precast concrete and in-situ stabilization of soil [25]. Various other research works have been carried out on GGBS which include its experimental investigation and application [22, 24, 25].

3.3 Concentrated Silica Fume (CSF) as Admixture

The (CSF) obtain from Ferro-Silicon Industries, has a small particle size greatly smaller than that of cement, that occupy the gap in a concrete mix between cement particles, decrease the water requirement and add high durability to a closely compacted concrete. Durable concrete can be achieved by replacement of 5 to 10% of cement by CSF. The application of CSF for lower grades increases project costs only without corresponding technical advantages. Investigation on condensed silica fume as an admixture include [27].

3.4 Ternary Blended Cement (TBC)

Countries used TBC in concrete production. It involves fly cinder slag, fly fiery debris silica fume or slag-silica smolder. The European Standard EN 197 for cements records 27 distinct mixes for cement. By and large, mineral admixture complimentarily effects the hydration of cement. More so, limestone fillers have positive effects on the cement test. Ternary concretes with little quantity of limestone filler of about 12% – 30% GGBS give a good resistance to chloride ingress and great performance in sulphate low environment [22]. Various researchers have carried out research on ternary blended cement [28-33].

3.5 Carbon Dioxide

Carbon dioxide has the global atmospheric advantage [34], used for pre-cast concrete and producers used it to decrease vitality utilization and traditional steam use is energy intensive. Its curing gives strength development lower than steam curing, but have better performance when the structure is properly pre-conditioned. In addition, the water absorption of steam cured structures is higher than carbon dioxide cured blocks [35].

3.6 Corrosion Inhibitors in Reinforced Concrete

Calcium nitrate corrosion inhibitors has the potential to protect the corroding reinforcement. Approximately 3–4 percent calcium cement nitrate by weight is adequate to prevent corrosion in reinforcement steel [22].

3.7 Great-performance Concrete

The additives such as silica fumes, which are by-products of the ferrosilicon production process and super plasticizers made it possible for the concrete performance rise, the plain concrete to change the concrete grade of compressive strength M_{30} to high grade of compressive strength $M_{60} - M_{90}$ and to a higher grade of high performance concrete of compressive strength $M_{90} - M_{130}$ [36].

3.8 Trivial weight Aggregates

These products are widely manufactured and used in span structures by utilizing expanded clay, sintered fly fiery debris, etc. The strength depends on the type and quality of the aggregate weight, the fraction size, the total quantity, the type and quality of the concrete binder. The elasticity modulus is decreased due to the addition of lightweight aggregate in concrete [22].

3.9 Water Resistant and Unconfined Shrinkage Concrete

According to Puertas et al., [37] the use of polycarboxylate superplasticizers admixture in cement paste do not affect the mechanical strength of the cement paste. The admixture or superplasticizer decrease water content and binders' hydration in concrete [37]. The distinctive calcium oxide and admixture decrease early and long term drying shrinkage cause by cracking on concrete [38-41]. The mixture of distinctive calcium oxide and a water retarding polycarboxylate superplasticizers produces unconfined shrinkage concrete without wet curing.

3.10 Composite Reinforcement

The replacement of steel reinforcements with composite fiber-reinforced polymers (FRP) is recommended in extremely corrosive environments. Although FRP materials may be anti-corrosive, but lacks ductility. Fiber reinforced polymers is used to increase the structural load and to resolve construction defects [22]. Toozandehjani et al., 2018 [42] stated that a combination of good corrosion resistance, fracture toughness, oxidation resistance, high specific strength and replacement of metal alloys is part of the reason for the high demand of composite reinforcement. Advanced composite reinforcement for structural application are very much ideal in extreme conditions for conventional reinforcement.

3.11 Utilization of Titanium dioxide

Titanium dioxide mixed with binder possesses the high performance property of clean surface and pollution reduction in concrete construction. The photocatalytic action produces surfaces with considerable self-cleaning and improved environmental quality [43]. The adoption of titanium dioxide in glass fiber-reinforced concrete makes the benefits of photocatalytic efficient and economical, produces cleaner and brighter environment that involve cladding panels and façade elements, fixed formwork, liners form, roofing tiles, motorway and railway sound barriers.

3.12 Super hydrophobic coatings

Leaks and dampness are a common problem of all kinds of concrete structure. The water is well-thought-out to be the major foe to buildings. In the recent development many super hydrophobic coatings have been produced and tested. These consist of manganese oxide, Polystyrene nanocomposites, Precipitated calcium carbonate, zinc oxide, Nano silica and carbon nanotubes (CNT) structured coatings [4]. Many conventional

means are employed in the production of waterproof structures. These involve incorporation and use of admixtures, paints, polymeric coatings and membranes [4]. Some hydrophobic materials include oils, fats, alkanes, and greasy substances [4]. Silica nanoparticles are used to develop various polymer binders and hydrophobic agents for surface structures.

3.13 Hydro-ceramics

Hydro-ceramics is produced from concentrated NaOH and metakoline. Hydro-ceramics materials are new technology in construction industries. These materials can effectively replace the air-conditioning in structures. The hydrogel bubbles in hydro-ceramics have possesses the ability to store up a greater quantity of water to its volume of water when compared. Bubbles evaporate at hot weather but decrease the temperature in the marked space. The utilization of material on walls and other building materials can greatly reduce energy consumption and this will be highly economical for the homeowner [44].

4. Biological materials

Owing to the danger imposed by micro crack occurrence in the concrete structure, especially when exposed to a moist environment, it is therefore imperative to develop durable concrete structures devoid of cracking. This has gingered researchers to work on various ways of developing environmentally friendly techniques. Prior to this period, remediation of cracks is most time achieved through regularly using synthetic polymers and this chemical are not environment friendly [4, 45, 46, 47]. Presently, bacterial induced carbonate mineralization has been recommended and this is an environment friendly method for the remediation of cracks. This technique is called autogenous healing [4]. The basic autogenous healing mechanism depends on a number of physical, chemical and mechanical processes. The contribution of calcium carbonate is significant in this process [4]. Some bacteria have the potential to heal micro cracks and these bacteria can be found in soil, sand and some other natural minerals [4]. Bio concrete is a product manufactured with a formula as a remedy to cracks in concrete and add aesthetic values to concrete. It protects the building's integrity when water enters and corrodes the reinforcing steel.

5. Production of bricks

There has been a major technological breakthrough in the production of durable, reliable and high strength bricks.

5.1 Use of Cigarette Butts in Production of Bricks

According to Dziadosz & Kończak [18] stated that Innovation in construction materials produces a lighter, effective and efficient bricks from a cigarette butt. [5]. Plate 1 shows a brick produced from cigarette butt.



Plate 1: Cigarette Butt Bricks

Source: Treacy [48]

5.2 Pollution absorbing bricks

Pollution absorbing bricks thermal insulation, was incorporated as a standard ventilation system of the building. It consists of external bricks façade system and indoor insulation. The filtration system in the brick divides the matter particles suspended into the removable hopper at the base wall. The brick offers better air quality and also helps to reduce airborne breathing problems [5, 49]. Plate 2 shows a plate describing pollution absorbing bricks.

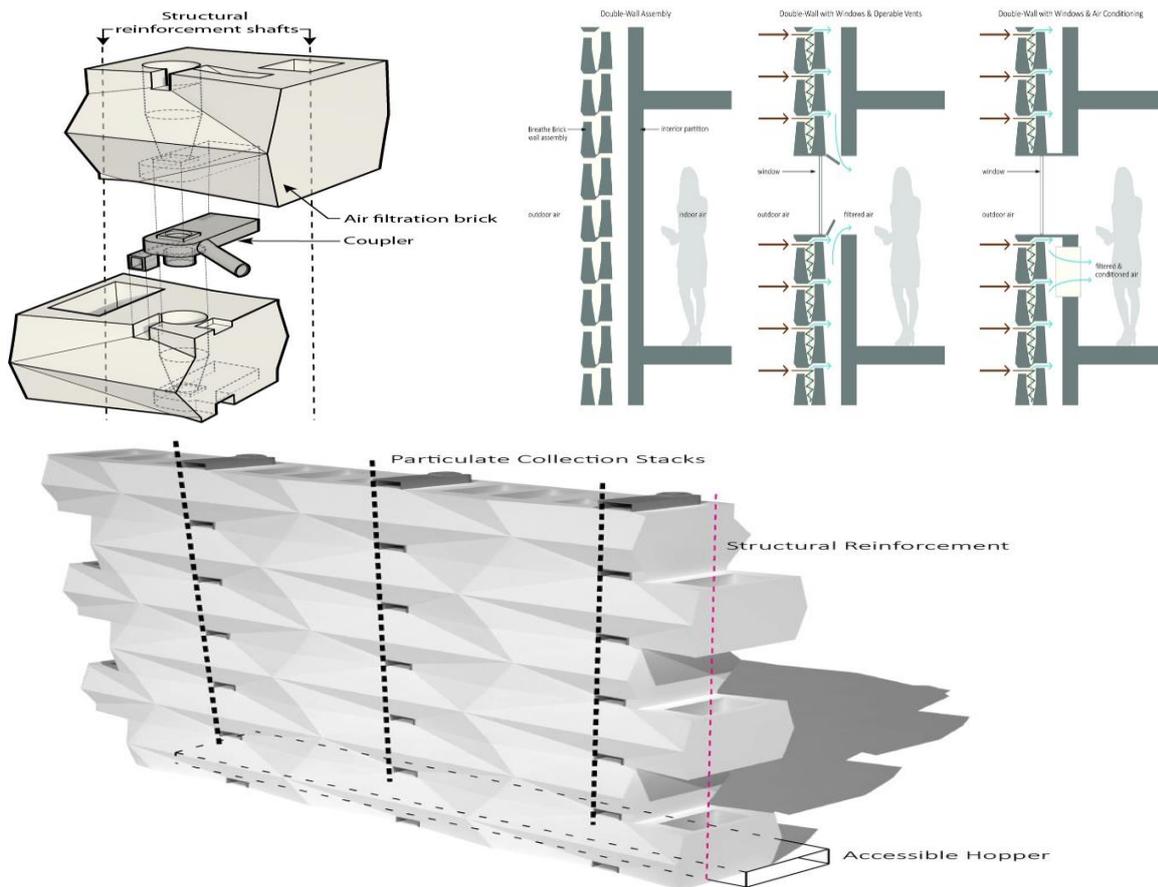


Plate 2: Pollution absorbing bricks

Source: Rory [50]

5.3 Three Dimensional Printing (3DP) in Civil Engineering

3D printing is one of several processes in which materials are connected or solidified to create a three-dimensional object with a combination of material (such as liquid molecules or powder grains) under computer control. 3D printing can be used both in rapid prototyping and in the production of additives. Objects of almost any geometry or form can be produced using 3D model data [51]. The printer produces an in-situ earthenware blocks with auxiliary capacity design in a construction workplace. These bricks can be mass-produced within 15-20 minutes [5]. Hardened bricks are stacked and form walls, vaults or pillars [5]. Researches have been done on the application of 3D in civil engineering construction [50, 52, 53, 54].

5.4 Cooling system in bricks

Hydrogel and Clay together produce a material with a cooling advantage on the interior of the building. Hydro-ceramics can reduce the temperature indoors by 6°C. Its cooling effect is due to the presence of hydrogel absorbing large amounts of water. The absorbed water decreases temperature when heat is present [5].

6. Wood

Wood as construction material received a major breakthrough. The construction industry is presently enamored with mass timber.

6.1 Pellucid wood material

The crystalline wood is useful in the construction industry for the production of windows and solar panels. The production of translucent wood is made possible by separating the wood veneer lining through nanoscale tailoring. The large scale production of translucent wood can be produced [5].

6.2 Laminated timber

Structural laminated timber is an engineered, stress-rated product consisting of two or more layers of lumber glued together with a long grain running through the length. This composite material has more homogeneous distribution and higher mechanical properties than wood [55]. Laminated timbers are also called Cross Laminated Timber. It can be employed in high-rise commercial building construction. Laminated timbers have incredible tensile and compressive strength. It is often produced young trees. Laminated timbers are sustainable and eco-friendly substitute to hardwood products. Their structures are of different shapes and sizes. Laminated timbers are in pre-fabricated and ready to use state [5].

7. Other construction materials

7.1 Green-mix concrete

Green-mix concrete is a new construction material that durable, stronger and more environmentally friendly. These concrete ingredients mixed with suitable agricultural or industrial waste and material recycled to produce sustainable products [16, 56, 57, 58].

7.2 Geometric microstructure

Some researchers have established a method of controlling waves travel through materials without structural composition change that keep structures from seismic events. Researchers have successfully formed a steel plate microstructure pattern to buckle and acoustic waves. The waves redirected carry enormous energy to residential buildings through a cloak metamaterial property from tsunamis [5].

8. Glass and plastic

Glass and plastic are not left out in the innovative trend. Presently, there are a lot innovative materials derived from plastic and glass. Some already exist in Polish markets such as blast resistant, impact resistant, bullet resistant, and fire resistant glass materials [36]. Some of these finished products have higher mechanical strength more than three to six times than that of plain glass, high thermal resistance and resistance to temperature changes. They are better materials due to their ability to shields noise in streets, highways and support large loads in structural environments such as building facades, skylights etc. [36]. Studies reveals that plastics of high molecular weight are suitable for building structures owing to lightness, great chemical resistance, and light transmittance but have low elasticity coefficient, high rheological defects, low thermal resistance, low tensile strength and ageing caused by UV radiation. Plastics reinforced with glass fibers are sustainable and reliable, the plastic strength increases from (10-80) Mpa to (130-600) Mpa [36].

9. Conclusion

Concrete construction practiced presently is being driven by sustainability, durability, reliability, cost, safety of human and environment and strength. Minimizing micro cracks in concrete can be achieved through the right binders with admixture in the batching plant to improve concrete structure in efficient way. Construction materials consumed up to 40% of the entire cost of project in construction projects. Some of the innovative construction materials include 3D printing, 3D printed ceramics, pollution absorbing concrete, laminated timber, aluminum foam, bamboo reinforced concrete, bio-receptive concrete, bricks made from pollutants, plaited microbial cellulose, super plasticizers etc. The innovations in the area of construction materials is the making of a Super Ductile Rebars used during earthquake. Success story were recorded in the area of turning wastes to wealth. Construction materials consumed up to 40% of the entire cost of project in construction projects. More importantly the implementation of innovative construction materials should be based on satisfying some of these requirements such as sustainability, durability, reliability, safety, economy, improved quality, enhanced mechanical and physical characteristics, flexibility in extreme conditions and locations, simple assembly and environment friendly. This study provides construction industries latest information on series of innovative construction materials available in the markets. This will further enrich the database of construction materials.

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