Development of new environmental-friendly concrete types

S. D. Mavridou and P. P. Banti
Engineering Project Management MSc, School of Science and Technology, Hellenic Open University, 26335, Patra, Greece

Presenting author email: smavrido@civil.auth.gr

Abstract
The growth of the world population, urbanization and industrialization have led to overconsumption of natural resources, increased energy waste and environmental pollution. The need for the development of new strategies and techniques, which will focus on a healthy living environment while ensuring conservation of natural resources making at the same time cement and construction industry a more environmentally friendly sector, is considered more urgent than ever.

Scientists of all disciplines are oriented in this direction, while engineers play a dominant role in this effort, since concrete's production is responsible for one of the largest energy and natural resources' consumption worldwide. Taking into account that the cement industry is considered to be the most energy intensive of all manufacturing industries and concrete the most popular building material with a continuously increasing consumption, it can be easily concluded that engineers are now forced to investigate innovative ways of reducing the environmental footprint of constructions.

Present paper is monitoring and criticizes most of the existing environmental-friendly concrete types by focusing on each type's production/components, pros and cons in terms of physical and mechanical characteristics as well as durability and uses. This constitutes an effort to illuminate the trends and needs of modern society, always based on sustainable development and environmental protection.

Keywords: environment, pervious/conductive/ light transmitting/self-healing concrete, blingcrete^{TM}, innovation, resources efficiency and savings

1. Introduction

Concrete was often captured by its fixed and widely known image due to the rapid urbanization of the 1960s. However, since then, concrete has made significant progress; it has been developed, not only in technical terms, but also in aesthetic ones. It is no longer the grey, cold, heavy material since it may be transformed to a more resistant, friendlier, colored and beautiful building material. Besides that concrete, similarly to bitumen, is a material that has and is still absorbing all new challenges [1].
Moreover, the World Earth Summits in Rio de Janeiro, Brazil in 1992, and Kyoto, Japan in 1997 made it clear that in order to achieve a long-term sustainable development, which according to Bundtland is defined as "*the ability of humanity to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs"*, it is essential that the rate of greenhouse gas emissions must either be reduced or at least stay at the same levels. Primary greenhouse gas emissions, which affect directly sustainable development, are the carbon dioxide (CO_2) emissions, while other greenhouse gases include nitrous oxide (NOx) and methane (CH_4), but their amount emitted is relatively small compared with that of CO_2. So many studies examine the use of alternative materials (eg fly ash, superplasticisers) for the production of cement, since the manufacturing of Portland cement contributes significantly to the CO_2 emissions. The U.S.A. and Canada are the largest contributors of CO_2 emissions in the world with CO_2 emissions estimated at approximately 20 tons per capita per year, followed by the EU countries at about 9 tons. Developing countries like China and India have low emissions at present (3 and 1 ton, respectively), but their rapid industrialization is going to increase the rate of emissions per capita significantly in the near future [2].
Towards sustainable development, scientists are focusing on developing new concrete types, which can be characterized as environmentally friendly. As environmentally friendly concrete, is defined as the one made of cement, which is either produced by the addition of small amounts of recycled aggregates or it can be replaced in various percentages or mixed by fly ash, pozzolana, lime or rice husk ash, or made of aggregates, which may be replaced by several solid wastes, such as recycled rubber, C&D Wastes, recycled glass, ceramic wastes etc. Those replacements aim at decreasing the cement production, thus decreasing CO_2 emissions, as well as utilizing secondary materials, which result in savings of naturals resources as well as protection of the environment by not disposing those harmful materials often in illegal deposits.
There are also other types of concrete, not studied widely; these concrete types are characterized by the addition of new components, which provide concrete mixtures with specific characteristics. Such indicative concrete types are *light transmitting concrete*, by addition of optical fibres or resins (polymers) in order to save energy for lighting, *pervious concrete* by the use of only coarse aggregates in order to manage rainwater and avoid flood runoff, *Bio or self-healing concrete*, in which bacteria are added, so that concrete heals its own cracks, *Light Reflecting Concrete*/*BlingCrete*^{TM} by the addition of glass, which has the ability to return the light (natural or artificial) back precisely in the direction of the its source leading to higher safety, as well as *conductive concrete* by the use of small particles or fibers of steel, which can be used as deicing pavement surface avoiding the use of deicing agents which harm durability of concrete. All those new environmental friendly concrete mixtures have as a result savings in money and restoration actions by also leading to improved durability of concrete mixtures.
Present paper focuses mainly on these concrete types by presenting their basic compounds, their pros and cons in terms of physical and mechanical characteristics as well as their possible uses.

2. Concrete types

2.1 Translucent Concrete or Light Transmitting Concrete

2.1.1 Introduction

Nowadays, the costs for energy and environmental problems have increased worldwide. The main purpose of the light transparent concrete is the use of solar energy in order to reduce the energy used by other sources. Additionally, it is an aesthetic material, which has high density and prevents the entering of light through its mass, so it is impossible to distinguish forms, colors or shapes behind it. On the contrary, a wall made of translucent concrete, due to the embedded optical fibres, obtains a transparency sufficient to provide a visual impression of the external world, eg the outline of the shadow of a person from the other side of the wall [3].
Light transmitting concrete's conception has been given in 2001 by the Hungarian architect Aron Losonczi, who thought to combine the *advantages of concrete*, which is one of the most popular

building materials with the advantages of abundant raw materials, low cost and simple production, with *the ones of the optical fibres*, which are materials with good light guiding property. This may lead to a novel functional material. So, in 2003 the first translucent concrete of this type, named LiTraCon has been produced; a concrete which allowed the entering of light at a percentage of 80%, while its weight reached only 30% of the one of conventional concrete [1].

Translucent concrete, apart from its usual compounds (cement, aggregates, water, additives and admixtures) may contain either plastic or optical fibres or resins fig 1 [4]. These materials are the ones that allow light to pass through concrete's mass giving to it transparency. Usually, the use of optical fibres is suggested and preferred related to resins, because of the cost. There are some benefits from the use of optical fibres such as safety; there is no electricity, heat in the fibre optic cable so it is ideal for use in and around water, precious artifacts, while it is also user friendly since it does not break, cable is protected and durable, while it needs no maintenance actions.

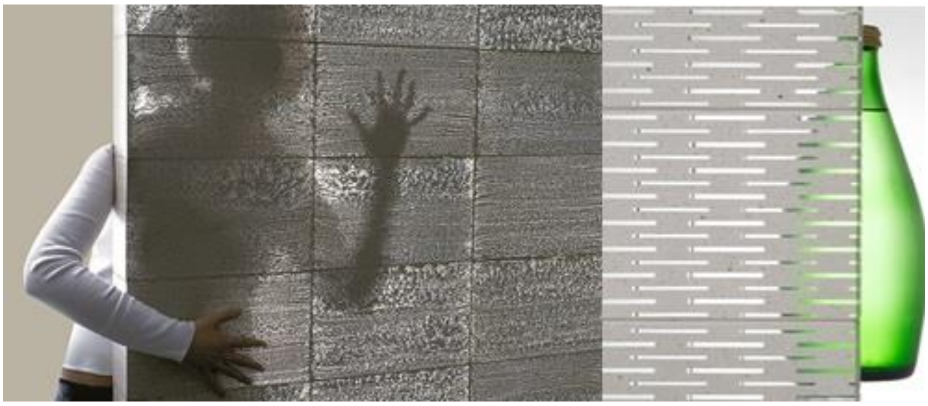

Figure 1. Translucent concrete made of optical fibres or resins [5,6]

Optical fibers are flexible and transparent, while the light is transmitted between the two ends of the fiber with minimal losses. For the transmission of light, the thickness of the optical fiber should range from 2μm to 2mm, i.e. about as much as the diameter of human hair. Transparent concrete can be produced by the addition of optical fibres in percentages from 0,25 to 5% per volume of concrete [7,-9]. It can be produced in the factory in prefabricated panels or in the lab. Optical fibers are arranged in a parallel form, forming a matrix, allowing the light to be transmitting through them [10,11]. Indicative characteristics of transparent concrete are showed on Table 1.

Table 1. Properties of Transparent Concrete blocks by Litracon Company [5]

Characteristics of transparent concrete	
Form	Prefabricated blocks
Ingredients	96% concrete, 4% optical fibre
Density	2100-2400 Kg/m^2
Block size	600mm x 300mm
Thickness	25-500mm
Color	White, grey or black
Fiber distribution	Organic
Finished	Polished
Compressive strength	50 N/mm^2
Bending tensile strength	7 N/mm^2

2.1.2 Pros and cons

Transparent concrete shows some advantages and disadvantages. The main disadvantages are its cost, since optical fibers are a relatively expensive material (indicative cost according to Litracon is $1000/m^2 for 25mm thickness), its time consuming production as well as the required experienced personnel to produce the concrete specimens. Those are some of the reasons that this material is not a widely used one and there aren't many manufacturers of translucent concrete. There are very few of them, namely LitraCon, Lucon and Lucem Lichbeton.. Finally, as all new concrete types, it still requires acceptance from cities and states

However, main advantages of light transmitting concrete include the following: Light transmitting concrete is frost and de-icing salt resistant, making it highly recommendable in cold countries, it is under fire protection classification A2, it provides very high UV resistance while light, colors, shapes and borders are distinct through its mass [12]. Moreover, energy savings due to less need for use of artificial lighting during the day as well as due to the act of optical fibers as heat insulators can be achieved, it provides greater safety, create better supervision of outdoor buildings such as schools, museums , prisons , etc, the passage of light remains unchanged over time, while it is more strongly perceived during the night, it has very good architectural properties for good aesthetical view to building, while it is ideal for places where light is not able tom reach [1,13].

2.1.3 Uses

Light-transmitting concrete can be used as building material for the construction of external and internal walls. Its use is recommended in the eastern and western walls of a building, since due to the lower angle at which sunlight is incident on the optical fiber, the light intensity is greater. It can also be used for the production of translucent concrete blocks suitable for floors, pavements and load-bearing walls, facades, interior wall cladding and dividing walls based on thin panels, partitions wall and it can be used where the sunlight does not reach properly, in furniture for the decorative and aesthetic purpose, in light sidewalks at night as a material which increases visibility in dark subway stations, for lighting indoor fire escapes in the event of a power failure and as illuminating speed bumps on roadways at night [1].

2.2 Pervious Concrete

2.2.1 Introduction

The development of permeable concrete (pervious concrete) has its origin in the USA. In Europe, it was first used in the 1800s, while it became popular in the 1920s in Scotland and England. Its popularity increased in Europe after 2^{nd} world war due to the scarcity of cement [14]. The basic aim for its invention was to create a product with high porosity, which would allow the management of rainwater, avoiding flood runoff and prevent contamination of natural water resources [15]. So, a new product has been produced; this product named pervious concrete (Figure 2) has continuous gaps, which are deliberately incorporated into the concrete mass.

Figure 2. Pervious concrete [16,17]

Main compounds of pervious concrete are coarse aggregates, which are coated by an appropriate amount of cement paste, while preserving the interconnectivity of the voids. There are main recipes suggested all over the world for the production of pervious concrete (Table 2), which are related to the quality of aggregates used as well as for the desired application.

Table 2. Indicative recipes for the production of pervious concrete

Materials	*Florida*[18]	*Massachusetts*[18]	*Colorado*[18]	*Research of AbhiShek Gupta*[19]	*Research of InnocentImmuna*[14]
Cementitious materials	355kg/m^3	370kg/m^3	360kg/m^3	270-415 kg/m^3	356 kg/m^3
Coarse aggregates	1540kg/m^3	1600kg/m^3	1365kg/m^3	1190-1480kg/m^3	1543 kg/m^3
Water	75-90kg/m^3	105kg/m^3	80kg/m^3		95 kg/m^3
w/c	0.21-0.25	0.28	0.22	0.25-0.34 (with admixtures) 0.34-0.40 (without admixtures)	0.27
Voids content	22-25%	18%	35%		
Polypropylene fibres (optional when no fines is present)	-	-	-	0.1% by vol/ 0.9kg/m^3	
Admixtures					Plastol5500 (160ml/kg)

Some of the basic characteristics of this new “green” concrete type are given below:
Density of pervious concrete depends on the properties and proportions of the materials used, as well as on the compaction procedures used in placement and ranges between 1600 kg/m³ and 2000 kg/m³, which is in the upper range of lightweight concretes. Its permeability depends mainly on the materials and placing operations, while typical flow rates for water through pervious concrete are 120 L /m^2/min, or 0.2 cm/s to 320 L /m^2/min, or 0.54 cm/s. Its *compressive strength* may vary between 2.8 [15] or 3.5 MPa to 28 MPa, which is suitable for a wide range of applications, with a common one of about 17 MPa. However, according to other research, compressive strength at 7 and 28 days reached the values of 10-14 and 12-20MPa, respectively. Its flexural strength ranges between about 1 MPa and 3.8 or 4 MPa, while it may be affected by the degree of compaction, the mixture’s porosity, as well as the aggregate: cement (A/C) ratio. As far as drying shrinkage is concerned, pervious concrete develops it sooner, but is much less- roughly half- than the one of conventional concrete,. In general, 50% to 80% of shrinkage occurs in the first 10 days, compared to 20% to 30% in the same period for conventional concrete. Decreased shrinkage allows pervious concretes to be made without control joints, allowing them to crack randomly. Its durability and especially freeze-thaw resistance depends on the saturation level of the voids in the concrete at the time of freezing. Moreover, the open structure of pervious concrete makes it more susceptible to acid and sulphate attack over a larger area than in conventional concrete. Because of the rougher surface texture and open structure of pervious concrete, abrasion and raveling of aggregate particles can be a problem, so applications such as highways generally are not suitable for pervious concretes [15, 19].

2.2.2 Pros and cons

Pervious concrete shows some advantages and disadvantages. Some of its benefits are environmental ones since it ensures rapid runoff of rainwater, it replenishes water tables and aquifers, it allows for more efficient land development since water and air are allowed to pass through the concrete and enter into sub-base, it prevents warm and polluted water from entering stream, it mitigates surface pollutants. Moreover, its light reflectivity is higher than the one of asphalt surface, reducing and heat island effect, it eliminates the need for detention ponds and other costly storm water management practices, it improves friction as a surface wearing course, it increases skid resistance of pavement, and it has reduced reflection on the pavement, which is more noticeable at night. Furthermore, due to its light color, it absorbs less heat from the sun and significantly reduces the temperature of the pavement or floors made by it, while it is ideal for the protection of trees planted in paved urban areas and in parking lots. With the use of permeable concrete, air and water easily reaches the roots and help Trees to grow. Although it may sometimes be slightly more expensive than conventional one, it proves more economical due to its durability and fewer maintenance actions. Snow melts more quickly due to the increased void content, while due to its low shrinkage rate due to the increased void content, and due to the low quantity of water used for its production, cracking is delayed and are of smaller width, so structural integrity is not affected. Finally, savings in materials since no fines are included and cement needed per m^3 is decreased, increased insulation is attributed to the included voids, it has potential to reduce roadway noise and helps increase of water resources providing filtered water with reduced emissions [20, 21].

Some of its *disadvantages* are the need for prevention of the runoff from adjacent areas onto pervious concrete, the fact that in case of included reinforcement, epoxy coated bars should be used so cost may be increased, concrete must be vibrated in a way that permeability does not decrease, frequent maintenance is required and it is still a new material that requires acceptance from construction sector [20].

2.2.3 Uses

It must be noted that permeable concrete, because of its high porosity, it may result in steel corrosion, so it must be avoided in reinforced concrete's applications. However, there are many applications such as: basements with increased presence of water [22], lightweight structural walls with increased insulation properties, pervious pavement for parking lots, residential roads, alleys and driveways, well linings, trees gates in sidewalk, swimming pool decks, tennis court, noise barriers, sub base for conventional concrete pavement, greenhouse floors [20].

Figure 3.Pervious concrete compared to conventional/ standard one [23,24]

2.3 Self-Healing Concrete

2.3.1 Introduction

Crack formation due to factors such as shrinkage, alcalisilica reaction, creep etc into concrete is related to its strength and durability since it increases concrete's permeability, letting a path for water and chemicals such as sulphates, chlorides and acids to enter and cause steel corrosion. Without immediate and proper treatment, cracks tend to expand further and eventually require costly repair by the use of repairing agents such as epoxy or grout injection [25]. Self-healing concrete, a type of concrete that heals by itself its cracks, without external maintenance actions, may be a solution to this problem. There are two basic approaches to self-healing concrete. The first aims to improve the auto genous physical self-healing mechanism of cracks, while the second aims at concrete's modification through addition of specific healing agents that can be incorporated in the concrete matrix, so that cracks are treated after their appearance [26].

2.3.1.1 Improvement of physical mechanism of autogenous healing of cracks

Concrete's healing properties of its cracks can be attributed either to the continuous hydration of unhydrated cement particles or the carbonation of calcium hydroxide [$Ca(OH)_2$]. Constant hydration is the main healing mechanism in young concrete due to their relatively high content of non- hydrated cement particles, while in older concrete, the precipitation of calcium carbonate ($CaCO_3$) becomes the main mechanism. So, water is necessary for both ways of healing. Cracks may be cured after some time, but this healing is limited to small ones. Therefore efforts aiming at improving the natural mechanism of autogenous healing of cracks have been made by the production of concretes, in which small cracks are created in order to achieve self-healing [this concrete has the name "Engineered Cementitious Composites (ECC) or Bendable Concrete"] [26].

2.3.1.2. Engineered Cementitious Composites (ECC) or Bendable Concrete

In recent decades, types of concrete with increasingly high compressive strength have been used for structural applications. However, most of these remain brittle, while the brittleness increases as compressive strength increases too [25]. Engineered Cementitious Composites (ECC) or Bendable Concrete, discovered by the team of the University of Michigan researchers, is an exception. This type of concrete shows similar characteristics to the ones of medium to high strength concrete. Compressive strength of ECC varies from 30 to 70 MPa, depending on the matrix composition, while compressive strain capacity is approximately double of that of FRC's (0.4 – 0.65%) [27]. Basic properties of ECC are showed on Table 3.

Table 3. Properties of ECC [27]

Compressive strength	First crack strength (MPa)	Ultimate Tensile Strength (MPa)	Ultimate Tensile Strain (%)	Young's Modulus (GPa)	Flexural Strength (MPa)	Density (g/cc)
20-95	3-7	4-12	1-8	18-34	10-30	0.95-2.3

ECC is produced by cement, sand, water, fiber (up to 2% by volume) and additives, with a w/c ratio and sand/cement ratio of 0.5 or lower. For the production of CEE, many types of fibers such as high modulus polyethylene (PE) fibres [28, 29] and polypropylene(pp)[30] fibres may be used. Due to its nature, ECC behaves more like a bending metal. This way many micro cracks due to the embedded ultrafine fibers are created opposed to conventional where fewer but larger cracks are generated [31].
Self - healing of microcracks is obtained when the dry cement with cracks, comes into contact with rainwater and carbon dioxide of the environment resulting in the formation of calcium carbonate which functions as a filling of the crack. Simultaneously, concrete's strength may be recovered due to the healing process. The self -healing ability has long been observed for many years also in conventional concretes, but to a smaller degree since the crack width in them is larger. Li and Yang, 2007 [32] conducting tests in ECC found that cracks with a width of less than 50 microns showed complete self-healing, while cracks with a width of more than 150 experienced partial self- healing.
ECC has been used in large-scale projects in Japan, Korea, Switzerland, Australia and the United States. Its main application is in bridges' construction, in roads, in high rice buildings located in areas with intense seismic activity (eg Japan). Although the cost of construction or repair with ECC is higher, longer life outweighs the difference compared to conventional concrete's cost. According to Li "*in 60 years, a bridge from ECC costs 37% less than the sum of the cost for the construction of reinforced concrete and the one of required maintenance actions"* [33].

2.3.1.3 Self-healing by the use of appropriate curing means

In recent years, scientists are trying to develop various methods by adding suitable therapeutic agents in concrete in order to achieve self-healing. Those methods have already been tested in the lab with satisfactory results. One of the major EU research programs in that field is HealCON, which is funded under the 7th Framework Program of the European Union for Research and Technological Development, which is coordinated by University of Ghent in Belgium. In order to examine the effect of healing, HealCON's scientists use non-destructive methods, such as sonometer (Figure 4), in order to show the formation of the cracks as well as their exact location. First, pressure is applied to a concrete block containing any of the foregoing therapeutic agents. Because of cracks' creation acoustic waves are generated and measured by the use of sensors [34].

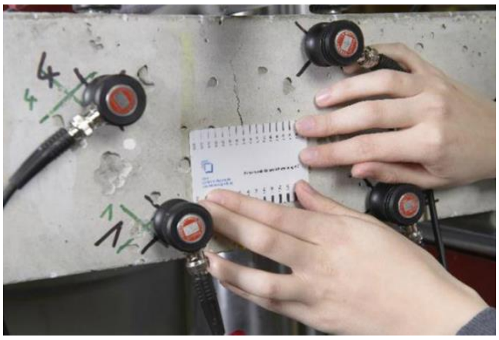

Figure 4. Sonometer [34]

Self- healing can be achieved by adding: a) hydrogel b) capsules containing a curing agent, and c) bacteria [34]. Of the above, the third method is of greater interest and will be presented more detailed.

2.3.1.4 Addition of hydrogel

Hydrogels (hydrogels) are polymers which absorb moisture. Materials containing hydrogels can multiply their original size by 10 to 100 times. By the addition of hydrogel in concrete, developed cracks can be cured or limited because of the expansion of hydrogel which prevents further intrusion of water into concrete [34].

3.1.2.2 Addition of capsules with curing agent

According to this method, epoxy resins or polyurethane can be enclosed into capsules and added to the concrete. When a crack is formed, capsules are broken and the polymer is released to form a hard mass which seals the gap. This method results in an increase on the structural stability [34].

3.1.2.3 Addition of bacteria (Bio-concrete or Bacterial Concrete)

When bacteria are used to heal cracks in concrete, the major hindering factor is the highly alkaline pH of concrete, which may restrict the growth of the bacteria. So, it is important to find a cell eg polyurethane- of high mechanical strength and biochemical inertness or silica gel, which could protect bacteria from the surrounding environment. Bio crete, a special type of concrete which heals its cracks by producing limestone biologically, has been developed by the team of Prof Henk Jonkers at Delft University (Figure 5). His team examined the crack healing capacity of a specific bio-chemical additive, consisting of a mixture of bacteria and organic compounds, packed in porous expanded clay particles.

Figure 5. Bio-concrete [35]

For several years, Jonkers team was looking for the appropriate bacteria, which would be able to survive in the highly alkaline environment of concrete (pH = 13) and even survive for many years, till the moment that cracks were formed and needed healing. After many trials, Bacillus cohnii bacteria which are resistant to alkaline conditions and produce smaller spores that can survive for decades without food and oxygen have been chosen [36]. These spores can withstand mechanical and chemical stresses and remain in dry state viable for over 50 years.
However, when bacterial spores were directly added to the concrete mixture, their lifetime was limited to one to two months. This decrease in life time was attributed to continuing cement hydration resulting in matrix pore-diameter widths typically much smaller than the 1-μm sized bacterial spores [37].

In 2011, Wiktor and Jonkers [38] developed a self-healing system that consists of two components, bacteria and their "feed", in particular a mixture of calcium lactate base, which can apart from healing; it can also lead to an increase in compressive strength as well-Figure 6-. In concrete mixture, 2-4mm size class was replaced by similarly sized expanded clay particles loaded with the bio- chemical self-healing agent plus 5%ww fraction calcium lactate corresponding to 15 gdm^{-3} concrete.

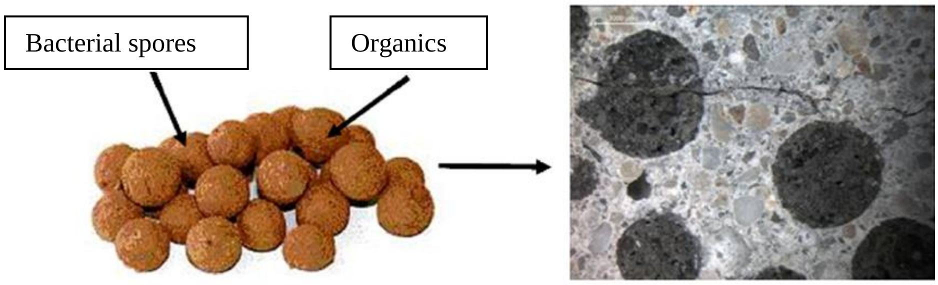

Figure 6.Self-healing admixture composed of expanded clay particles (left) , which act as reservoirs containing the two- component healing agent consisting of bacterial spores and a suitable bio-mineral precursor compound

These bacteria can remain inactivated in the concrete up to 200 years; however, when a crack is formed, and aggressive water enters inside concrete's structure and clay particles break, then bacteria are activated and start feeding by calcium lactate. As the bacteria are fed, they consume oxygen, resulting in the conversion of calcium lactate to undissolved limestone which solidifies and seals the crack. The oxygen consumption during bacterial conversion of calcium lactate to limestone has an additional advantage: it protects the steel from corrosion and thus increases the strength of the concrete [39].
Experimental studies, during a time period of 100 days, showed self-healing up to 100% of bio-concrete samples. On the contrary, same concrete composition samples without addition of bacteria and calcium lactate in clay pellets showed self-healing of up to 33%.

Table 4. A typical composition of self-healing concrete (LWA refers to Liapor R ¼ expanded clay particles) [40]

Compounds	Volume (cm^3)	Weight (gr)
2-4mm LWA	196	167
1- 2mm LWA	147	125
0,5-1mm Sand	147	397
0,25-0,5 mm Sand	128	346
0,125-0,25 mm Sand	69	186
Cement CEM I42,5N	122	384
Water	192	182
Total	1001	1796

Another research examined the use of ureolytic bacteria such as Bacillus sphaericus, which are able to precipitate $CaCO_3$ in their micro-environment by conversion of urea into ammonium and carbonate, increasing locally the pH and promoting the microbial deposition of carbonate as calcium carbonate in a calcium rich environment. Concrete mixtures have been examined as far as water permeability, ultrasound transmission measurements and visual examination of the degree of crack filling are concerned. It was concluded that bacteria inside a silica gel precipitated $CaCO_3$ crystals inside the cracks, so cracks were filled completely. In particular, crack sealing by means of this biological treatment resulted in a decrease in water permeability and water flow, if autoclaved bacteria were used instead of active ones, while the decrease in water permeability was attributed to crack filling by the sol–gel matrix. Moreover, crack treatment with B. sphaericus, immobilized in silica gel, resulted in an increase in ultrasonic pulse velocity, indicating that crack bridging has been obtained, while visual examination of the cracks certified that this technique resulted in complete filling of the cracks. However, further experiments have to be conducted in order to examine the durability of this crack healing technique [41].

Pros and cons

Main advantage of self-healing concrete is the self-curing of its cracks, reducing the cost of maintenance actions. On the contrary, addition of polymers or bacteria may increase cost and decrease concrete's strength. So, further optimization of the proposed system should be made, eg reduction of the amount of the healing agent, in order to become economically competitive with currently existing repair techniques and eliminate possible strength loss by the use of the bacteria.

Uses

Specific type of concrete may be used in aggressive wet environments where corrosion is more intense. Calcium carbonate precipitation has been used for consolidation of sand columns, healing of cracks in granite or for surface treatment of limestone. For these applications the use of bacteria, precipitating $CaCO_3$, proved its efficiency [40]. Some additional potential applications of ECC are generally in construction industry, in high energy absorption structures/devices, including short columns, dampers, joints for steel elements, and connections for hybrid steel/RC structures. Structures subjected to impact or 3-D loading may also take advantage of the isotropic energy absorption behavior of ECC, such as highway pavements, bridge decks, and blast-resistant building core elements. In addition, structures subjected to large deformations, such as underground structures which need to conform to soil deformation and require leak prevention, are also potential targets for ECC applications. Other applications of ECC being considered are in permanent formwork, extruded elements with structural properties, FRP reinforced concrete structures, and as a binder for radio-active waste treatment [42] for leaching control.

2.4 Light Reflecting Concrete ή BlingCrete^{TM}

2.4.1 Introduction

Concrete that reflects light (light-reflecting concrete or BlingCrete^{TM}) has been developed under the research program «BlingCrete» at the University of Kassel in Germany. BlingCrete^{TM} combines the positive characteristics of concrete (strength, durability, fire safety) and those of retroreflection. Such surfaces have the ability to return the light (natural or artificial) back precisely in the direction of its source. BlingCrete^{TM} accomplishes this optical phenomenon by incorporating glass microspheres in the concrete body (Figure 7) [43].

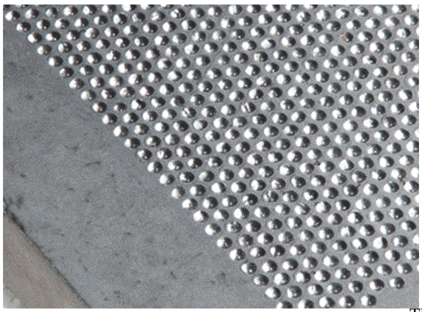


Figure 7. BlingCrete^{TM} [43, 44]

BlingCrete^{TM}'s manufacturing process is similar to the one of prefabricated elements. For the preparation of this type of concrete, High and Ultra High Performance Concretes are used, since that way better adhesion of the pellets and a more precise control of their position in the matrix can be achieved. Color of the matrix can be white, gray or anthracite or other colors like yellow, red, green etc. Glass particles may be positioned at any grid or pattern or in a random distribution. Glasse's sizes range from 0,7mm to 7mm with a standard size of 2mm; however, combinations of various sizes are possible [43]. Crucial for the reflective power are the roundness, clarity, and refractive index of the beads, as well as the bond between the glass microspheres and the substrate [45].

2.4.2 Pros and cons

Main properties of BlingCrete™ are its reflectivity, its high resistance to frost and de-icing salt, its excellent skid resistance, vandal resistance, its excellent grip, excellent fire resistance – non flammable, high alkali resistance [46]. However, there are many properties, such as slip resistance, chemical resistance, UV Resistance, stain resistance, solubility in water, thermal conductivity that are not specified yet.

2.4.3 Uses

BlingCrete™ may be used in Architecture, Interior Design, Retail Design, Industrial Design, Exhibition Design, Healthcare Design, Landscape Architecture, Transportation Design, Aviation, Spa /Health club interior, Hotel, Public Transport- tunneling and underground space projects [47]. Other potential applications of this type of concrete are safety-related marking of danger spots in construction (stairs, sidewalks, platform edges and tunnels), as well as the design of integrated guidance systems and novel surface components (façade, floor and ceiling).

Especially, after receiving the "International Tunneling & Underground Spaces Award", its use in internal tunneling is very promising [43].

Figure 8. BlingConcrete™ in tunnel [43]

2.5 Conductive concrete

2.5.1 Introduction

Removing ice from pavement can be accomplished by a combination of several means, such as melting naturally or by chemical treatment. Various deicing chemicals are available commercially, while the most common one is sodium chloride, which can be used sole or combined with fine aggregates. According to Nebraska Department of Roads officials, the deicing operation in Omaha uses road salt mixed with sand. The application rate ranges between 90-137 kgr/3,66m lane-mile and about 2000 tons of salt and 5000 tons of sand are usually used in a winter season [47]. However, the use of such chemicals may cause surface scaling or corrosion of reinforcement.

The electrically conductive concrete (Figure 9) is a type of concrete started to grow during last years. It differs from conventional one as it contains a proportion of electrically conductive components such as graphite, steel slag, stainless steel fiber and carbon fiber in its mixture in order to attain a stable and relatively high electrical conductivity [48].

Figure 9. Electronically conductive concrete [49]

Xie et al. (1995-1996) summarized existing know how in conductive concrete, where fibers or conductive aggregates had been used. When fibers are used, concrete shows increased strength but lower conductivity with a resistivity value of about 100 W.cm, due to the small fiber-to-fiber contact areas. On the other hand, addition of aggregates produces concrete with a higher conductivity and a resistivity value of 10 to 30W.cm, but relatively low compressive strength (less than 25 MPa), which is due to the high water content required during mixing to offset the water absorption by conductive aggregates, such as carbon black and coke. In particular, steel shavings with particle sizes ranging between 0.15 and 4.75 mm and steel fibers with four different aspect ratios between 18 and 53 were added to the concrete as conductive materials. However, there are many disadvantages that may come up by the production of conductive concrete; those may be the limited availability of supplies of steel shavings, the need for further treatment/cleaning in case steel shavings are contaminated and finally the fact that steel shavings pose a safety hazard for handling and a specialized mixing procedure is required in order to ensure uniform distribution [50,51].

Yehia and Tuan, 1998 have developed at the Institute for Research in Construction, National Research Council of Canada an innovative concept of using an "electrically conductive" concrete, which when it is connected to a power source, heat is generated due to the electrical resistance in the cement admixture with metallic particles and steel fibers and can be used for deicing and anti-icing. Coke breeze (combination of steel shaving from steel fabrication and steel fibers) is mixed with cement in order to increase electrical conductivity of concrete. The simplest power source for heating the conductive concrete overlay is DC power. Through a regulated power supply, an AC power can be transformed to the required voltage and current depending on the resistance of the specimens. The voltage should not exceed 48 volts, which is the safe threshold of a human being. One alternative to power conductive concrete overlay is to use photovoltaic (PV) power generation [52].

In 2001, Tuan & Yehia developed a conductive concrete by using carbon fiber and steel fibers. The carbon powder was used to replace the steel shavings of the conductive concrete developed earlier in 1998. The mixture had a compressive strength of 4500 psi and providing an average heating power 55 W / square feet with a heating rate of 0.25 ° F / min to a cold environment [53].

Table 5. Indicative characteristics of conductive concrete with carbon products (25% per volume) added to the steel fibres (1,5% v. of concrete)

Tests	Results
Modulus of elasticity (MPa)	27.565
Compressive strength (MPa)	41-55
Flexural strength (MPa)	5.3-5.9
Rapid freeze-thaw resistance	None of the specimen failed after 300 cycles

Current conductive concrete has been used at a demonstration project in RocaNeb in 2002. Conductive concrete mix with carbon powder and steel fibers was used to cast a ~10cm inlay for the deicing application in Roca Spur Bridge. The conductive concrete deicing system has shown excellent deicing performance at least for five years [53].

Moreover, research on a conductive mortar, made of calcination of ceramic matrix and dispersed graphite powder has been studied as far as electrical resistivity and piezoresistivity (change of the

electrical resistivity with stress/strain) is concerned. Addition of 10 wt%, graphite powder and a conductive aggregate volume of 30%, including 0,6% vol. carbon fiber resulted in mortar with good characteristics and lower by one or two orders of magnitude resistivity of the conductive aggregate mortar (CAM) compared to conventional one. To improve the dispersibility of carbon fiber and the flowability of mortar, small amounts of hydroxypropyl methylcellulose and polycarboxylic superplasticizer were used [54].
Wu et al, 2015 [55] examined conductive concrete for pavement deicing by the use of steel fiber, carbon fiber, and steel fiber-graphite as far as compressive strength and electric performance is concerned. Main composition of conductive concrete was cement Portland I42,5, coarse aggregates of maximum size of 16mm, medium sand with a ratio of 0.44, naphthalene superplasticizer which can reduce 20% of water by a 1% dosage of the cement mass, rust inhibitor in order to protect the steel fiber from corrosion, which is 1% of the cement mass, Hydroxy-propyl-methylcellulose as dispersive agent with a dosage of 0.4% of the cement mass in order to disperse the carbon fiber as well as graphite, up to 4%, 1% steel fiber and 0.4% carbon fiber with a particle size of 200 mesh. Three different sizes of graphite powder are used, and its carbon content is greater than 98%. The particle sizes of graphite are 200, 425, and 600 mesh, with a density range from 2.1 g/cm^3 to 2.3 g/cm^3. Main properties of steel and carbon fibres are showed on Table 6.

Table 6. Basic properties of steel and carbon fibres used for the production of conductive concrete [55]

Property	Steel fiber	Carbon fiber
Density (g/cm^3)	7.8	1.78
Length (mm)	35-40	6
Diameter	0.6 (mm)	7±0.2(μm)
Aspect ratio	50-70	NA
Electrical resistivity (20^{o}C)/(Ωcm)	1.3x10^{-4}	3x10^{-3}
Tensile strength (MPa)		3500
Tensile modulus (GPa)		200
Content of carbon (%)		≥93

This conductive concrete showed a compressive strength of 40MPa or greater, with a resistivity of 322Ωcm after 28 days. Heating experiments on this concrete resulted in an increase of specimen's temperature by 8.7^{o}C after 2.5 hours under 27V and 21.8^{o}C after 2 hours under 44V. Moreover, resistivity of concrete was found to decrease with temperature rising.

2.5.2 Pros and cons

Some advantages of this new type of concrete can be the increased road safety and traffic capacity, since many traffic accidents are caused by ice and snow on the road as well as the use of alternative to chemicals for deicing of road pavement or bridges decks leading to reinforcement's protection from corrosion due to the absence of Cl^-.
On the contrary, as any new technology, also conductive concrete has an increased cost due to the included conductive aggregates, special care during mixing with conductive aggregates should be taken (eg carbon fibres should be mixed uniformly inside concrete's matrix, with the addition of a carbon fiber dispersive agent, or it should be coated with resin in order to prevent fibers from spreading) as well as appropriate mixing time in order conductive aggregates to spread uniformly. Finally, when graphite is used, it should be taken into account its poor adhesion with cement matrix

2.5.3 Uses

Conductive concrete may be used as electromagnetic shielding often needed in the design and construction of facilities and equipment to protect electrical systems or electronic components, as radiation shielding in nuclear industry, as anti-static flooring in the instrumentation industry and hospitals as well as a cathodic protection of steel reinforcement in concrete structures [56]. Other covered fields by conductive concrete are building, road engineering, electric power, water conservancy and so on because of its electric conductivity, its electrocaloric effect and electromagnetic effect [48].

3. Conclusions

The growth of the world population, urbanization and industrialization have led to overconsumption of natural resources, increased energy waste and environmental pollution. The need for the development of new strategies and techniques, which will focus on a healthy living environment while ensuring conservation of natural resources and making cement and construction industry a more environmentally friendly sector, is considered more urgent than ever.

Development of new more environmentally friendly concretes such as light transmitting, pervious, self-healing, conductive, Blingcrete™ and more, is of crucial importance, since cement and concrete construction covers a great percentage of construction sector. Scientists focus their research on production of concrete mixtures with high mechanical strength but also longer life cycle through improvement of its durability. Towards this direction, basic components of concrete such as cement and aggregates are replaced partly or as whole by alternative materials. Those materials aim at decreasing the environmental footprint of concrete, while at the same time saving natural resources and utilize wastes or byproducts.

According to present review, it can be noted that the development of new concrete types is a sector with future and many potential, given specific applications and construction needs. However, taken into account disadvantages of examined concrete types, it can be easily concluded that the cost is an important factor that need further optimization, while some properties of concrete, such as strength or durability should be improved further at the lowest cost.

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