ENVIRONMENTAL CONCRETE: NEW WAYS OF BUILDING A GREEN PLANET

N Trindade, COBA, Engineering and Environmental Consultants, Portugal
S Lopes, Department of Civil Engineering, University of Coimbra, Portugal

Abstract

Concrete is, nowadays, the most common structural material used in construction. Due to its limited durability, to the extensive use of natural resources in its production and to the amount of residue generated by its use, the concrete, as it is known today, might not have a place in the near future, as demands for greener materials grow.
A new range of materials is, slowly but decisively, arriving. As far as concrete structures are concerned, a completely new material is unlikely to be invented and a reinvention of the traditional concrete would be the shape of things to come. The new concrete will be more sustainable, with a smaller carbon footprint and will also be easier to fabricate, and, at the same time, more efficient, durable and cheaper.
In this article the different members of this innovative family of concrete that, in what concerns to sustainability, are of the utmost importance in the genesis of a new civil construction philosophy, will be presented.

Keywords: Concrete, environment, sustainability, new materials

1. Introduction

The amount of available natural resources has been exponentially declining in a planet where the population growth increases everyday. It is predicted that at the present growth rate, the energy resource provisions, based in non-renewable sources in biosphere will be depleted in a very near future. The construction industry, due to the large amount of resources it consumes, the residues produced, its contribution to the global economy and environmental and social impacts, plays a decisive role in this problematic.

The sustainable use of concrete, a fundamental material in construction, is the ideal mean of profoundly intervene and stop the process of ecological and civilizational self destruction that is being carried on since the beginning of the 20’Th century.

New types of concrete first started to be developed with the objective of optimizing the production of traditional concrete, reducing its costs and improving its mechanical properties. With the generalization and massive adoption of sustainable development principles, with implications in all areas of society, the search for a concrete both economical and environmentally efficient has become a priority.

The quest for a consensual substitute of traditional concrete with Portland cement, regards different aspects. On one side, the development of sophisticated production methods and use of new materials, especially synthesized for integration in concrete, on the other, the promotion of recycling and incorporation of industrial sub-products.

The selection of an ideal environmental concrete seems obvious. The one that all together has the optimal mechanical, ecological and economical features. However, as we will see along this text, the choice of a substitute for the Portland cement concrete is not that evident.

2. Traditional concrete

Concrete is fundamentally constituted by four types of elements: the binder (cement), the aggregate, chemical admixtures and water. The homogeneous mix of the four elements is in liquid state in the beginning, evolving to solid, as its properties change over time. Only 28 days after its application the concrete achieves its characteristic strength.

The properties of hardened concrete are of the utmost importance and depend of the complex internal structure of this material.

The most common binder in traditional concrete is Portland cement. This cement is a predetermined, well balanced, chemical combination of calcium, silicon, iron and aluminium, subjected to a complex and rigorously controlled production process that involves a large number of operations.

Aggregate is the granular material with no pre-defined shape or volume and with adequate dimension and properties to be used in engineering structures. Suitable aggregates include crushed stone, river bed natural gravel and sand [1].

When concrete is being mixed, it is common procedure to include chemical admixtures, with the objective of modifying its properties. These substances constitute less than 5% of the total mass and can be classified according to its effect on concrete [2].

Water plays two important roles, the hydration of concrete and the humidification of the surface of aggregates, for better adhesion. The quality of the water used in mixtures, and particularly the particles it contains, has great influence over the chemical and physical properties of concrete.

3. Concrete and sustainability

Every construction activity implies the consumption of material and energy resources from the environment and the construction industry is one of the greatest responsible for this. The dilapidation of natural resources takes place during the gathering, production and transportation of the components of concrete as well as the manufacture of steel that incorporates the concrete as reinforcement and the execution of the structures in the construction site.

Only 1% of the water that exists in the planet is available for consumption and use in the human activity. Therefore it is understandable that the governments and international organizations have growing concerns about the control over the use of water and regulate its use, by licensing its consumption, limiting its exploitation, promoting the reuse and above all fomenting a careful management of this precious natural resource [3]. The industry of construction is one of the sectors that consume more water. The consumption of water accompanies practically all of the life-cycle of concrete, from the extraction of its virgin materials to the demolition of the concrete structures [4].

The fabrication processes of cement haven't suffered major modifications over the years, but the installations and technologies associated with this processes have evolved significantly, allowing the increase of production and the reduction of consumed energy. The making of cement originates the emission of carbon, sulphur and nitrogen oxides (COx, SOx e NOx) and dust [5]. A study made by the Japan Cement Association estimates that by each tonne of cement produced, 794.5 kg of CO2, 155 g of SOx, 1.68 kg of NOx and 60 g of dust are released to the atmosphere. About 90% of the CO2 emissions result from the production of clinker. This includes the decarbonation of limestone (60%) and the consumption of fuel (30%). The production of clinker is also the major responsible for the emission of NOx and dust. The biggest percentage of SOx emissions is associated with the production of the energy necessary to manufacture cement [5].

Aggregates are, in general, very stable materials, both physically and chemically and, therefore, hardly ever aggressive to the environment. The main problem is not the material itself, but the way it is used in the constructive activity – in massive quantities. The environmental impacts are a result of its production, transportation and unloading.

Sand and gravel originated from the dredging of rivers are the ideal aggregates, due to its round shape and appropriate distribution of sizes. Additionally, its obtainment is relatively simple and inexpensive. However the excessive extraction of aggregates from river beds, originates unbalances in fluvial ecosystems, disturbances in flood control and irreparable damages in natural landscape. The extraction of sand from sea bed, presents the same difficulties and problems. For this reasons it is in solid ground, through the crushing of stone that the most practical option resides, because after the extraction it is, at least, possible to carry out the reforestation of the affected areas.

The transportation of aggregates through long distances also implies the consumption of fuel in large amounts, which consequently originates significant CO2 emissions.

The industry of steel is one of the biggest consumers of fossil fuels. Approximately one billion tonnes of steel is produced each year, worldwide and a significant part of that steels is incorporated in concrete as reinforcement.

The production and subsequent transportation of concrete, originate, directly, substantial environmental impacts. One of the most serious consequences is global warming that comes from the consumption of electric energy and fossil fuels. Electric energy is used in silo storage, heating and cooling of the constituents of concrete and in the process of mixing. Fossil fuels are used also in the heating and cooling of the constituents of concrete and in the transportation to construction sites.

Because the production of concrete involves the release of SOx and NOx, it can also prompt the acidification of the environment. The acidification is the process of chemical alteration of the environment that results from the excess of acidifier substances in water and soil. The atmospheric deposition of NOx and SOx as a result of combustion is its main cause. The excess of these acidifier substances has negative effects on land and aquatic flora [6].

The production of concrete also leads to the accumulation of solid waste, which results from the returned concrete, from the aggregate in washing waters and in dehydrated mud.

Dust and noise are also negative effects of concrete production. Noise is mainly generated from ready mixed concrete installations, during the reception of the aggregate and loading of the transport trucks. Dust has its main origin in cement and aggregate silos.

During the execution of concrete structures, there are some environmental aspects to take into account. The installation of shutters and temporary structures, concrete pumping and vibration, result in the consumption of electric energy and fossil fuels that originate air pollution and global warming. The noise generated during the vibration of concrete and the solid waste originated from shuttering also have a negative influence in the natural environment.

An important aspect of the environmental effects of concrete, which is frequently forgotten, are the skin diseases originated from direct contact with fresh concrete or cement, due to the abrasive effect of alkali and chromates. Since July 2002 it is required by the European Union the signalling of the presence of chromates in the cement packages, when in quantities above 2 mg/kg [5].

The bleaching of concrete is a process in which organic and inorganic materials are washed-out, with the rain and soil water. It's the organic materials, especially heavy metals that have a negative influence on the environment.

4. Environmental Concrete

Concrete can be classified as environmental when, due to a multitude of reasons, it has low impact on nature. The environmental quality of concrete is related fundamentally with: the nature of the materials necessary to its production; its properties, especially durability and performance; the amplitude of its application and, above all, the inherent costs of its life-cycle, and its aggressiveness in the environment.

The careful selection of the raw materials to use in the production of concrete is of the utmost importance. Also the way in which those raw materials are obtained and transported must be optimized.

It's of fundamental importance a correct management of the water used in concrete. Starting in the planning stages, it is imperative to optimize the consumption and minimize the waste, for example, by promoting the reuse of resources. This control should be continued through the execution stage. The activity of water management allows a minimization of water consumption through the implementation of good technological and operational practices and reduction of the volume of waste water through the adoption of treatment and reuse measures.

The results obtained by the optimization of cement production are extremely positive from the environmental viewpoint, but the limits to that optimization are being reached. For that reason, other means of saving the natural resources are also being used. A good example is recycling, which is being increasingly adopted by the cement industry and that can promote up to 60% reduction in the environmental load [5]. The recycling activity can be performed, for instance, by using alternative fuels in the production of cement, via co-combustion of residues and fossil fuels. The emission of CO2 is enormously reduced with the adoption of this process, in detriment of incineration without recycling.

The reduction of CO2 emissions can also be achieved by using more energy efficient productive structures. An estimated 30% CO2 reduction has been obtained through the implementation of this measure by the cement producers [5]. Additionally, the type of cement should be selected and produced according to its application and the specific needs for durability, allowing the wider use of residue mixed cement as a substitute for Portland cement.

The effective reduction of SOx can be achieved though desulfuration of raw materials and fuels.

The decrease of NOx emissions can be accomplished by using controlled combustion and SNCR (Selective Non Catalytic Reduction) techniques. Electrostatic filters can be used to prevent the release of dust during cement production.

Environmental impacts regarding aggregates can be minimized through recycling or reuse of sub products. It's becoming very common the use of blast furnace slag as well as ash from domestic residues, glass, bricks and other ceramic waste, plastic and rubber. These materials are however not free from defects. For example, the use of glass as an aggregate may interfere with the strength, durability and even the prospect of recycling of concrete. Therefore the materials that can better substitute the traditional aggregates result from recycling of construction and demolition waste. For now they represent 1% of the total amount of aggregates used in the production of concrete [5].

Because the massive use of aggregates is unavoidable, it is important to have in mind three aspects that will affect directly the construction industry [5]:

- The average quality of the aggregate will decrease, because, due to environmental restrictions it will be more difficult to use exclusively good quality aggregate;
- The required performance of concrete will be diversified and therefore so will the quality of aggregate;
- The recycling of demolished concrete and the reuse of sub products will be accelerated, due to social pressure.

As a consequence, the construction industry has to adopt a politic of using the right materials in the right place and situation.

A way of attenuating the environmental sequels is by optimizing the means of transportation of raw materials so that the waiting time and distance are as short as possible.

The washing water of the equipments involved in transportation and production have a very basic PH, meaning that treatment is essential before being returned to natural watercourses. This treatment is made in condensation and decantation tanks, after which the water can be reused in new washes.

The volume of solid waste can be reduced by correct planning of the quantities needed in the construction site.

To reduce the noise generated by the transportation of aggregates, the concrete-mixer trucks, receptacle, can be coated with rubber. Dust can be avoided by hermetically sealing the silos [5].

During the execution of concrete structures, the shuttering residues can be avoided through the use of reusable shutters, or in alternative, by using recyclable shutters. The noise generated by the vibration of concrete can be prevented by using self-compactable concrete that needs no consolidation.

Human diseases that result from direct contact with cement or fresh concrete can be avoided by reducing the amount of chromates in cement.

In the design stage of concrete structures some measures should be taken into account. The development of low-energy, long-lasting yet flexible buildings and structures, the exploiting of the thermal mass of concrete in a structure to reduce energy demand and the planning of the restoration after activity has ceased.

5. Different groups of environmental concrete

Depending on its characteristics, three major groups of environmental concrete can be acknowledged. On one side, those that, by its use of improved constituents and production processes, possess superior characteristics, in particular, durability. On the other side those that, by incorporating industrial sub products in its constitution, liberate the environment from the waste that, otherwise, if disposed would have serious ecological consequences. And finally, those that aggregate the features of the two previous groups, by concatenating excellent economical and mechanical characteristics with the reuse of detritus from industrialized production activities.

6. Types of environmental concrete

The cement and concrete industries face challenges related with the enhancement of durability and performance while increasing the sustainability in production. For each tonne of Portland cement produced, about a tonne of CO_2 is released. The cement industry contributes with 7% of the total emissions to the atmosphere. The cement industry is also associated with large energy consumption, about 4 GJ per tonne, only overcome by the aluminum and steel production [7].

It is urgent to reduce the consumption of this material without compromising the necessary performance of concrete structures [8].

6.1. High performance concrete with fly ash

Due to the high amounts used in construction, concrete is the perfect vehicle for the safe and economical incorporation of millions of tonnes of residues and industrial sub-products, like fly ash, originated in thermoelectric plants [7].

It is estimated that the annual production of ashes, worldwide, exceeds 700 millions tonnes. At least 70% (about 500 million tonnes) are fly ashes, with potential to be used as pozolanic addition to concrete [9]. Nonetheless, in the past, almost 75% of fly ash produced made its way to landfills and today only 20% are used to produce cement and concrete. To assure a sustainable development of the concrete industry, the use of pozolanic and cement-like sub products must be encouraged and substantially increased [7].

Therefore, the replacement of large quantities of cement by fly ashes is highly advantageous, economically, in terms of energy efficiency, durability and ecological and environmental benefits in general.

In specific situations, the use of conventional concrete is economically inadequate, because of premature degradation, with subsequent high maintenance and repair costs as well as the drastic reduction of the life of the structure. The amount of high performance concrete used in construction has been increasing and has been used in a wider range of applications. This type of concrete can be obtained by adding high quality silica fume or fly ashes to conveniently selected aggregate. Therefore, the initial cost of high performance concrete, when compared with conventional concrete is substantially raised, which means it can only be used in a limited number of special structures. It is fundamental that the improvement of the performance of conventional concrete is made through the incorporation of low quality fly ashes and regular aggregates.

To reduce the costs of production it is necessary to use high dosages of fly ashes, allowing the extensive use of this industrial sub product and contributing to minimize the environmental impacts [8].

It is possible to produce high performance concrete with fly ash substitution reaching 40%, keeping the compression resistance similar to mixes without fly ash incorporation. The workability and durability of concrete are also improved with the addition of fly ashes. The replacement of 60% of cement by fly ashes originates concrete with inferior mechanical characteristics, nonetheless, and considering the little amount of cement used, it’s compelling to verify that the workability and durability still increase. Even in this case, and in certain circumstances, it can be considered that this mixes have improved performance and especially enhanced economic and environmental characteristics. This demonstrates that it is possible to improve workability, mechanical performance and durability of concrete, without, necessarily, increasing its cost [8].

From the experimental results obtained by Camões, 2005 [10], it is possible to take the following conclusions about high performance fly-ash concrete:

- High values of resistance to compression can be achieved;
- In what concerns to long term resistance, this type of concrete has advantages over traditional concrete;
- The incorporation of a copolimeric last generation super-plastifier, allows the production of high performance fly-ash concrete with high workability and reduction of the amount of water necessary to prepare the mix.

Consequently, high performance concrete with high volume of fly-ashes has higher workability, durability, sustainability and lower cost than conventional concrete.

6.2. Blast furnace slag concrete

Another by-product that can be recycled and integrated as a cement substitute in concrete is Blast Furnace Slag. It is a non-metallic material, consisting primarily of silicates, aluminosilicates, and calcium-alumina-silicates and obtained in the production of iron.

It is created by grinding a pelletized or granulated iron blast furnace slag to cement fineness. “Molten slag—the non-metallic minerals remaining after the iron is removed—is tapped from the blast furnace. At this point, slag can either become a waste, a construction aggregate or a hydraulic cement. If air cooled, slag can be recovered as a non-cementitious lightweight aggregate. Alternatively, if molten slag is rapidly quenched with large amounts of water in a controlled process, it becomes “granulated”, the consistency of sand. The rapid cooling of molten slag prohibits formation of crystalline compounds, and produces instead glassy “granules” which, when ground to a fine powder, become a hydraulic cement, known as slag cement (also referred to as ground granulated blast furnace slag)” [11].

Similar to fly ash, but much easier to find, “slag” as it is commonly referred, creates very strong cementitious material when mixed with lime and water.

Slag is usually integrated by directly replacing a fraction of Portland cement in a concrete mix (25 to 80 percent, depending on the application). The obtained concrete possesses improved workability and pumpability, increased durability, 28 day strength and sulphate resistance, reduced permeability and heat of hydration and better control over the alkali silica reaction, sulphate attack and corrosion of reinforcing steel [12].

The extensive use of slag cement improves considerably the sustainability of concrete structures. On one side it allows the reuse of industrial waste that otherwise would be disposed and accumulated in landfills. On the other side it contributes to the reduction of virgin material required to fabricate concrete. It also reduces inherent energy and greenhouse gases in concrete.

Blast furnace slag can be integrated with concrete in high percentages, up to 50 percent of the total for paving and structural mixes. Many gravity and mass concrete structures employ 65 to 80 percent slag cement to decrease heat generation. These high replacement rates in everyday concrete significantly reduce the embodied greenhouse gas emissions and energy in concrete by reducing the need for Portland cement [11].

Slag cement concrete also has some advantages regarding its application. When applied during hot weather, the process is simplified because set times in the concrete are lengthened. However, in cold weather, slag replacement rates are usually lowered due to its effect on set time [12].

6.3. Geoconcrete

The essential difference between Geoconcrete and traditional concrete is in the binder and in the liquid activator used. While in the traditional concrete, Portland cement is the binder and water is used as the activator, in Geoconcrete, the binder can be obtained from any material, named the precursor, that contains silica, alumina and, eventually, calcium, in the form of oxide or hydroxide. The activator is formed by an alkali. The process of alkali activation reverses the series of natural chemical reactions of degradation of silica stones with the obtainment of clay. Starting with clay or other materials with similar chemical composition, it is possible, at a certain temperature and pressure and in a short period of time, to transform the precursor in a solid material with mechanical capacity and with reasonable chemical and thermal inertia.

With this process it is possible to obtain superior resistances (160 MPa in simple compression and 17 MPa in flexo-traction) [13] to the ones obtained with high performance, Portland cement, concrete. Furthermore, the reaction time can be very quick, ranging from hours to days, if necessary. Depending on the activation conditions, the hardening and attainment of mechanical resistance are normally achieved in a shorter time than traditional concretes.

Products obtained by alkali activation also have a great resistance to the attack of acids and are not susceptible to alkali-aggregate reaction or to the action of sulphates, as long as there is no calcium in its constitution. This concrete can also resist to high temperatures, between 900 and 1000 ºC and its resistance to attrition is superior to the obtained with traditional concrete [13].

One of the biggest advantages is the possibility of incorporation of construction and demolition waste and because most of this waste is formed by concrete, ceramic products, porcelain and stone, these can be used as binders, after inexpensive transformation. This transformation includes grinding to increase the reactive susceptibility and dehydration.

Geoconcrete has multiple applications and it can even be more versatile than Portland cement concrete.

One of the enormous advantages of this type of concrete is the fact that it generates five times less greenhouse gases than traditional concrete [13].

6.4. Geopolymers Concrete (E-Crete)

Another example of the use of alkali-activated binders is the Geopolymers based concrete. Geopolymers are inorganic polymers (synthetic aluminosilicate) produced from industrial waste or by-products, including fly ash and bottom ash from power stations, blast furnace slag from iron making plants, and concrete waste. After transformation, this source materials form a solid binder very similar to Portland cement, both in its performance and applications. This material can be integrated in concrete, as a partial or total substitute for Portland cement.

One of the main advantages of Geopolymers cement resides in the way it is produced. While the manufacture of Portland cement requires intensive energy use, especially due to the high temperature needed to drive the calcination of limestone, the synthesis of Geopolymers uses very little energy, mainly because of the absence of such step. Furthermore, during the calcination stage, large amounts of CO2 are released to the environment (approximately 60% of the total CO2 produced in cement manufacture arises from the calcination reaction itself)

While the activators used in geopolymers processing produce some Greenhouse gases, the overall CO2 saving due to widespread geopolymer utilisation is in the order of 80-90% when compared with Portland cement. Other enhanced properties like superior resistance to fire and aggressive chemicals increase the economical viability and sustainability of this type of concrete [14].

6.5. Rice hulls ash concrete

Rice hull is one of the most abundant agriculture residues worldwide that does not have a direct application. It can be used in the form of ash, with pozolanic characteristics, as a partial substitute of Portland cement.

This raw material corresponds to 1/5 of the 300 million tonnes of rice produced annually, worldwide [15].

Due to its physical and chemical particularities, namely low density, abrasive characteristics, low nutritious value and high silica content, only a small portion of this sub-product is used, creating considerable problems in terms of storage.

One of the ways of reducing this waste is by incineration. The controlled combustion in industrial furnaces is used both as an energy source and as a mean of obtaining a highly pozolanic ash with a cellular structure that has a high specific surface. About 2.0*106 J/kg of heat is produced in the process of combustion of the rice hull, resulting in 20% of ash with high silica content. Depending on the efficiency of the combustion, the ash can contain as much as 95% silica [15].

The most promising use of this sub product is its application in the concrete industry, as a main constituent of concrete, along with clinker, due to its high content in silica that the hulls have.

Cement substitutes like rice hulls ash constitute an invaluable resource in countries that produce rice but have low economical capabilities to produce or import Portland cement. And in this case, this constituent of concrete can be produced in a very simple way.

This material represents an important value for the cement industry. Not only solves the problem of deposition and storing of this sub product but it can create new jobs and reduce economical and energy costs. But one of the most important characteristics of rice hulls ash is the improvement of the durability of concrete. Therefore it contributes to a more sustainable construction not only because of the use of a residue, but also because of the improvement of the properties of concrete [15].

6.6. Carbon emissions absorbing concrete

Several companies are developing a new generation of green concrete that in addition to having a low production carbon footprint and being highly recyclable is capable of absorbing and locking significant amounts of atmospheric CO2 into the material itself. These materials are obtained by utilizing magnesium oxide and special mineral additives, causing minimal CO2 emissions (less than 0.5 tonnes of CO2 per ton of cement) [16] and requiring low temperature processing. [17]

The absorption of Carbon Dioxide happens during the hardening of the concrete. The process, known as concrete carbonation, occurs naturally as concrete cures and what this new systems do is improving storage capacity of CO2 in concrete [18].

One of the additives that allows concrete to behave this way is a calcined magnesite (magnesium carbonate, found in relative abundance in nature) based, reactive material named "Magnesia". By blending this material with conventional cement, the Magnesia hydrates to magnesium hydroxide and a concrete capable of absorbing larger quantities of CO2 during carbonation is obtained. The more magnesia added to the mix and the more permeable the concrete is, the more CO2 can be absorbed. A typical concrete block made with this material is expected to fully carbonate within a year.

Because of the low alkaline nature of this mix, bigger quantities (and many different types) of waste materials can be added, without reducing the strength of the concrete. Portland cement concretes on the other hand can't include such large amounts because of the formation of alkaline lime that causes delayed and disruptive reactions [19].

Other possible additive is the green-colored mineral Olivine, used as a supplement material. This mineral, with a relatively short weather resistance time, when integrated in concrete with high porosity, as a substitute for sand and gravel, is capable to absorb, in the course of his life, an estimated ten times more CO2 from the air than the amount of CO2 liberated in the concrete production. This offers the unique and innovative possibility of development of a “carbon negative” range of concrete products [20].

Companies researching this type of concrete also defend its improved durability, resistance to shrinking and cracking, and reduced permeability to water. Although still in tests if it successfully proves itself, in industrial trials, suitable for large-scale construction projects, this type of concrete is expected to arrive in the market within a few years. Furthermore, for now most of these systems are optimized for precast concrete, but are being enhanced to adapt to other concrete applications [20].

6.7. Ultra High Performance Concrete

Durability and performance are the two main characteristics that classify high performance concrete as environmental. Much denser than usual, this concrete has improved mechanical characteristics, with higher tensile and flexural (bending) strength. As a consequence, up to three times less concrete is needed to achieve the same results, allowing thinner structures that can span greater distances.
In many situations, ultra high performance concrete structures can be built without conventional reinforcement or prestressing steel, giving engineers the unique possibility to design complicated, curved geometrical shapes that otherwise could not be possible or would require advanced technical means and planning, with the addition that these structures can be cast on site.

Even higher resistance values can be achieved through steel or organic fiber-reinforcement.
The high density of this type of concrete makes it virtually impermeable to corrosion from abrasion and chemicals, resulting in longer-lasting structures that cost less to maintain and result in a lower carbon burden during its live-cycle.

Although more expensive than traditional concrete, the fact that it doesn't need steel reinforcement, makes it competitive and economically viable. Moreover, the high environmental impact of steel production, both in virgin materials exploitation and energy used during production, is avoided. No steel means also that there will be no corrosion with the consequent resulting costly (both economic and ecological) repairs.

Further advantages result from the obvious fact that lighter structures require smaller foundations with less associated labor and equipment [21].

6.8. Other examples

In addition to cement substitutes, there are other ways of making concrete equally sustainable, based on the core environmental principles, recycling and reduction. Many materials can be used as recycled aggregate, like construction and demolition residues, fibreglass, discarded glass, granulated plastics, wood products, old tires or waste paper. Other alternatives, such as glass fibre reinforced concrete, foam and ceramic based concrete, because they take less energy to produce or are stronger than traditional mixes, can reduce the overall amount of concrete in use, resulting in decreased emissions and energy expenditures [22].

More specific products like “Grasscrete” which is a method of laying concrete in a checkered, cellular pattern, allowing grass to grow between the concrete blocks resulting in less concrete used and improved drainage [23] or “Carbon Concrete”, an oil refinery by-product, thermoplastic based cement substitute, for flooring and paved roads, also give their contribution to a more sustainable concrete market.

Housing construction materials/methods like “Grancrete” which is a reinforcement-free ceramic concrete are specially designed for simplicity and therefore adequate for the suppression of lack of adequate construction resources in 3rd world countries. This material is simultaneously durable and completely biodegradable and can be easily manufactured from locally available materials and magnesium oxide/potassium phosphate made binder [24].

7. Conclusion

The solution to the environmental problems associated with the concrete live-cycle does not lie in the replacement of concrete by other construction materials. Instead it resides on the reduction of the impacts of concrete and cement, in nature.

Due to the massive use of concrete nowadays, even a small decrease in the environmental impact of each ton of concrete produced, would result in large environmental benefits. The advantages of transitioning from traditional concrete to environmental concrete are enormous and this can be achieved with the means that society used to come up with concrete in the first place, innovation and technology.

New types of concrete, greener and more sustainable are being presented everyday. Universities, investigation centres and even major companies are realizing how huge the development of a carbon neutral or negative concrete, with high performance and durability that could, in addition, integrate sub products of other pollutant industrial activities, could be and the impact it would have in our way of life and our planet.

Due to the fact that only a few types of green concrete have been widely used and tested, and also because none of them have simultaneously all the ideal characteristics, previously mentioned, there isn't a general consensus to which one presents the most advantages. Nonetheless, the reduction of the aggressions to the environment is common to all.

The decisive environment concrete has yet to be created, or at least generally accepted. A few of the most widespread solutions, like fly ash and slag concrete, seem to be a good answer for the immediate, but even they have not been tested in a long term. Some of the new concepts and ideas and even green concrete products giving their first steps in the construction market are very promising and acclaimed by many as the concrete of the future.

References

[1] Petrucci, E. (1998). *Concreto de Cimento Portland*. Globo, São Paulo.
[2] Almeida, E. (2005). *Tecnologia do Betão - Adjuvantes Para Betão*. Universidade do Algarve, Faro.
[3] Associação Portuguesa de Betão Pronto (APEB), (2003). *Guia do Ambiente para a Indústria de Betão Pront*o. APEB, Lisboa.
[4] Mateus, R. and Bragança, L. (2006). *Tecnologias Construtivas Para a Sustentabilidade da Construção*. Prometeu, Porto.
[5] Fédération Internationale du Béton (FIB), (2004). *Environmental Design*. Bulletin 23, Lausanne, Switzerland.
[6] Carvalho, M. (2007). *Stepwise EPD - A Declaração Ambiental do Produto e o Betão Pronto*. Betão - Revista da Associação Portuguesa das Empresas de Betão Pronto, nº18, Págs.19-24.
[7] Malhotra, V. and Mehta, P. (2002). *High Performance, High Volume Fly Ash Concrete:Materials, Mixture Proportioning, Properties, Construction Practice, and Case Histories*. CANMET, Ottawa, Canada.
[8] Camões, A. (2002). *Betões de elevado desempenho com incorporação de cinzas volantes*. Universidade do Minho, Departamento de Engenharia Civil, Guimarães.
[9] Mehta, P. (1999). *Concrete Technology for Suitable Development*. Concrete International pp. 47-53.
[10] Camões, A. (2005). *Betões de Elevado Desempenho com Elevado Volume de Cinzas Volantes*. Universidade do Minho, Departamento de Engenharia Civil, Guimarães.
[11] Prusinski, J., Marceau, M. and VanGeem M. (2005). *Life Cycle Inventory of Slag Cement Concrete*. International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Skokie, IL.
[12] Freelists (2009). *Green concrete: fly ash vs. slag cement*. www.freelists.org (oficial internet site).
[13] Associação das Empresas de Construção e Obras Públicas (AECOPS) (2007), *Novo betão nasce dos RCD*. www.aecops.pt. AECOPS (oficial internet site).
[14] Zeobond (2009), www.zeobond.com. (oficial internet site).
[15] Urbanismo & Construção (2006). *Betão com Cinza de Casca de Arroz*. Artigo da revista Urbanismo & Construção, Portugal.
[16] Green Futures Magazine (2009), www.forumforthefuture.org/greenfutures. (oficial internet site).
[17] Novacem (2009), www.novacem.com. (oficial internet site).
[18] Inhabitat (2009). *New Precast Concrete Sucks CO2 Out of the Air*, www.inhabitat.com. (oficial internet site).
[19] Tec Eco (2009). *Eco-Cement*, www.tececo.com. (oficial internet site).
[20] Cement & Concrete Centre (2009). *Green concrete absorbs CO2*, www.materia.nl. (oficial internet site).
[21] Deem, S. (2002). *New Concrete Technologies From France*. Popular Mechanics June 2002 issue, USA
[22] Green Living Ideas (2009). *Can Concrete Be Eco-Friendly?*, greenlivingideas.com. (oficial internet site).
[23] Grass Concrete (2009). www.grasscrete.com. (oficial internet site).
[24] Grancrete (2009). www.grancrete.net. (oficial internet site).