The Environmental Impact of Recycled Concrete

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Abstract

Concrete is a building material used worldwide and consumes large amounts of raw materials. The concrete structure is cheaper than steel structures; the raw materials can be found in almost anywhere and can be moulded easily. Nevertheless, the concrete industry produces a lot of waste and the old concrete many times goes to landfills. The aim of this work is identify, in a critical way, the aspects related to the concrete used in the 'sustainable' architecture developed nowadays. Concrete has many advantages respect other materials, but can not be recycled in the same way if compare to metals, for instance. Actually, it occurs a downcycling, because the old concrete is transformed in recycled aggregate and the new concrete made with this recycled aggregate needs new cement. Sand, gravel, limestone and other materials many times are extracted from nature on a destructive way. The recycled aggregate production is about 5% of the total aggregates needed to supply the construction industry. As other industries, the transformation activities to produce concrete generate waste. The standards are mostly conservative and the amount of recycled concrete aggregates used normally does not exceed 20% in weight on coarse aggregates. Furthermore, there is always a residual concrete which is located at the concrete mixer truck at the end of each day. This concrete is treated as a waste and many times is discarded with no or little environmental control. These and other factors contribute to reduce the natural resources and to increase the amount of waste. From the development of this paper it can be noticed that the actual recycled concrete can not be characterized as sustainable, because there are many issues that must be solved until it becomes a real sustainable material.

Keywords: sustainability, concrete, recycling, waste

1. Introduction

Concrete is a compound material many used in buildings, mainly in multi-storey buildings. Cement is a material that needs 1 to 1.5 metric ton of lime; uses a lot of energy for its production, around 4000 MJ/metric ton and releases 0.8 to 2 metric ton of carbon dioxide to the atmosphere to produce the clinker (Kumar et al, 2006). A building made of reinforced concrete structure is demolished at the end of its lifecycle and its residues are normally sent to the landfills. Nevertheless, all the concrete mass treated as waste can be incorporated into new concretes in the form of aggregates. Another issue that helps to increase recycling aggregate is the difficult to find natural aggregates locally (Topçu and Günçan, 1995). The higher price of natural aggregates contributes to increasing the concrete price and decreasing the materials resources available for next generations. Transport of such aggregates is a problem of costs too, because aggregates are heavy and low-price products.

2. Recycled aggregates

Natural aggregates are products made of sand and crushed stone; and recycling aggregates are made mainly of crushed concrete and asphalt pavement (Goonan, 2000). According to the same author, natural aggregates corresponded to 36% of total raw materials produced by United States in 1900. There was a growth in production along six decades, which increased the proportion of natural aggregates up to 70% respect to the total raw materials. Since these years the percentage of natural aggregates is more and less steady, around 70 to 73% of all raw materials demand.

Aggregates are the most used materials in the world, because they are available in almost sites on the planet, which makes their price is very low. Only in United States are extracted 3,000 million metric tons of coarse and fine aggregates per year. It has started to study the applications of recycled aggregates in concrete in the way to diminishing the environmental impact caused by natural aggregate extraction, due to the enormous quantity of natural aggregate used in buildings construction. Normally, the decision of sending the construction and demolition wastes to the landfills or to a recycling plant is responsibility of a firm contracted to demolish the building (Goonan, 2000). In this case, the firm studies economic aspects and local laws. Goonan (2000) argues that the recycled aggregates market in The United States correspond to 5% of the total aggregates market of that country and are used in low cost applications. One of the causes of this low percentage is the fact that recycled aggregates of construction and demolition wastes do not have uniform quality. From this, test results can be very different, which decreases the confidence of architects and engineers for using recycled aggregates. However, many researches have been made in this area to create standards and recommendations with the aim to encourage the use of recycled aggregates.

Some of the limitations in using recycled aggregates are respect to transport, the quality of aggregates and the raw materials availability which in this case is highways and buildings that will be demolished. Transportation cost has to be low and the demand for demolishing structures must guarantee a constant supply of aggregates and force the market to stay at large cities. The growing urbanization, mainly after The Second World War has created a great demand for new buildings and the demand for natural aggregates too. Nowadays, these same buildings do not comply with the new standards and many are demolished to take place to new ones. Therefore, large cities now are converted into urban deposits of recycled aggregates. The production of recycled aggregates in The United States is around 140 million metric tons per year, which correspond to 5% of total aggregate market (Taylor, 2007). The machinery normally used for natural aggregates transformation can not be used for recycled aggregates due to the metal content in the concrete; and metal must be sorted from aggregates (Wilburn y Goonan, 1998). Concretes that will be recycled are previously sorted to remove products which are not concrete or masonry at building site. From this point, there are basically two methods to obtain recycled aggregates from concrete. One is crushed the concrete at a recycling plant facility and the other one is with a mobile plant. Each method uses basically the same procedures.

The quality of materials which arrives at the recycling facilities is the part that recyclers have little or no control, due to the wide range of variety of materials transported from different sources. Construction and demolition wastes contain non metallic materials, such as wood and plastic that must be collected. The energy types employed to processing and transporting the recycled aggregates are electricity and diesel. Wilburn y Goonan (1998), estimated that the energy necessary to process one metric ton of concrete into recycled aggregates is 34 MJ, for processing one metric ton of recycled asphalt aggregate requires 16.5 MJ and to process one metric ton of natural aggregates is 5.8 MJ. The high difference in energy consumption between recycled and natural aggregates is due mainly to the labour in identify and remove materials like wood, plastic and glass from construction and demolition wastes for further processing. Energy values for transport are 2.7 MJ/metric ton-kilometre for fine aggregate and 3.8 MJ/metric ton-kilometre for coarse and recycled aggregates (Wilburn y Goonan, 1998).

3. Carbonation of CO_2

Carbonation is a chemical reaction in which calcium hydroxide present in cement reacts with carbon dioxide in the air and the result is calcium carbonate. Carbonation increases concrete resistance with the past of the years. However, when steel is used as reinforced concrete carbonation can be a problem, because carbonation decreases concrete pH. This can cause oxidation of steel and hence structural problems. Dodoo et al (2009) investigated the carbon cycle of a building with reinforced concrete and wood-frame structure. The work demonstrates that construction phase releases the most carbon dioxide of all building life-cycle. These authors made calculations to determine the amount of carbon dioxide absorbed by concrete through carbonation during the building life-cycle. Recycled concrete has a high CO_2 absorption rate respect the same concrete used as structure (figure 1). Carbonation in wood-frame structures showed in figure 1 is due to the concrete used as foundations. The carbonation rate of concrete in wood-frame structure is low because concrete is underground land and reacts slowly than concrete exposed to air.

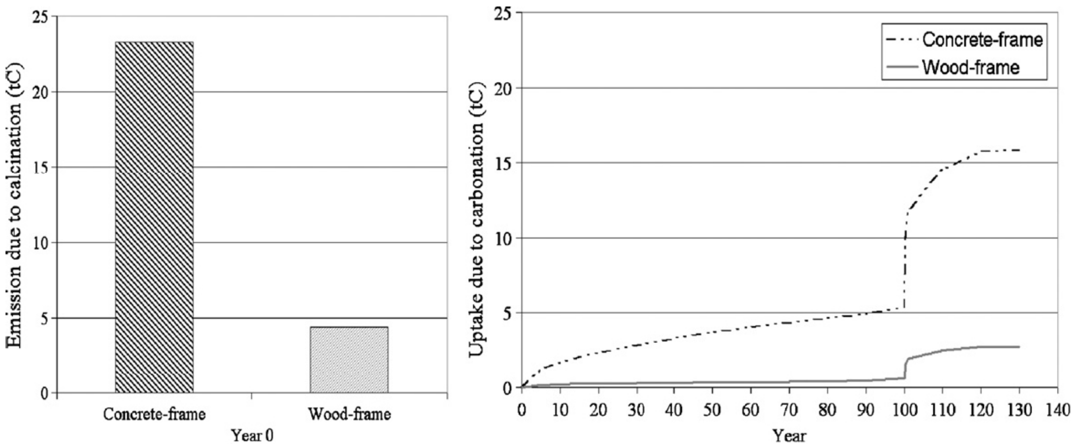

Figure 1 Carbon flows through cement calcination (left) and carbonation of concrete and cement mortar during the service life and after demolition (right) for the concrete and wood-frame buildings (Dodoo et al, 2009)

Carbonation presented in figure 1 is due mainly to the exposed area of crushed concrete which is higher at recycling facility yards or building sites than the interiors of buildings. The most marked difference in carbonation is in the first 4 months of demolished concrete. Concrete can absorb up to 68% of carbon dioxide released in concrete calcination, for a building service life of 100 years and subsequent recycling of this concrete. However, non-renewable energy resources used to crush and transport concrete to recycling plants do not allow high gains of carbonation. Steel structure recovered during crushing and separation operations of concrete contribute to the carbon cycle because steel recovered from structure can be recycled.

4. Characteristics of recycled concrete aggregate

The international literature provided numerous works at recycled concrete aggregate area, mainly from the beginning of 1980 (Hansen, 1992). The topics most investigated are durability and mechanical characteristics. The quality of aggregates made of recycled concrete affects directly the properties of new concrete mixes. Some recycled aggregate properties, such as dimensions, resistances and water absorption are investigated. Aggregates influence directly porosity and mechanical resistance, among other characteristics because the proportion content of aggregates in concrete varies around 70 to 80% in mass and therefore affects the quality of concrete. Investigations in this area are divided in two types: one type is with natural fine aggregates and coarse recycled aggregates; another group is with fine and coarse aggregates partially or totally made with recycled concrete. The percentage of recycled aggregates has influence on the new concrete properties too. Absorption is an aspect that is investigated a lot, because water is the primary agent which can degrade materials. Water transports aggressive agents to concrete and it can cause chemical and physical problems in concrete structures and this affects concrete durability (Levy y Helene, 2004).

4.1 Aggregates absorption

Water absorption of masonry recycled aggregates, concrete recycled aggregates and the mixtures of two ones must be a maximum of 20%, 10% and 3% respectively in mass of aggregates (Rilem, 1994). Sagoe-Crentsil et al (2001) investigated the relation between fine natural aggregates and coarse recycled aggregates and they shown that coarse recycled aggregates have 5.6% of water absorption and that fine natural aggregates have 1% of water absorption. The authors argue that de difference is due partially to mortar wastes which are presented in the recycled aggregates. Gómez-Soberón, (2002) observed in his investigation that water absorption in recycled concrete aggregates varies from 5.8 to 6.8%, while water absorption in natural aggregates varies from 0.9 to 1.1%.

Katz (2003) investigated the compressive strength of concrete which was crushed to serve as a source of aggregate for new concretes. In the investigation it can be noted that as smaller is the crushed aggregate as higher is the water absorption. Coarse aggregates among 9.54 to 25 mm had absorption of 3.3% in 28 days. Medium aggregates (2.36 to 9.5mm) had 8% and fine aggregates (less than 2.36mm) had 12.7% of water absorption. These differences in porosity are due to the high cement content presented in fine aggregates. The percentage of old cement in aggregates is 6.8% to coarse, 13.2% to medium and 24.5% to fine aggregates. In comparison, natural aggregates have low porosity and its absorption percentage varies from 0.5 to 1.5%. Mortars are less dense and more permeable to water then natural aggregate, because it is function of concrete age and the quality of mortar presented in the concrete (Gómez-Soberón, 2002). Levy y Helene (2004) measured the water absorption of natural, concrete and masonry aggregates. Natural aggregate has absorption between 0.8-1.8% for coarse and fine respectively. Recycled concrete aggregate has 5.6% for coarse and 7.9% for fine aggregates. Recycled masonry aggregate obtained 7.9% for coarse and 13% for fine aggregates. The researchers recommend that recycled aggregates must be saturated before put them in the mix in the way to not reduce the workability of fresh concrete by high absorption rates.

4.2 Compressive, tensile and flexural strengths

Respect to the compressive strength, tests with concrete with coarse recycled aggregates carried out by Sagoe-Crentsil et al (2001) demonstrated that there is no difference superior to 5% with a coarse recycled aggregate content up to 23%. On the other hand, Gómez-Soberón, (2002) founded a reduction about 11% in the compressive strength between specimens made of 100% recycled aggregates respect to specimens made of natural aggregates only. However, when it was a 30% replacement of natural aggregates, the compressive strength decreased 5%. Tensile strength of a concrete with recycled aggregates has 10% lower strength that concrete made of natural aggregate and it maintained steady up to 90 days of tests.

Katz (2003) obtained different results. According to his investigation, the values of compressive strength of concrete made of with 100% recycled aggregates are 24% lower in comparison to concrete made of natural aggregate. Etxeberria et al (2007) tried to obtain concrete mixes with recycled aggregates with the same strengths to concretes made of natural aggregates. The mixes studied have natural aggregate replacement rates between 25%, 50% and 100%. The results shown that concrete with 25% replacement obtained practically the same compressive and tensile strengths then the control concrete. However, concretes with 100% natural aggregate replacement must have its cement content increased in 12% and diminishing its w/c ratio in 20% in order to obtain the same resistances to those conventional concretes. For the same cement content and w/c ratio, the compressive strength of concrete with 100% natural aggregate replacement drops 20 to 25% respect concretes made of natural aggregates only. (Etxeberria et al, 2007).

Ajdukiewicz y Kliszczewicz (2002) analyzed high performance concrete made of recycled aggregate. The aggregates used were recovered from high performance concrete structures demolished from 2 to 7 years. The authors tested six different groups. The first group is the control specimens with natural aggregates only; the second one is formed by 2-16mm recycled aggregates and natural quartz sand. The third group is made of 100% recycled aggregates. The tree last groups are the same of anterior groups with the addition of 3% of plasticizer and 10% of silica fume in mass of cement. The w/c ratio in all groups was 0.3-0.4. The test results shown that the addition of plasticizer and silica fume increases compressive strength 50% respect to the group of control. Concretes with 100% recycled aggregates and with those additions obtained superior resistances respect to the group of control.

4.3 Other factors

Creep is affected by the young's modulus. Gómez-Soberón, (2002) calculated the young's modulus for a concrete which uses recycled aggregates only and is 10% lower than concrete made of natural aggregate. The difference of young's modulus increases to 18% for tests carried out at 90 days. This means that concrete with recycled aggregates can be more suitable to long term deformation forces. Retraction of concrete with recycled aggregates was measured by Katz (2003) and the results show that this concrete has retraction around 0.7mm/m in comparison with 0.32mm/m encountered in conventional concrete. Li (2008) explains that the superior retraction observed in concrete with recycled aggregates is due mainly for two factors. The first one is that the old cement paste has superior retraction respect natural aggregates and the second one is that the water content necessary to adequate the mixture to the slump test is higher, which creates voids and therefore much more retraction.

Investigations are carried out to recycle the waste wash water produced in ready-mixed concrete plants and ready-mixed concrete trucks. According to Sandrolini y Franzoni (2001), each day exists an amount around 200-400 kg of concrete inside of concrete trucks. This fresh concrete is washed out and aggregates can be removed mechanically with the addiction of 1000 litres of water for reuse in new mixes. However, this water can not be discharged in the environment without previously treatment, due to high amount of solid particles and its extremely high pH. The authors comment that the practice to recycle water at ready-mixed concrete plants is thought sedimentation basins and sediments are disposed of in authorized landfills. Concrete made with recycled water has 28-day compressive strength 4% lower then concrete made with distilled water. As reported by Šelih y Žarnić (2007), the EN 1008 standard affirms that the solid matter content in water can not exceed 1% in mass. The result of the investigation showed that the effect of recycled water in concrete mixes tested is minimum.

One of the problems that affect the utilization of recycled aggregates is the variation in performance and the availability of buildings that will be demolished for continuous concrete supply. Another factor is the proportion of contaminants in recycled aggregates, for instance, gypsum, wood, organic matter, among others. Gypsum presented in large quantities in concrete can affect the durability of steel reinforcement; because gypsum has high sulphate concentrations (Khalaf and DeVenny, 2004). Organic matter such as papers and wood reduce the mechanical properties of concrete, due to its lightness. Concrete and masonry recycled aggregates are classified in tree groups, according to the Rilem Recommendation (1994). The type I is classified is aggregates made of masonry rubble; type II aggregates referees to concrete rubble and type III is aggregates which contains both concrete and masonry rubble. This classification is for aggregates with 4mm diameter or higher. Additional requirements for group III are the following: The natural aggregate content must be at least 80% in mass of total aggregate content and the maximum content of group I is 10%.

The Real Decreto 1247/2008, of the Ministry of Public Works of Spain about structural concrete (EHE-08) provide data about the use of concrete containing recycled aggregate in its composition. The standard informs that both natural and recycled coarse aggregates must have maximum water absorption of 5%, when the aggregate proportion is superior to 20%. However, the water absorption can rise up to 7% if the aggregate content does not exceed 20%. This standard is not prohibitive for proportions above 20% of recycled aggregates; however specific tests must be made to ensure a good quality concrete with these higher percentages. The concrete produced with recycled aggregates can be employed either in plain concrete or reinforced concrete up to $40kN/mm^2$. Nevertheless, the standard prohibits its use with prestressed concrete. The maximum content of impurities is 5% for ceramic materials, 1% for light particles and 1% for other materials such as glass, metals and plastics. The durability of concrete made of recycled aggregate is a much discussed theme. The instruction EHE-(08) argues that the durability of concrete with 20% addition of recycled aggregates has similar performance to conventional concrete. At higher levels of recycled aggregates it should be take some measures to reduce the attack of some atmospheric agents, with the reduction of the w/c ratio, increasing cement content or using plasticizers.

4.4 Other types of wastes

Many investigations have been made with the aim to incorporate wastes of other industries in aggregates for concrete. The most investigated materials are glass, tires, marble wastes and PET bottles. The incorporation of crushed domestic glass as aggregates into concrete mixes is possible, as informed by Polley et al (1998) and Park et al (2004). According to Polley et al (1998) the mechanical characteristics are significant altered at 20% of addition of crushed glass in fine natural aggregate. On the other hand, Park et al (2004) argue that the incorporation of 30% of crushed glass in fine natural aggregate does not affect significantly the mechanical properties of concrete. In fact, the compressive, tensile and flexural strengths decrease respectively 0.6%; 3.4% and 3.2% respect to the conventional concrete. They report that “recycling waste glass as an aggregate is effective for environmental conservation and economical advantage.” (pp 2181-2182). On the contrary, bottle glass should be recycled into glass again and not transformed into aggregate for concrete. Glass used as fine concrete aggregate can not be extracted from cement paste, due to its particle dimension which is around

0.6mm in diameter after crushed. In this case it can be noted that this crushed glass is not effective to conserve the resource materials, because it will be necessary more raw materials to make new glass bottles. Polley et al (1998) emphasize that the primary concern about the use of such glass is that the silica present in the glass reacts with the alkalis contained in the cement paste. This alkali-silica reaction expands the concrete and it can cause structure deterioration. The studies carried out show that after a 730 days period the glass content aggregates can expand 10 times higher than the maximum acceptable requirement. Tawfiky Eskander (2006) investigated the effects of crushed PET bottles and marble wastes in GRP (Glass Reinforced Plastics) with the aim to salve costs more than environmental concerns. The work made by Ghaly y Gill (2004) utilizes plastics in coarse aggregates for concrete. The results show that the compressive strength is 29% lower for a 15% replacement of natural coarse aggregate respect the concrete made of natural aggregates only.

The ideas are interesting from a point of view, because industrial waste can be reduced. Another good point of these applications in new concretes is the smaller amount of natural aggregates require as well as the transport of then, since the aggregate extraction occur far from urban centres. However, all of these applications do not reach the closed-loop. On the contrary, the materials cycle still opens because cement will be produced continuously in large quantities, as well as the extraction of raw material for other industries.

5. Methods of recycling used concrete

Construction and demolition wastes are formed by a various types of materials, such as masonry, concrete, wood and plastics that should be sorted to keep the rubble as more uniform as possible and according to the standards. The sorting methods of such wastes can be made manually or automatic, in recycling plant facilities or in mobile plants.

In the recycling plant facilities the construction and demolition wastes can be reclaimed from building site and sorted by dimensions, density, magnetic and material type. In manual sorting there is a group of workers which collects and sorting the materials in distinct containers. On the other hand, mechanical sorting can be made by water or air jets. In manual separation, the materials are transported to a finger screener which classifies the input materials by size; fine, medium and large. After this, fine materials are conducted to sorting stations where people select the materials and direct then to specific containers. Magnetic belts put on conveyor belts collect objects that contain iron and deposit then in specific containers. In the sequence, wastes are transported by conveyors and workers separate materials such as wood, non ferrous metals, cardboard, among others. It can be noted that this process creates a high amount of dust, mainly in the finger screen. Workers must use masks to avoid dust inhalation and earplugs due to high noise levels emitted by conveyor and materials movement. As a result of high amount of dust and to provide higher productivity it can be use a sorting station partially or totally automated. Basically there are two automatic methods to sorting the heavier particles to the lighter particles using water or air jets. The method with water separates wastes when water entries and fills partially a container. The container starts to turn, the lightweight materials float and the heavy materials sink. The materials are then separated and can be sorted again or be deposited in a specific local.

One alternative to recycle construction and demolition wastes is doing it on the building site with a mobile plant. The advantage more evident with this equipment is salve CO_2 emissions with the transport of such wastes to the recycling plant facility. CO_2 emissions are related only to the mobile crusher plant. Wastes that are not suitable to be transformed into aggregates are sent to a recycling plant facility. Mobile plants are mainly used in large buildings, because the large amount of wastes makes possible move a mobile plant to the building site. Other advantage is that mobile plants cost less than a recycling plant facility and there is the possibility to transport then easily which depends on demand. The crushers must be compact to permit easy transport by conventional trucks. Construction and demolition wastes are deposit in the crusher feeder and under the feeder there is a screener which takes the smaller particles without the necessity to crush them. The larger particles are crushed and pass through conveyor belts where exists a permanent magnetic belt which reclaims particles that contains iron from the others. The disadvantage of this machine is the elevated wear in comparison with recycling plant facilities, because crusher grinds many materials and this can damage the machine.

Aggregates produced by ready-mixed concrete plants and transported by concrete trucks can be recycled too. The percentage of concrete which remains in concrete trucks is approximately 3%. The principle is basically simple and separates fine and coarse aggregates from cement paste. Concrete trucks deposit fresh concrete in hoppers on the ready-mixed concrete plants and concrete is washed. A screener inside the hopper together with water separates the aggregates from cement paste. Particles larger than 0,2mm are sorted and transported by a screw conveyor. Aggregates can be transported to a deposit or accumulated in containers. The smaller particles and water are conducted to a container which maintains the particles in suspension for use this water on future mixes. Another function of water deposits is utilizing it to wash the concrete trucks with posterior dump in the hoppers. Aggregates are used in future mixes too. The precast industry has equipments to recycle fine and coarse aggregates as well as the water used in the concrete mixes. The sorting operation is basically the same of that encountered in ready-mixed concrete plants. However, there is a difference in the water cleaning. The idea is that grew water be treated to be used in the concrete production.

6. Final considerations

From the previously exposed it can be observed that the only renewable part of recycled aggregates is the urban deposit, that is, old buildings that can be demolished. Many types of the equipments produced for this industry use fossil fuels and most of the electricity is generated by non-renewable energy resources. Furthermore, it is used more energy to transform the construction and demolition wastes into aggregates than to transform natural stone in aggregate. The recycled aggregate production is very little in comparison to aggregate demand. Currently, it is very difficult the total replacement of natural aggregates by recycled aggregates, due to the differences in recycled aggregate characteristics and standards restriction.

The high costs of equipments many times are not a good alternative, because the demand can be limited. Furthermore, the type of equipment will take into account if it is a recycling plant facility or a mobile plant. The quality of recycled aggregates can vary a lot, depending on the type of the old concrete and the impurities presented in the rubble. Other issue is the high amount of steel and energy required to manufacturing equipments used in this industry. This leads to iron ore extraction and the production of large amounts of wastes from the steel industry.

Many investigations have been made to produce new concrete mixes from old concretes. Glass, tires and other materials were used to replace the natural aggregates. However, the results reached until now can demonstrate that concrete made with recycled aggregates is not sustainable. In fact, it can be said that these initiatives reduce the environmental impact because less amounts of natural aggregates are extracted. On the other hand, many virgin materials are continuously extracted form the earth's crust to produce cement in large quantities. Despite a change in the type of energy used for the cement calcination, which consumes almost 50% of the total concrete life-cycle energy, it still contaminates atmosphere with carbon dioxide. Not even studies about concrete carbonation can bring an effective solution of CO_2 absorption by the demolished concrete. This is due to the consumption of fossil fuels of demolished equipment, crushers and transport of concrete which releases a lot of the CO_2 in the atmosphere. The diversity and the mixes of such wastes made in the recycling plants difficult the implementation of recycled aggregates and concretes produced with these aggregates are used in lower performance concretes respect to concretes made with natural aggregates. In conclusion, there are many issues that must be solved until concrete becomes a real sustainable material.

Acknowledgments

Author Luiz Vefago wish to acknowledge the financial support of the Programme AlBan, the European Union Programme of High Level Scholarships for Latin America, scholarship no. E07D401547BR

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