Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 95 (2014) 305 – 320

Procedia Engineering

www.elsevier.com/locate/procedia

2nd International Conference on Sustainable Civil Engineering Structures and Construction Materials 2014 (SCESCM 2014)

Toward green concrete for better sustainable environment

Bambang Suhendro *

Department of Civil and Environmental Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia

Abstract

Eight to 10 percent of the world's total CO_2 emissions come from manufacturing cement. The global warming gas is released when limestone and clays are crushed and heated to high temperatures. Green concrete is defined as a concrete which uses waste material as at least one of its components, or its production process does not lead to environmental destruction, or it has high performance and life cycle sustainability. Various efforts have been conducted by researchers to arrive at some alternatives that are able to significantly reduce high energy consumed and environmental impacts during fabrication process of cement, including implementing the concept of industrial ecology and green chemistry as well as nanoengineering that study the behavior of the structure and organization of nanoparticles of cement in the mix for achieving higher performance. The cleaner technologies in concrete production, such as substituting relatively high percentage of cement by fly ash (up to 100%), the use of other natural pozzolans, development of concrete with recycling or waste materials, and developing nanoconcrete by integrating CNT's or self sensing CNT's in the concrete mix for higher performance in terms of strength, stiffness, and durability, have been developed and are addressed in this paper. Several efforts that have been done so far in implementing the concept of green concrete and material development of nanosilica in Indonesia is discussed. Finally, problems in the realization of and potential barriers to green concrete as well as political scenarios that have been adopted by several countries through implementation of various priorities and deregulation in various fields are also discussed.

Peer-review under responsibility of organizing committee of the 2nd International Conference on Sustainable Civil Engineering Structures and Construction Materials 2014

Keywords: green concrete; nanosilica; nanoconcrete; CNT's; fly ash; recycling; alternative aggregate.

* Corresponding author. Tel.: +62-274-546-675; fax: +62-274-546-676.
E-mail address: bsuhendro@tsipil.ugm.ac.id

Peer-review under responsibility of organizing committee of the 2nd International Conference on Sustainable Civil Engineering Structures and Construction Materials 2014
doi:10.1016/j.proeng.2014.12.190

1. Introduction

1.1. The need to reduce CO_2 emissions

Conservation and environmental protection has become a major world issue in the global context. Since The World Earth Summit 1997 in Kyoto, Japan, which initiated the need to reduce CO_2 emissions on a large scale (targeted before 2010 emissions reduced by about 21%) to avoid catastrophic global world, so many huge industrial countries around the world have agreed to formulate regulations that dreams related to the mission of the protection and preservation of the environment can become a reality [1]. About 8 ~ 10% of total world CO_2 emissions, which are believed to be the main drivers of global climate change did not come from polluting vehicles on the highway or a forest fire, but comes from the cement manufacturing process in cement factories. Global warming gas is released when the raw material of cement, limestone and clay is crushed and heated in a furnace at high temperature (± 1500^0C). Each year, approximately 1.89 billion tons of cement (which is a major component of concrete) have been produced worldwide.

1.2. Energy to produce structural element

Compared with other engineering materials, such as wood, steel, and aluminum, concrete is a material that is relatively more environmentally friendly. As an illustration, Struble and Godfrey [2] (2006) has compared the environmental impact generated by a conventional reinforced concrete beams with steel beam profile which has the capacity to support the same moment (Fig. 1). The energy required to produce the reinforced concrete beam shown in Fig. 1 was estimated to be 109 MJ and the energy to produce the steel I-beam was estimated to be 237 MJ. Thus the energy to produce a reinforced concrete beam was about half the energy to produce a similar steel I-beam. However, since concrete is produced on a very large scale throughout the world, with annual consumption approaching 20,000 million metric tonnes in 2009 [3], the impact on the environment is also very huge.

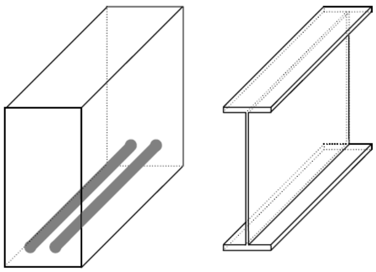

Fig. 1. The energy required to produce reinforced concrete beam (109 MJ) was about half of that of steel I-beam (237 MJ) [2] (Struble & Godfrey, 2006)

1.3. Cleaner technologies to produce concrete

Related to cleaner technologies to produce concrete, most major targets are: (a) the reduction of CO_2 emissions, (b) a reduction in energy consumption or fuel derived from fossil in the cement manufacturing process, (c) reduction of substances that can endanger health or the environment such as the use of several types of chemicals in the concrete mixture, (d) savings the use of cement through substitution with flay ash waste in the higher portion or the use of other waste, (e) the use of new cement replacement materials, such as inorganic polymers, alkali-activated cement, magnesia cement, and sulfoaluminate cements, and (f) various possibilities of recycling cement/concrete and the use of alternative aggregates. Other significant contribution are policies or regulations of various countries/institutions/industries and willingness of the community to use green concrete.

Various efforts that have been, and will be conducted by researchers around the world to reduce the enormous energy and reduce or even eliminate the impact of warming on the cement manufacturing process (through a variety of alternatives, including nanoengineering) will be described and discussed in the first part of this paper. In the second part, an alternative form of savings through the use of cement substitution with fly ash waste in the higher portion (not just 15% but allows up to 100%), will be described and discussed as well, along with the various possibilities of recycling and the use of alternative aggregates. In the third part of this paper, problem anticipation that will arise in the context of the implementation of the ideas that the green concrete can be realized in Indonesia, will also be discussed.

2. Green concrete and sustainability

Major forces that were responsible for economic and social transformations in society are: population growth, industrialization and urbanization, globalization of market economy and consumerism, and environmental pollution. The forces are interconnected. Their combined impact has triggered another force, namely ***climate change***, which is threatening to cause serious damage to human civilization on the earth. Global warming is the most important sustainability issue today in the public mind [3].

Green concrete is defined as a concrete which uses waste material as at least one of its components, or its production process does not lead to environmental destruction [4]. It should also have high performance and life cycle sustainability. In other words, green concrete is an environment friendly concrete. Green concrete improves the three pillars of sustainability: environmental, economic, and social impacts. The key factors that are used to identify whether the concrete is green are : amount of portland cement replacement materials, manufacturing process and methods, performance and life cycle sustainability impacts.

Green concrete should follow reduce, reuse and recycle technique or any two process in the concrete technology. The three major objective behind green concept in concrete is to reduce green house gas emission (carbon dioxide emission from cement industry); to reduce the use of natural resources such as limestone, shale, clay, natural river sand, natural rocks that are being consume for the development of human mankind that are not given back to the earth; and the use of waste materials in concrete that results in the air, land and water pollution. This objective behind green concrete will result in the sustainable development without destruction natural resources.

3. Various efforts to reduce energy and impact of global warming

3.1. Nanoengineering

Nanoscience and nanotechnology provide enormous opportunities to engineers to enhance the properties of materials by working in atomic or molecular level. Nanotechnology is an emerging field of science related to the understanding and control of matter at the nanoscale, i.e., at dimensions between approximately 1 and 100 nanometres. A nanometre is only 1/1,000,000,000 metre (10^{-9} m), and as an illustration, human hair is approximately 5,000 nanometres in diameter.

Matter can exhibit unusual physical, chemical, and biological properties at the nanoscale, differing in important ways from the properties of bulk materials and single atoms or molecules. Some nanostructured materials are stronger or have different magnetic, thermal or electrical properties compared to other forms or sizes of the same material. They may become more chemically reactive or reflect light better or change color as their size or structure is altered [5].

Concrete's strength and durability lies in the organization of spherical nanoparticles, namely calcium silicate hydrates (each about 5 nanometers in diameter). A more dense formation is achieved by stacking them in a pyramid that reaches highest density of packed spherical objects of 74%. The strongest concrete materials have particles with this arrangement. If we can find particles other than calcium silicate hydrates that will pack in high densities without the burning, that's quite the invention. Ulm and Constantinides [6] have identified that magnesium could be an alternative material to replace the calcium silicate hydrates.

Learning from the nature, human bone could show us how to manufacture concrete with much less CO_2 emissions. Human bone achieves a similar packing density to concrete at the nanoscale, but this packing density is achieved at body temperature. Bone strength is achieved naturally without the CO_2 release. However, the hardening of minerals in the bone takes a longer time. This is where nanoengineering comes into play. With nanoengineering, the goal would be to copy the process of bone formation and accelerate that to form a new building material [7]. The study of bone properties to create green concrete is quite compelling and interesting.

- Carbon nanotubes

  Carbon nanotubes (CNTs) can be idealized as rolled form of graphite sheets where carbon atoms are arranged in a hexagonal array. The ends are capped by a dome shaped half fullerenes molecules. The mechanical properties of the nanotubes greatly depend on the atomic arrangement of the nanostructure.

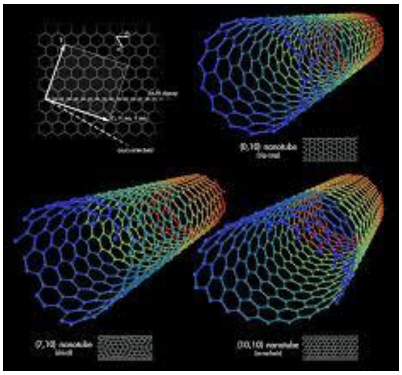

Fig. 2. Carbon nanotubes [8]

Two forms of carbon nanotubes are available, i.e.: single-walled (SWCNTs) and multi-walled (MW CNTs). The carbon nanofibers (CNFs) with diameter of 200 nm has tensile strength of 7 GPa and modulus of elasticity of 400 GPa (compared to 0.4 GPa and 200 GPa, respectively for tensile strength and modulus of elasticity of regular reinforcing steel). It has not only facilitated to overcome many limitations of conventional materials, but also tremendously improved the mechanical, physical and chemical properties of the materials as well. Strength, ductility, creep and shrinkage, fracture behavior, and durability of cementitious construction materials greatly depend on the micro- and nano-scale formation of the material. To develop high performance, multi functional, ideal (high strength, ductile, crack free, durable) construction material, carbon nanotubes (CNTs) show promising role to modify/enhance the characteristics of the conventional construction materials such as concrete and steel. A crack free durable concrete is possible if certain issues such as uniform distribution of CNT in composite and bond behaviour of CNT modified concrete can be addressed.

Because of the symmetry and unique electronic structure of grapheme, the structure of a nanotube strongly affects its electrical properties. CNTs can have conductivity up to eight times higher than that of copper. It can carry a current density achievable by any conventional metallic wire, thus making them as potential candidates as nano-scale wires and as efficient sensing purposes. Carbon nanotubes polymer composite films that can be used as strain sensors has been developed by Pham et al. [9](2008). Utilization of carbon nanotubes as strain sensors for structural health monitoring system of civil structures has been reported by Li, Thostenson & Chou [10](2008), among others. In short, CNTs can play the pivotal role to redefine the scope and ability of civil engineering, in general, and structural engineering, in particular [11].

- Carbon nanotube cement composite and its formula for compressive strength

  Ghasemzadeh et al. [12] developed computational formula by analytical method for representing compressive strength of carbon nanotube (CNTs)/ cement composite. For this purpose Representative Elementary Volume (REV) as an indicator element of composite was chosen and analyzed by elasticity relationships and Von Mises' criterion applied to it.

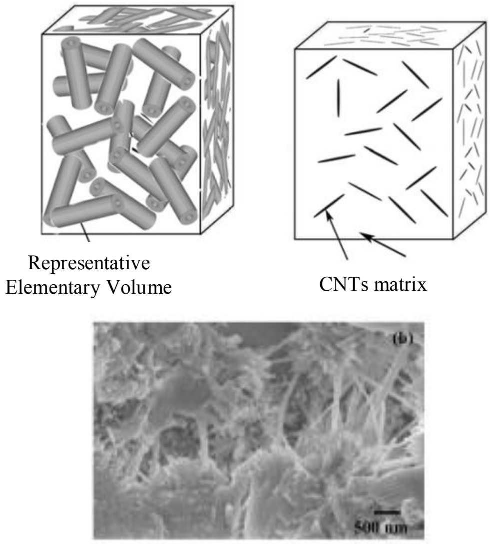

Fig. 3. Nanotube /cement composite with random orientation of fibers [12] and its SEM images [13]

- Nano concrete with carbon nanotube

Yu, Kwon and Han, from the University of Minnesota Duluth, among others, have initiated to develop a new style of concrete, so called nanoconcrete, by integrating Carbon Nanotubes (CNTs) into the concrete mix. The CNTs are relatively new technology and their properties are still being studied. It is also a huge step for nanotechnology. Nanocyl offers a broad range of Carbon Nanotubes and specialized Carbon Nanotube compounds which can be easily integrated into a variety of substrates and materials used for researching and developing new applications (Fig. 4).

Fig. 4. Nanocyl NC 7000 [8] and Indonesian silica sand [14]

In structural material application, CNTs show changes in electric potential when a stress is applied. The relationship between stress and changes in electric potential is reliable and highly linear such that it is suitable for sensor application. By integrating it the concrete would become an alternative smart material suitable for civil engineering applications for better sustainability.

The mechanical properties of 10 and 20 micron carbon nanotubes (CNTs) in a cementitious composite have been studied experimentally. The test results showed that the compressive and flexural strength performed at 7 and 28 days for the cementitious composites with CNTs are higher than those of the cementitious composites with no CNTs. A scanning electron microscope (SEM) study of the microstructures of the composites mixed with the CNTs and the composites with no CNTs showed that the CNTs filled up the pore space in the composites.

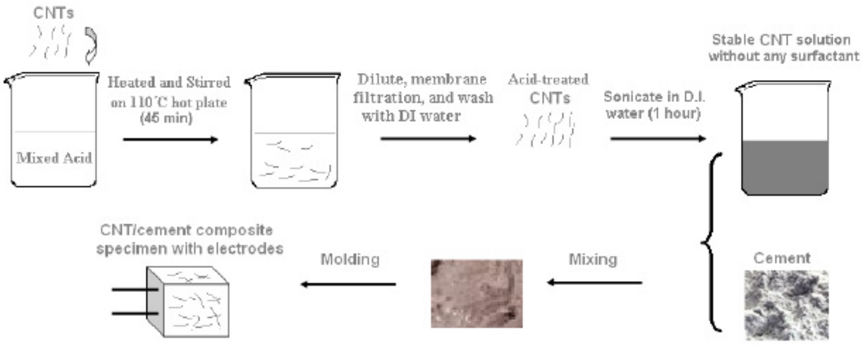

Fig. 5. CNT/cement fabrication perocess [8]

- Self sensing carbon nanotube

  Yu and Kwon [8] conducted the development of self-sensing carbon nanotube (CNT)/cement composites. The piezoresitive property of carbon nanotubes enables the composite to detect the stress/stain inside the pavement. Meanwhile, CNTs can also work as the reinforcement elements to improve the strength and toughness of the concrete pavement. Piezoresistive CNT/cement composites are developed and tested in this study. Experimental results show that the electrical resistance of the composite changed proportionally to the compressive stress levels. The piezoresistive responses of the composite with different fabrication methods are also studied (Fig. 5). The surfactant wrapping of CNTs is also effective to disperse CNTs into the cement matrix and give promising piezoresistive properties. A set of lab and road tests were performed to test the effectiveness of the self-sensing concrete by applying dynamic loads under the controlled environment. Experimental results demonstrated that the CNT/ cement composite function as excellent stress/strain sensors.

- Nanosilica development in Indonesia

  Material development of nanosilica Indonesia for concrete mix based on local silica sand has been reported by Jonbi et al. [14]. Sources of silica sand in Indonesia are from Bangka Belitung, Pangkal Pinang, South Sumatra, Lampung, West Kalimantan, South Kalimantan, West Java, and East Java. The local silica sand is commonly used as filler in the concrete mix. The challenge is then to explore the possibility of using such silica sand in the form of finer powder - nanosilica to develop added value for being able to act also as reactive pozzolan, and advancing application of nanosilica for high performance concrete.

Table 1. Indonesian nano silica content [14]

Oxides in %	Type of Nanosilica		
	NS Jiangsu	Aerosil	NS Indonesia
Na_2O	-	-	1.86
Al_2O_3	-	-	12.63
SiO_2	99.94	99.99	84.26
S	-	-	0.85
ZnO	0.02	-	-
TiO_2	0.04	-	-
CuO	-	0.01	-
BaO	-	-	0.32
Fe_2O_3	-	-	0.08

The silica sands are processed to become nanosilica by using Polishing Liquid Milling Technology (PLMT), a method to produce nanopowder developed by Indonesia Center of Ceramics. Bangka Belitung silica sand was choosen for further processing. The results of characterization using PSA (*Particle Size Analyzer*), SEM (*Scanning Electron Microscope*), XRD (*X-Ray Diffraction*), and XRF-EDS (*X-Ray Fluorescence - Energi Dispersive Spectrometer*) shows that the Indonesia nanosilica contains more than 50% particles of 70 nm, with 84.26% SiO_2 content [14]. As comparation, commercial Jiangsu nanosilica contains 99.94% SiO_2 while Aerosil HDKN 20 contains 99.99% SiO_2. Indonesia nanosilica is mainly crystalline, while Jiangsu and Aerosil HDKN 20 are amorphous silica particles. The Indonesia nanosilica needs futher treatment, i.e.: SiO_2 purification process, a process to produce SiO_2 amorphous, and perform separation of nanoparticles with a size of less 100 nm.

Table 2. Concrete mix proportion [14]

Mixture Proportions Kg/m^3	Ref.	NS3	NS5	NS10	NS15	NS3 -SF5	N5-SF5	NS10-SF5	NS15-SF5
Cement	900	900	900	900	900	900	900	900	900
Silica fume	120	-	-	-	-	45	45	45	45
Nanosilica	-	27	45	90	135	27	45	90	135
Ratio water/binder	0.23	0.23	0.23	0.26	0.3	0.24	0.25	0.27	0.3
Sand	638	638	638	638	638	638	638	638	638
Coarse aggregate	1094	1094	1094	1094	1094	1094	1094	1094	1094
Viscocrete 10 ex Sika	15	15	15	20	22	15	15	21	24

The Indonesia nanosilica resulted from previous work, has been used by Jonbi et al. [15] to develop sustainable concrete by enhancing the compressive strength, permeability and durability, using as much as possible local materials. Two groups of mix proportion were prepared, i.e.: concrete mix with nanosilica: (a) NS3, (b) NS5, (c) NS10, (d) NS15, respectively, concrete with nanosilica cement ratios of 3, 5, 10, and 15% by weight, and concete mix with nanosilica and silica fume: (e) NS3-SF5, (f) NS5-SF5, (g) NS10-SF5, (h) NS15-SF5, respectively, concrete with nanosilica cement ratios of 3, 5, 10, and 15% plus 5% silica fume each. Reference mix containing silica fume of about 13% of cement weight was also prepared. Water to binder ratios vary from 0.23 to 0.30 and an admixture of viscocrete was used and varied to maintain 5 cm slump. The hardened concrete was tested at ages 1, 3, 7, and 28 days. It includes compressive tests, permeability tests, RCPT (Rapid Chlorid Permeability Tests), and SEM (Scanning Electron Microscope).

At the age of 28-day mixes NS3, NS5, NS10, NS3-SF5, and NS5-SF5 possesses compressive strength of around 91 MPa, which are at the same order of the reference mix (concrete with silica-fume cement ratio of 13%). The highest compressive strength, 132 MPa (increase by 45% compared to reference), was resulted from NS10-SF5. Mixes with 15% nanosilica content (NS15 and NS15-SF5) resulted in relatively lower than that of reference, due to angglomeration effects. The results of permeability tests show that mixes NS5, NS10 and NS5-SF5 experienced water permeation at the same order with reference mix (i.e. about 1 cm), while mix NS10-SF5 shows the lowest water permeation of 0.6 cm. Mixes NS3, NS15, NS3-SF5, and NS15-SF5 have relatively higher permeation (2~3cm) [15]. Normal concrete usually has a water permeation of about 5 cm.

The results of RCPT show that mixes NS10 and NS5-SF5 have values at the same order with reference mix (i.e. about 60 Coulombs), while mix NS10-SF5 shows the lowest RCPT value, i.e. 45 Coulombs, which indicates the high resistance of concrete against chloride ion penetration. From the aforementioned test results, it was concluded that mix NS10-SF5 is the optimum mix proportion for green concrete utilizing the available local materials.

3.2 Industrial ecology and green chemistry

Improving the cement within concrete is an essential part of addressing durability, maintenance and environmental concerns. Great opportunities lie in the utilization of cements based on alternative compositions, binding-phases and green chemistry. This allows cement to be synthesized from a variety of materials including recycled resources and mineral wastes, which reduces the energy demands during production. Phairs [16](2006) introduced industrial ecology and the principles of green chemistry as a means of driving the research, development and commercial attractiveness of alternative and sustainable cements (Fig. 6).

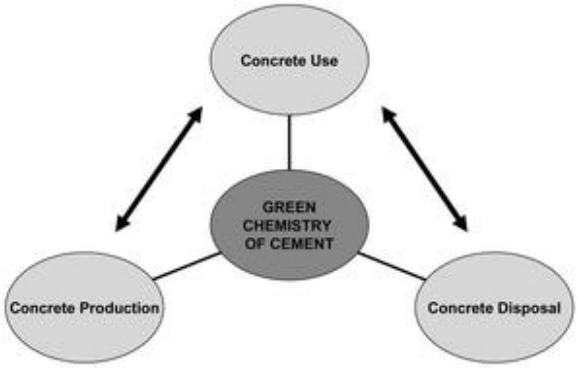

Fig.6. Industrial ecology and green chemistry concept [16](Phair, 2006)

Three promising alternative cements were reviewed (alkali-activated cements, magnesia cements and sulfoaluminate cements) and compared to blended ordinary Portland cements in terms of their chemistry and properties. Emphasis is given to the material properties, durability, performance and applications of the greener alternative cements. It was shown that alternative cements have considerable potential in terms of environmental, engineering and economic properties.

Utilization of inorganic polymers (geopolymers) in sustainable concrete has been reported among others by Duxson et al. [17]. The material is an alkali-activated aluminosilicates with CO_2 emissions that are much smaller than the Portland cement to produce it. The resulting concrete is also reported to have sufficient strength and high chemical resistance. Geopolymere concrete also has to be made so as to achieve equal quality with high performance concrete. Nonetheless thorough understanding of the chemistry of geopolymerisation still needed to support that this technology is successfully applied.

Effect of aggregate on the microstructure and mechanical properties (compressive strength and tensile strength) Geopolymeric Mine Waste Mud (GMWM) binder has been put forward by Torgal et al. [18] (2007). Aggregate factors that are reviewed include: aggregate / binder ratio, aggregate dimensions, and type of aggregate (schist, granite and limestone). While the results obtained are GMWM has the power (press and drag) high at a young age, and the dimensions of the grain effect on tensile strength.

Duxson et al. [17] have discussed the role of inorganic polymer (geopolymers) technology in the development of green concrete. This material is alkali-activated aluminosilicates, with a much smaller CO_2 footprint than traditional Portland cements, and display very good strength and chemical resistance properties as well as a variety of other potentially valuable characteristics. It is widely known that the widespread uptake of geopolymer technology is hindered by a number of factors, in particular issues to do with a lack of long-term (20+ years) durability data. There are also difficulties in compliance with some regulatory standards in Europe and North America, specifically those defining minimum clinker content levels or chemical compositions in cements. Work on resolving these issues are ongoing, with accelerated durability testing showing highly promising results with regard to salt scaling and freeze–thaw cycling. Geopolymer concrete compliance with performance-based standards is comparable to that of most other high-strength concretes.

4. Saving the use of cement

Another alternative in reducing CO_2 emissions through: (a) the substitution of cement with flay ash, (b) the use of ground granulated blast furnace slag from steel plants, (c) use of micro silica, (d) the use of pozzolanic materials and limestone powder, (e) various kinds of ash from the burning of domestic waste and bio-fuels, and (f) crushed waste glass [19] (Nielsen & Glavind, 2007).

4.1. Substitution of cement with fly ash

Substitution of cement with fly ash waste has long been known and applied. It has been recognized also that the optimal portion of the substitution of cement for structural purposes only around 15 ~ 20%. Availability of waste fly ash coal combustion products in various power station (power plant) and this industry is very large and if not handled properly will pollute the environment. Studies have been conducted to strive for substitution portion of cement with fly ash can be improved. Since 1985, CANMET has developed a high-performance concrete with fly ash use in a portion of the concrete mix is higher, but the resulting concrete has mechanical properties, permeability, and good durability [20].

Nielsen [21](2002) have reported the results of testing the material of Green Concrete with high ash content of the waste flay, both in normal and aggressive exposure, with the proportion / percentage weight of the mixture: A1 (cement: micro silica: flay ash = 57: 5: 38, the ratio of water / binder = 0.42) were exposed in aggressive environments, and P5 (using concrete slurry used), and P7 (using fly ash from bio-fuels) with the ratio of water / binder = 0.70 which is exposed in the normal environment. As a control has also tested a mixture of AR (86: 5: 9) were exposed to an aggressive environment, and PR are exposed to a normal environment. Test results are listed in Fig. 5 (curve stress - strain), Table 2 (the value of fc ', εc, and Ec), and Fig. 6 (curve Ec relationship with fc'). It appears from these data that the quality of Green Concrete has been made to achieve 40 ~ 60 MPa, the workability and better durability than conventional concrete. In Figure 5, the parameters A = εc Ec / fc '.

The use of fly ash for cement substitute as much as 50% (by mass), which was given the designation HVFA (High Volume Flay Ash) concrete, tangible has been applied for retrofitting structures (such as prestressed concrete shear wall and foundation extra belt) Baker Hall building (6 floors) 40-year-old at the campus of the University of California, Berkeley, USA [22]. A full description of the concrete, which include the proportion of the mixture, the implementation principles, and mechanical properties have been reported in HVFA journal article in Concrete International (2002).

Furthermore Uzal, Turanli, and Mehta [23] reported that their initial research results with the concrete containing natural pozzolan high volume (50% of the mass of cementitious material), which was named the High Volume Natural Pozzolan (HVNP) indicates achievement that promises to structural applications, reaching 14 MPa strength (aged 3 days) and 38 MPa (age 28 days). Natural pozzolan used is a low-calcium fly ash and granulated blast-furnace slag. The larger portion of the fly ash can be used to substitute cement the reduction of CO_2 emissions in the cement manufacturing process will also be reduced.

In spite of the not following building code requirement, in 2000 (14 years ago), UC Berkeley is one institution willing to be a pioneer in applying high-volume fly ash concrete in their earthquake resistant building construction projects in their own campus [24]. The high-volume fly ash concrete mixture reduces environmental impacts and can save money while producing more durable concrete structures. The foundations of Wurster Hall Building, the home to the College of Environmental Design, as well as Barker Hall, incorporate totally 4,300. cubic yards high-volume (50%) fly ash concrete which requires far less fossil fuel to produce than conventional concrete. The main goal in the project was to make sure that those who study and work in these buildings will be safe in the event of a major earthquake. The two projects are part of the campus's on-going SAFER program, a multi-year $1 billion-effort to seismically strengthen more than a quarter of all buildings on the central campus to improve life safety in the event of a major earthquake.

Berry et al. [25] have clearly demonstrated the use of 100% fly ash concrete with conventional aggregates and recycled pulverized glass aggregates for use in structural and non-structural applications. The benefits of using 100% fly ash concrete are at least two fold: reduced environmental impacts from the production of cement, and reduced need for stockpiling of common waste-steams. The typical proportions for 1 m^3 of concrete are shown in Table 3.

Table 3. Proportions for 1 m^3 of 100% fly ash concrete [25

]

Concrete	Water (kg)	Fly Ash (kg)	Fines (kg)	Coarse (kg)	Borax (kg)
Conventional aggregate	91.77	382.99	315.57	631.14	4.77
Recycled pulverized glass aggregates	120.23	601.27	274.83	274.83	7.49

The concrete mixtures have w/c ratios in the range of 0.20 – 0.24, and retarder dosage rates to provide approximately a 2.5 hour set time. The basic mixtures exhibit workability (10 to 15 cm slump) and strength (at least 27.6 MPa at 28 days) consistent with concrete used in common construction. Both mixes have demonstrated strengths of over 55.2 MPa 84 days. It is important to note that these strengths were achieved with very workable mixtures with no chemical admixtures (excluding set retarder).

The modulus of elasticity of the 100% fly ash concrete with conventional aggregates was 25.3 GPa (at the same order with conventional normal concrete), while that of pulverized glass aggregates was relatively lower. The tensile strength of the concrete was reported to be 7.5% of the compressive strength, which somewhat slightly lower than that of normal concrete of 10%. Both mxes performed well with respect to alkali silica reactivity, with expansion values well below the 0.1% criteria of 16 days (0.015% and 0.053% respectively for conventional and pulverized glass aggregates).

Several structural applications (foundation, footing, floor slab, and beam of office buildings) and non-structural applications (architectural panels) of the 100% fly ash concrete have been conducted in several large scale pilot projects over the past 10 years.

Glavind & Jepsen [26] has prioritized taking 4 steps to go green concrete in Denmark, namely: (a) improving the utilization of residual products such as fly ash in large scale, (b) the use of residual products from concrete plant, such as: stone dust, and concrete slurry, (c) the utilization of residual products of other industries, such as fly ash from bio-fuels and combustion of sewage sludge ash in waste processing installations, and (d) the use of a new type of cement that is more environmentally friendly, such as mineralized cement, the addition of limestone, and waste-derived fuels.

The comparison of CO_2 emissions generated in the service life cycle of a bridge pillar located in aggressive environments (50 years, as a special case) by 4 kinds of different design principles, namely: (a) Reference column, made of conventional reinforced concrete, (b) A column made of green concrete (containing 40 ~ 50% fly ash), (c) B column made of green concrete (containing 40 ~ 50% fly ash) with stainless steel reinforcement, and (d) column C is made of green concrete (containing 40 ~ 50% fly ash) with stainless steel cladding have been investigated. It appears that the use of the three green concrete could reduce CO_2 emissions by up to less than 30% compared to conventional concrete.

According to Mehta [3] there are 3 structural engineer's tools for sustainability of the cement industry or reducing CO_2 emissions: (a) **consume less concrete for new structures**, by developing innovative architectural concepts and structural design, using highly durable concrete, and using pre-fabricated elements for easy assembly, (b) **consume less cement in concrete mixtures** by using superplasticizer instead of more mixing water and cement to obtain the required consistency of fresh concrete, and optimizing the size and grading of aggregates, and (c) **consume less clincer in the cementing material** by selecting blended portland cements and concrete mixtures that contain high volume of coal fly ash, granulated blast-furnace slag, natural or calcined pozzolans, silica fume, and reactive rice-husk ash.

4.2. Green engineered cementitious composites (ECC green)

Kaoleian et al. [27] have developed a concrete material which referred to as engineered cementitious composites (ECC), which resembles the mixture proportion of concrete fiber (i.e. water, cement, fine aggregate, without coarse aggregate, fiber and chemical additives), with a polyvinyl alcohol fiber and polyethylene, and fiber volume fraction of about 2%. Through engineering micromechanics, as analytical tools for managing microstructure formation, Kaoleian et al. [27] managed to concoct a cement-based material that its good mechanical properties, very ductile, and high durability. Ductility minimum needed for cement-based materials resistant to the effects of temperature fluctuations and dynamic live loads, is 1.4% and below 0.1 mm crack width, which is very difficult to be met by conventional concrete, but can easily be met by the ECC.

To meet the demands of environmental protection, ECC material has been modified in order to quote an industrial by-products (but still maintain high mechanical performance) such as: recycled carpet as the fiber, the portion of waste fly ash substitution is higher for cement, the concrete mix. ECC material produced was named Green ECC. Proportion thereof is: 318 kg/m3 cement, class F flay ash 701 kg/m3, 701 kg/m3 sand , water 289 kg/m3, and 26 kg/m3 PVA fiber. The resulting compressive strengths of the tested conventional ECC mix, Current ECC mix, High Fly Ash ECC mix, and ECC with carpet fiber, respectively, were 35, 65, 33 and 55 MPa.

According Kaoleian et al. [26], a decrease in performance due to the substitution of cement with other materials, or the effect of waste utilization in the concrete mix can be compensated through engineered micro structure formation.

- Substitution of cement with waste incineration ash.

  Urban waste (municipal solid waste) can be used for the manufacture of concrete. Results of research conducted by Horiguchi et al. [28,29] indicates that the combustion ash (ash incineration) of sewage sludge (sludge organic waste) can be used to substitute cement in the concrete mix. These findings represent a promising new hope, as they relate to the utilization of waste in a sustainable manner and can reduce CO_2 emissions. The test results indicate that the proportion of a particular mixture, the resulting concrete can achieve adequate strength and flowability also sufficient mortar to be applied. Concrete characteristics of the resulting leachate also showed an acceptable level.

  The results of testing the compressive strength of concrete using some mix of SSIA (Sewage Sludge Combustion Ash), which reached fc '= 58 MPa (age 28 days) and fc' = 68 MPa (age 56 days), has been reported by [30]

4.3. Recycle materials

Naik [31] reported production of greener concrete using recycled materials. More than 5 billion tonnes of post-consumer wastes and industrial by-products generated annually in the U.S. are readily recyclable. Within the concrete industry, the most successful examples have been using coal fly ash to make high-quality, durable concrete and recycling old, demolished concrete as aggregates for new concrete. Since the 1990s, other by-products have been successfully used in concrete. These materials include: foundry sand and cupola slag from metal-casting industries; post-consumer glass; wood ash from pulp mills, saw mills, and wood-product manufacturing industries; sludge from primary clarifiers at pulp and paper mills; and de-inking solids from paper-recycling companies.

Concrete debris is the most important material for reuse as aggregate in new concrete. Using such debris to produce new concrete conserves natural resources and reduces valuable landfill capacity at the same time. The disposal of demolished concrete involves costs, while sources of suitable virgin aggregate are being depleted, and opening new sources of virgin material is getting increasingly difficult because of environmental concerns. Turning recycled concrete into useful or even high-quality aggregate poses well-known technical challenges. There are contaminants to be dealt with, high porosity, grading requirements, as well as the large fluctuations in quality [32](Meyer, 2005). *Dredged material* originated from the needs to dredge ports to keep shipping lanes open and also to deepen them to accommodate the larger modern vessels is also potential recycle material for concrete. Other potential recycle materials that could be used include recycled carpet fiber, excavated rock from tunnels, waste wood, rubber tires, plastics, pulp, and paper mill residuals.

Satyarno [33] reported that the brick masonry wall rubble, resulting from the damaged building subject to earthquake, could be recycled to become new bricks or concrete blocks. The recycled bricks are made by mixing the crushed brick masonry wall rubble with water and cement with certain composition. The quality of the recycled bricks can be made higher than that in the market by controlling the portion of cement in the mix. The concept has been implemented in housing rehabilitation program in Yogyakarta – Indonesia after earthquake. Beside recycling brick masonry wall rubble, other waste materials can also be used as recycled such as broken roof tiles, artificial aggregate from clay, pumice aggregate, cinder aggregate, and limestone.

5. Problems in the realization of green concrete

In addition to strive for minimal environmental impact during the use cycle of concrete (since the process of making cement, concrete manufacture until, for example 50 years, concrete buildings that have been used dismantled / broken), which is no less important aspect in the success of efforts to conserve the environment are: (a) government policies/institutions/ industries through various forms of regulation, (b) the willingness of the user community, and (c) the willingness of the industry itself to change the perception.

Cement and concrete industries that have grown rapidly and established, may have to change the situation due to issues of preservation and protection of the environment, due to a significant change from how concrete is designed, specified, manufactured, transported, printed, finished, and recycled money [34].

To illustrate that during the service life cycle use of concrete / concrete experience various stages that need to be considered in all aspects of conservation / environmental protection, Fig. 7 gives the illustration, and Figure 8 provides an overview of the macro-scale life cycle modeling [27]. During the transition policy for use in combination with a conventional concrete green concrete and sustainable gradually probably the right choice.

- Barriers to green concrete [35].

  Construction business practice is the first formidable institutional barrier. The building industry's profitability is largely determined by fast construction schedules, not by the life-cycle cost savings from the conservation of energy and materials. Experience shows that faster construction is not always less expensive. Poor-quality concrete requires costly repairs and tends to deteriorate faster. Thus, owners must pay a high life-cycle cost. Today's construction economy requires a fundamental restructuring.

  Building codes are another institutional barrier discouraging the use of recycled materials. Out-of –date codes specify the use of particular materials and mixture proportions for a job rather than specifying a particular standard of performance. For instance, all codes for concrete mixtures prescribe a maximum fly ash content (typically 15 to 25% by mass of the cementitious material) or minimum cement content. High performance concrete mixture with High Volume Flay Ash (HVFA) concrete prove that prescriptive specifications must be replaced with performance-based standards.
- The lack of a holistic approach in engineering education and research

  The shift from reductionistic to holistic construction practices must begin by reforming the present system of education and research in the fields of concrete science and technology. Greening of the entire concrete construction industry will have to proceed before green concrete replaces conventional concrete as the material of choice for general construction.

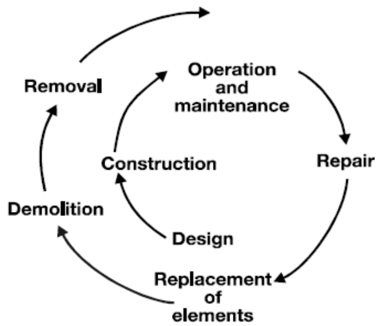

Fig. 7. Cycle service life use of concrete / reinforced concrete [27]

In Table 4, presents a political scenario that has been adopted by several European countries as well as internationally in order to realize the use of green concrete on a large scale through the implementation of various priority (high, medium, and low) and deregulation in various fields [30].

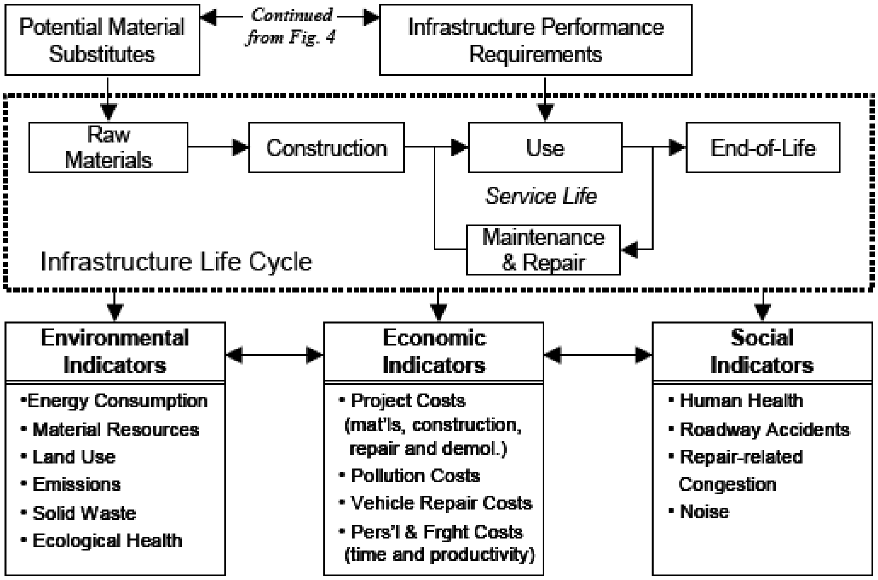

Fig. 8. Macro-scale modeling life cycle [27]

Table 4. Political scenarios at different countries [29]

	High priority	Medium priority	Low priority
Denmark	- CO_2 - Resource (water) - Fossil fuel (oil) - Substances harmful to health or environment (chemicals, heavy metals)	- SO_2, NO_X - Local supply of resources as sand, stone, gravel, chalk, and lime - Resource (recycling of waste of building industry)	VOC (only relevant related to the working environment)
The Netherlands	- Resource (energy) - CO_2 - Secondary materials/resources/land use/recycling	- Resource (water) (water only has a high priority concerning water use by building owner, showers, etc.) - NOX, SO2 - Substances harmful to health or environment (heavy metals)	- Indoor climate/radon - VOC (only relevant related to working conditions)
Italy	- CO_2 - NO_X - Waste	- CH_4 - N_2O - Resource (water)	- VOC (only relevant related to the working environment) - Substances harmful to health or environment (heavy metals)

	High priority	Medium priority	Low priority
Greece	Resource (energy)	- Fossil fuel (coal) - CO_2, CH_4, N_2O - Resource (water) - Solid waste - Substances harmful to health and environment (heavy metals) - Resources	SO_2, NO_X
European Union	- Substances harmful to health or environment (toxic chemicals, heavy metals) - CO_2, CH_4, N_2O - Resource (water)	- SO_2, NO_X - Selective demolition - Water quality	- VOC (only relevant related to the working environment) - Waste (increase reuse, recycling, minimized depositing, selective demolition)
International	- CO_2 - Resource (water)	Secondary raw materials, recycling/waste minimisation	Resource (energy)

In Table 4, presents a political scenario that has been adopted by several European countries as well as internationally in order to realize the use of green concrete on a large scale through the implementation of various priority (high, medium, and low) and deregulation in various fields [30]. The main priority is the various countries include the reduction of CO_2 emissions, CH4 and NOx, reduced use of fossil-based energy, use recycled materials, waste utilization, and reducing the use of substances harmful to human health.

6. Conclusions

Eight to 10 percent of the world's total CO_2 emissions come from manufacturing cement. Green concrete is defined as a concrete which uses waste material as at least one of its components, or its production process does not lead to environmental destruction, or it has high performance and life cycle sustainability. Various efforts that have been conducted to arrive at some alternatives that are able to significantly reduce high energy consumed and environmental impacts during fabrication process of cement, including implementing the concept of industrial ecology and green chemistry as well as nanoengineering that study the behavior of the structure and organization of nanoparticles of cement in the mix for achieving higher performance have been discussed. The cleaner technologies in concrete production, such as substituting relatively high percentage of cement by fly ash (upto 100%), the use of other natural pozzolans, development of concrete with recycling or waste materials, and developing nanoconcrete by integrating CNT's or self sensing CNT's in the concrete mix for higher performance developed have also been addressed in this paper. Several efforts that have been done so far in implementing the concept of green concrete and material development of nanosilica in Indonesia have also been reported. Problems in the realization of and potential barriers to green concrete as well as political scenarios that have been adopted by several countries through imple-mentation of varoius priority and deregulation in various fields are also discussed. Hopefully this paper will be useful for all of us in order to mobilize all parties to participate actively to the conservation and protection of the global environment the world, through the use of green concrete.

References

[1] Malhotra, V. M. (1999). "Making Concrete Greener with Fly Ash". *Concrete International*. 21 (5), May 61-66.
[2] Struble, L. and Godfrey, J. (2006). "How Sustainable is Concrete ?". *International Workshop on Sustainable Development and Concrete Technology*. University of Illinois at Urbana-Champaign , 201-211.

[3] Mehta, P. K. (2010). "Sustainable Cements and Concrete for the Climate Change Era – A Review". *Proc. 2nd International Conference on Sustainable Construction Materials and Technologies*. Ancona, Italy, June 28-30.
[4] Obla, K.H. (2009). "What is Green Concrete ?". *The Indian Concrete Journal*, April, 26-28.
[5] Birgisson, B., Mukhopadhyay, A.K., Geary, G., Khan, K. and Sobolev, K. (2012). "*Nanotechnology in Concrete Materials A Synopsis*". Transportation Research Circular, E-C170 December.
[6] Constantinides, G., and Ulm, F.-J. (2007). "The nanogranular nature of C-S-H." *Journal of the Mechanics and Physics of Solids*, 55 (1), 64--90.
[7] Ulm, F.J. (2007). "*MIT's Technology Review*".
[8] Yu, X. & Kwon, E. (2012). "*Carbon Nanotube Based Self-sensing Concrete for Pavement Structural Health Monitoring*". Research report – Univ of Minnesota Duluth, Contract Number: US DOT : DTFH61-10-C-00011.
[9] Pham, G.T., Park, Y.B., Liang, Z. and Zhang, C. (2008). "Processing and modeling of conductive thermoplastic/carbon nanotube films for strain sensing". *Composites Part B : Engineering*, Elsevier, 39 (1), January, 209–216.
[10] Li, C., Thostenson, E. T. and Chou, T.W. (2008). "Sensors and actuators based on carbon nanotubes and their composites: A review". *Composite Science and Technology* , 68, 1227–1249.
[11] Sasmal, S., Bhuvaneshwari, B. & Iyer, N.R. (2013). "Can Carbon Nanotubes Make Wonders in Civil/Structural Engineering?". *Progress in Nanotechnology and Nanomaterials*. 2 (4), Oct., 117-129.
[12] Ghasemzadeh, H. & Jalalabad, E.A. 2011. "*Comput-ing the compressive strength of carbon nanotube/ cement composite*". International Journal of Civil Engineering – Structural Engineering, 9 (3), September.
[13] Metaxa, Z.S., Konsta-Gdoutos, M.S. and Shah, S.P. (2011). "*Mechanical Properties and Nanostructure of Cement-Based Materials Reinforced with Carbon Nanofibers and Polyvinyl Alcohol (PVA) Micro-fibers*". A Final Report submitted to Infrastructure Technology Institute, SP-270-10.
[14] Jonbi, Hariandja, B., Imran, I. and Pane, I. (2012-a). "Material development of nanosilica Indonesia for concrete mix." *Advanced Materials Research,* Vols 450-451, Jan., 277-280.
[15] Jonbi, Pane, I ., Hariandja, B. and Imran, I. (2012-b). "The use of nanosilica for improving of concrete compressive strength and durability." *Advanced Materials Research,* Vols 204-208, Oct., 4059-4062.
[16] Phair, J.W. (2006). **"**Green chemistry for sustainable cement production and use". *Green Chem.*, 8**,** 763-780.
[17] Duxson, P., Provis, J.L., Lukey, G.C. and van Deventer, J.S.J. (2007). "*The role of inorganic polymer technology in the development of green concrete*". Department of Chemical and Biomolecular Engineering, The University of Melbourne, Victoria 3010, Australia.
[18] Torgal, F.P., Gomes, J.C. & Jalali, S. (2007). "Investigations about the effect of aggregates on strength and microstructure of geopolymeric mine waste mud binders". *Cement and Concrete Research,* 37 (6), June, 933-941.
[19] Nielsen, C.V. & Glavind, M. (2007). "Danish Experiences with a Decade of Green Concrete". *Journal of Advanced Concrete Technology* . Japan Concrete Institute , 5(1), February, 3-12.
[20] Bilodeau, A. & Malhotra, V.M. (2000). "High Volume Fly Ash System: Concrete Solution for Sustainable Development". *Materials Journal*, Vol. 97, January, 41-48.
[21] Nielsen, C.V. (2002). "Mechanical Properties for Green Concrete". *Featured at the XVIII Symposium on Nordic Concrete Research, Helsingør,* June, Denmark.
[22] Manmohan, D. & Mehta, K. (2002). "Heavily Reinforced Shearwalls and Mass Foundation Built with Green Concrete". *Concrete International*. Vol. 24, No. 8, August, 64-70.
[23] Uzal, B., Turanli, L. and Mehta, P.K. (2007). "High-Volume Natural Pozzolan Concrete for Structural Applications". *Materials Journal.* 104 (5), September, 535-538.
[24] Maclay, K. (2000). "*UC Berkeley retrofits take "green" approach to concrete foundations*." Media Relations, 27 Dec .
[25] Berry, M., Cross, D. & Stephens, J. (2009). "*Changing the Environment : An Alternative Green Concrete Produced without Portland Cement*". Orld of Coal Ash (WOCA) Conference – May 4-7, Lexington, KY, USA.
[26] Glavind, M. & Jepsen, M.T. (2002). "Evaluation of Green Concrete Types". *Proceedings of the XVIII Symposium on Nordic Concrete Research*. Helsinger, June.
[27] Kaoleian, G.A., Li, V.C., Kesler, S.E., Robertson, R.E., Batterman, S.A. & Moore, M.R. (2003). "*Sustainable Concrete Infrastructure Materials and Systems: Developing an Integrated Life Cycle Design Framework*". Research Report: CMS-0223971. August.
[28] Horiguchi, T. & Saeki, N. (2004). "*Compressive Strength and Leachate Characteristics of New Green CLSM with Eco-Cement and Melted Slag from Municipal Solid Waste*". Special Publication, Vol. 221, May.
[29] Horiguchi, T., Kikuchi, T., Nakagawa, Y. & Shimura, K. (2007). "*Physical Properties of CLSM Using High Volumes of Incineration Ash from Sewage Sludge*". Special Publication, Vol. 242, April.
[30] Damtoft, J.S., Glavind, M. & Munch-Petersen, C. (2001). "Danish Centre for Green Concrete". *Proceedings of CANMET / ACI International Conference.* San Fransisco, September.
[31] Naik, T.R. (2002). "Greener concrete using recycled materials". *Concrete International*. 24 (7), July, 45-49.
[32] Meyer, C. (2005). *"Concrete as a Green Building Material"*. New York: Department of Civil Engineering and

Engineering Mechanics, Columbia University.
[33] Satyarno, I. (2007). *Recycling Procedure of Brick Masonry Wall Rubble*. Yogyakarta: Department of Civil and Environmental Engineering, Universitas Gadjah Mada.
[34] Holland, T.C. (2002). "Sustainability of the Concrete Iindustry – What Should be ACI,s Role". *Concrete International*. Vol.24, No. 7, July, 35-40.
[35] Mehta, P. K. (2002). "Greening of the Concrete Industry for Sustainable Development". *Concrete International*, July, 23-28.