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Literature Review on Technical Aspect of Sustainable Concrete

S. P. Mukherjee[1] And Dr Gaurang Vesmawala[2]
[1] *P.G Student in Applied Mechanic Sardar Vallabhai Institute of Technology, Surat*
[2] *Assistant Professor in Applied Mechanic Sardar Vallabhai Institute of Technology, Surat*

ABSTRACT: *For a variety of reasons, the concrete industry is not sustainable. First, it consumes huge quantities of virgin materials. Second, the principal binder in concrete is Portland cement, the production of which is a major contributor to green-house gas emissions that are implicated in global warming and climate change. Third, many concrete structures suffer from lack of durability which has an adverse effect on the resource productivity of the industry.*

This paper discusses the Solution to this environmental problem, The solution to this problem is not to be replace concrete with other materials but to reduce the environmental impact of cement. A reduction in cement use is desirable in terms of energy and this can be achieved by using other cementitious materials or admixtures.

KEYWORDS: *Sustainable development; Cement; CO_2; Green Concrete; Supplemental cementitious materials; By-product*

I. INTRODUCTION

Engineers and architects have choices of the material and products they use to design projects – when it comes to a building frame the choice is typically between concrete, steel and wood; for paving applications the choice is generally between concrete and asphalt. Material choice depends on several factors including first cost, life cycle cost and performance for a specific application. Due to growing interest in sustainable development engineers and architects are motivated more than ever before to choose materials that are more sustainable. However this is not as straight forward as selecting an energy star rated appliance or a vehicle providing high gas mileage. On what measurement" basis can engineers and architects compare materials and choose one that is more sustainable or specify a material in such a way as to minimize environmental impact?[1]

Life Cycle Assessment (LCA) seems to offer a solution. LCA considers materials over the course of their entire life cycle including material extraction, manufacturing, construction, operations, and finally reuse/recycling. LCA takes into account a full range of environmental impact indicators—including embodied energy, air and water pollution (including greenhouse gases), and potable water consumption, solid waste and recycled content. [1]Sustainable development and sustainability have become increasingly popular over the last few decades, although they are amorphous concepts, and many governments, corporations and institutions are adopting them as policy. According to the World Commission on Environment and Development, sustainability means sustainable development, which meets the needs of the present without compromising the ability of future generations to meet their own needs. Sustainability seeks to balance the economic, social, and environmental impacts, recognizing that population growth will continue. [2] The promotion of sustainable development has put pressure on the adoption of proper methods to protect the environment across all industries, including construction. Today's ever-increasing demands could place a significant strain on the current energy infrastructure and potentially damage world environmental health by CO, CO_2, SO_2, NOx effluent gas emissions and global warming. Achieving solutions to environmental problems that we face today requires long-term potential actions for sustainable development. [2]

1.1 Forecast of CO_2 Emission

The exponential and unsustainable forecast of CO_2 emissions during the 21st century (Fig.1.1) is based on an estimated population increase from 6 to 9 billion; a corresponding growth in industrial development and urbanization.

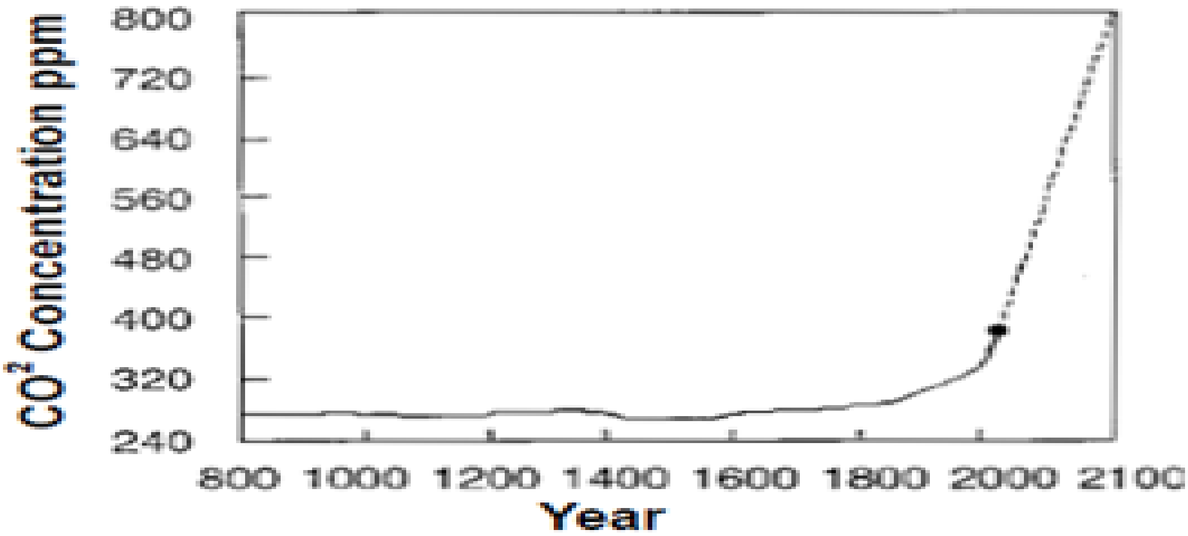


Fig 1.1 Historical and Future atmospheric CO_2 concentrations

1.2 Global Warming

One of the most pressing concerns for this industry is global warming, which is an increase in the average temperature of the Earth's atmosphere and oceans as a result of the buildup of greenhouse gases in our atmosphere. During the past century, global surface temperatures have increased at a rate near 0.6 ºC/century and the average temperature of the Atlantic, Pacific and Indian oceans, which cover 72% of the earth's surface, have risen by 0.06 ºC since 1995. Global temperatures in 2001 were 0.52 ºC above the long-term 1880–2000 average (the 1880–2000 annually-averaged combined land and ocean temperature is 13.9 ºC). Also, according to the USA Department of Energy, world emissions of carbon are expected to increase by 54% above 1990 levels by 2015, making the earth likely to warm 1.7–4.9 ºC over the period 1990–2100, as shown in Fig. (1.2.) [2]

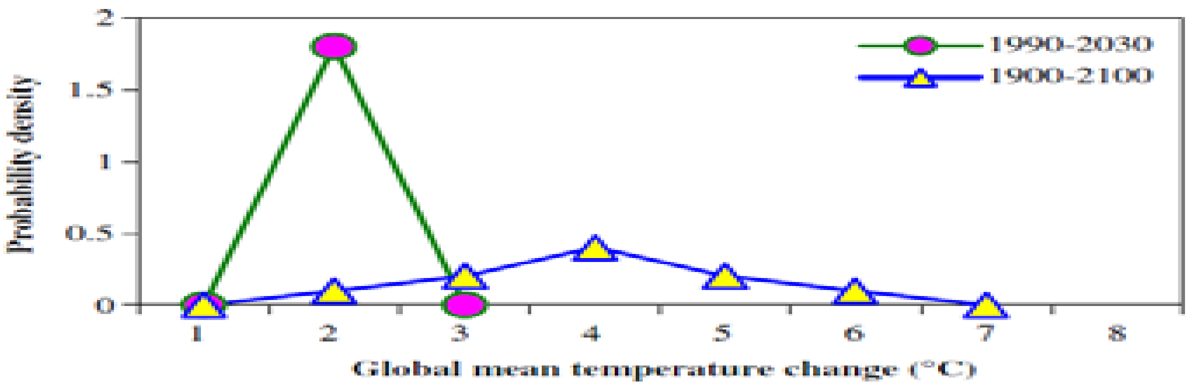


Fig 1.2 Global Mean Temperature changes over the period of 1900-2100 and 1990-2030.

This paper reviews the impacts on the environment, by one of the largest industries in the world, the concrete industry. The role of the cement industry in global CO_2 emissions, and alternative ways to reduce the use of large quantities of cement in mortar and concrete are especially discussed.

II. CEMENT & CONCRETE'S ROLE IN ENVIRONMENTAL IMPACT

Green Concrete is a revolutionary topic in the History of concrete Industry. This was first invented in Denmark in the year 1998 by Dr. WG. In Denmark a centre for Resource Saving Concrete Structures (short name Centre for Green Concrete) is formed with the aim of reducing environmental impact from concrete. To enable this, new technology is developed. The technology considers all phases of a concrete construction's life cycle, i.e. structural design, specification, manufacturing, maintenance, and it includes all aspects of performance. [2]

2.1 Cement Productions

Cement is considered one of the most important building materials around the world. It is mainly used for the production of concrete. Concrete is a mixture of inert mineral aggregates, such as sand, gravel, crushed stones, and cement. Cement consumption and production is closely related to construction activity, and therefore to general economic activity. Cement is one of the most produced materials around the world. Due to the importance of cement as a construction material, and the geographic abundance of the main raw material, limestone, cement is produced in virtually all countries. [2] Every 1 ton of cement produced leads to about 0.9 tons of CO_2 emissions and a typical cubic yard (0.7643 m3) of concrete contains about 10% by weight of cement. A cubic yard of concrete weighs about 2 tons, CO_2 an emission from 1 ton of concrete varies between 0.05 to 0.13 tons. Approximately 95% of all CO_2-emissions from a cubic yard of concrete are from cement manufacturing. [1]

The infrastructure needs of developing countries have led to huge increases in demand for Portland cement. According to the BAU scenario, cement consumption will grow at high rates on world levels in the 2000–2030 periods. On a global level, the 1600 Mt of cement consumption in 2000 will increase almost two-fold to 2880 Mt by 2030, implying an annual 2% growth rate. Figure 2.1 represents the regional consumption of cement in 10-year intervals, where 1997 is given in the figure as the base year. The chart shows that most growth takes place in the developing regions. However, the production of Portland cement, an essential constituent of concrete, leads to the release of a significant amount of CO_2 and other greenhouse gases (GHGs). [2]

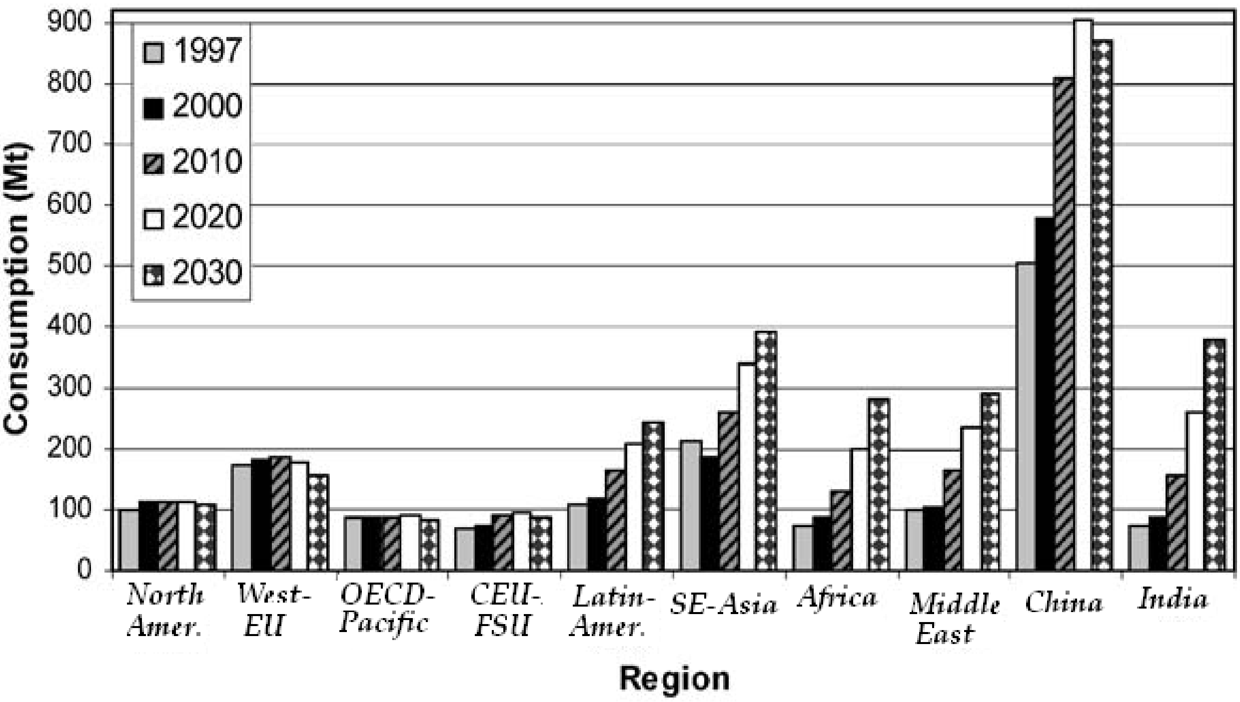


Fig 2.1BAU cement consumption by region

2.2 Concrete and CO_2

The concrete industry is known to leave an enormous environmental footprint on Planet Earth. Together with the energy requirements, water consumption and generation of construction and demolition waste, these factors contribute to the general appearance that concrete is not particularly environmentally friendly or compatible with the demands of sustainable development. [3] One important issue is the use of environmental-friendly concrete ("green") concrete to enable world-wide infrastructure-growth without increase in CO_2- emission. It is necessary to look for sustainable solutions for future concrete construction. The solution of this problem is use the green concrete which eliminates the negative impact of the cement industry, minimizing environmental impact, therefore, we should try to reduce the quantity of concrete used in buildings, to replace as much Portland cement as possible by supplementary cementitious materials, especially those that are by-products of industrial processes, such as fly ash, rice husk ash, palm oil fuel ash, slag, met kaolin and silica fume, and use that concrete wisely. [1]

III. LIFE CYCLES SCREENING (CASE STUDY)

As an example of the use of life cycle inventories, a case study has been performed for a column made of three different design principles compared to at reference principle, see table 3.1.

Table 3.1 Details for columns made from three different design principles (A, B and C) and a reference (column R)

Specification	Column R	Column A	Column B	Column C
Concrete Material	Ref. Concrete	Green concrete, A1	Green concrete, A1	Green concrete, A1
Geometry	h=6 m, d=0.7 m	h=6 m, d=0.74 m	h=6 m, d=0.7 m	h=6 m, d=0.7 m
Concrete cover	50 mm	50 mm	30 mm	30 mm
Steel	Black	Black	Stainless	Black
Construction	Traditional, in-situ	Traditional, in-situ	Traditional, in-situ	Cladding with stainless steel that replaces traditional shuttering in-situ
Maintenance and repair	Cleaning/washing Surface treatment every 3. Year repair after 25 years	Cleaning/washing Surface treatment every 3. Year repair after 25 years	None	None
Lifetime	50 years	50 years	75 years	75 years

The objective of the screening was to identify significant resource consumption and environmental loads of traditional concrete/design compared to green concrete/design occurring during the entire service life, this includes the environmentally viewed most critical maintenance/repair stage. [4] The performed lifecycle screenings quantify material usage (consumption of concrete) as well as CO_2-emissions generated at the involved stages during the lifecycle of the columns. In order to limit the analysis, the environmental screening comprises only those issues where the environmental impacts of the green concrete columns differ from those of the traditional one. [4] The results of the environmental screening for the 3 green concrete columns (A, B, C) and the traditional concrete column (R) is presented in Table 3.2 with to the CO_2-emission and in Table 3.3 with regard to the consumption of concrete.

Table 3.2 CO2-emissions for different designs of concrete columns

Design solution	Column R	Column A	Column B	Column C
kg CO2 per year	281	144	88	82

Table 3.3 Consumption of concrete for different designs of concrete columns

Design solution	Column R	Column A	Column B	Column C
kg Concrete for Construction	5897	5897	5266	5266
kg Concrete for Maintenance/Repair	775	775	0	0
kg Concrete, Total	6672	6672	5266	5266

The comparison demonstrates that column B (stainless steel reinforcement) and column C (stainless steel cladding) present the most environmental-friendly design solutions both with regard to the CO2-emissions and the consumption of concrete. In figure 3.1 the sources for the CO_2-emission is shown for the four column types. It can be seen that concrete raw materials and repair are the main sources to the CO_2-emission and that the use of green concrete significantly reduces the CO_2-emissions. Reinforcement and shuttering become significantly CO2-sources for solution B and C, respectively, but the total CO_2-emission is still low compared to the reference and solution A. [4]

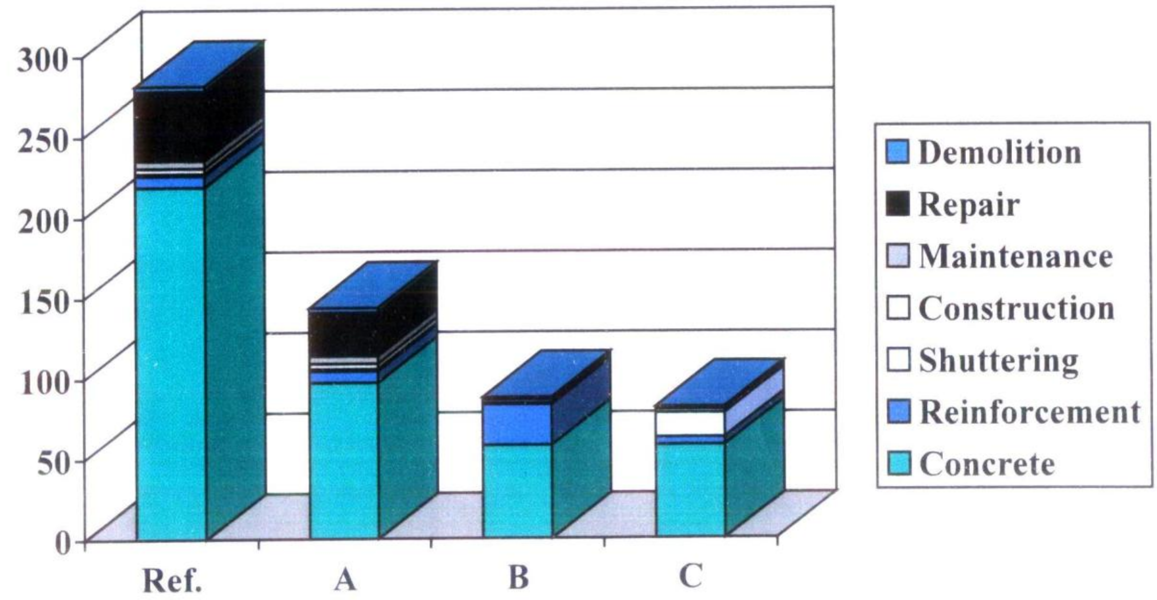


Figure 3.1 Sources of CO_2-emission for four types of columns

IV. REDUCTION OF CARBON DIOXIDE EMISSION THROUGH GREEN CONCRETE

One approach to help achieve higher infrastructure sustainability is the development and use of new materials, deliberately designed with sustainability as a primary goal, in terms of improved social well being, increasing economic prosperity, and reduced environmental impact. This can be accomplished through many methods, such as the replacement of dwindling raw materials with suitable waste products, the development of improved materials to replace less sustainable materials, or the use of new materials to extend infrastructure service life. Reductions will be achieved not only as a result of modifications to existing cement production methods, and the solution to this environmental problem is not to replace concrete with other materials, but to reduce the environmental impact of cement.

A reduction in cement use is desirable in terms of energy and this can be achieved by using other cementitious materials or admixtures. There are many steps to remove problems that affect sustainability, as well as to reach green concrete, including the use of supplemental cementitious materials (SCMs) to reduce cement consumption, through the use of lower amounts of cement and reasonable amounts of supplementary cementitious material (SCM). Every ton of pozzolanna effectively saves a ton of cement there are often engineering constraints limiting the percentage of cement that can be replaced? In the past, these limits have typically been in the range of 10-15%, but more recently, structures containing high volumes of pozzolanic materials can be seen. Incorporating industrial by-products/pozzolanic materials is becoming an active area of research because of their improved properties such as workability, long-term strength and durability. [1]

4.1 Production of Green concrete

Four ways to produce green concrete are being investigated.

1. To increase the use of conventional residual products, i.e. fly ash in large quantities.
2. To use residual products from the concrete industry, i.e. stone dust (from crushing of Aggregate) and concrete slurry (from washing of mixers and other equipment).
3. To use residual products from other industries not traditionally used in concrete, i.e. Fly ash from bio fuels and sewage sludge incineration ash (from sewage treatment plants).
4. To use new types of cement with reduced environmental impact (mineralized cement, limestone addition, waste-derived fuels). [4]

V. TYPES OF SUPPLEMENTAL CEMENTITIOUS MATERIALS

5. 1 Pulverized-Fuel Ash (PFA) or Fly Ash

PFA is a by-product of burning pulverized (finely ground) coal to generate electric power. The shales and clays (contents of silica, alumina and iron oxide) and other contents in coal, melt while in suspension, and then with rapid cooling they are carried out by the flue gases and form into fine spherical particles. Fly ash particles are generally spherical in shape and range in size from 0.5 µm to 100 µm. They consist mostly of silicon dioxide (SiO_2). Fly ash is an important pozzolanna, which has a number of advantages compared with regular Portland cement. First, the heat of hydration is lower, which makes fly ash a popular cement substitute for mass structures. Previous studies have found that the use of fly ash as an additive material for concrete gives positive results in terms of mechanical and chemical properties. [2], [3]

5.2 SILICA FUME (SF)

SF is a by-product of the manufacture of silicon and ferrosilicon alloys from high purity quartz and coal in a submerged-arc electric furnace. It is a powder with particles having diameters 100 times smaller than those of anhydrous Portland cement particles. The most important influences in the use of silica fume as an admixture in cement based materials are increases in tensile strength, compressive strength, compressive modulus, flexural modulus and the tensile ductility, but decreases in the compressive ductility, it enhances the freeze-thaw durability, the vibration damping capacity, the abrasion resistance, the bond strength with steel rebar, the chemical attack resistance and the corrosion resistance of reinforcing steel. Furthermore, it decreases the alkali-silica reactivity, the drying shrinkage, permeability, creep rate, coefficient of thermal expansion and dielectric constant. [2], [3]

5.3 Ground Granulated Blast furnace Slag

Ground granulated blast furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. Use of slag or slag cements usually improves workability and decreases the water demand due to the increase in paste volume caused by the lower relative density of slag.

5.4 Rice Husk Ash (RHA)

Globally, approximately 600 million tons of rice paddy is produced each year. On average, 20% of the rice paddy is husk, giving an annual total production of 120 million tons. Rice husk is an external covering of rice, which is generated (about 90% by mass) during de-husking of paddy rice. The RHA is rich in silica content, obtained by burning rice husk to remove volatile organic carbon such as cellulose and lignin. It is estimated that, one ton of rice yields 200kg of husk and about 40kg of ash. According to Mehta, the amorphous silica powders with high surface area are more reactive than the crystalline form of silica. The fineness of ash will significantly affect the reactivity of RHA in lime, mortar or concrete mix. [2], [3]

5. 5 Palm oil fuel ash (POFA)

Palm oil fuel ash (POFA) is produced as a result of the burning of palm oil shell and husk (in equal volume) as fuel in palm oil mill boiler to produce steam for electricity generation and palm oil extraction process. Both physical properties and chemical analysis indicated that POFA is a pozzolanic material. Various researchers reported that POFA has pozzolanic properties and highly reactive and can be used as a unique cement replacement for building construction materials if the POFA is ground to reduce the particle size (GPOFA), the median particle size is reduced to 10 µm. [2], [3]

5.6 Met kaolin (MK)

Met kaolin is refined kaolin clay that is fired (calcined) under carefully controlled conditions to create an amorphous alumina silicate that is reactive in concrete. Replacing Portland cement with 8% - 20% (by weight) met kaolin produces a concrete mix which exhibits favorable engineering properties, including: the filler effect, the acceleration of OPC hydration, and the pozzolanic reaction. [2], [3].

VI. TYPES OF OTHER GREEN MATERIALS THAT CAN BE USED IN PRODUCING GREEN/SUSTAINABLE CONCRETE

6.1 Recycled concrete

Construction and demolition waste (C&D waste) constitutes a major portion of all generated solid waste. With the increasing scarcity of suitable aggregate, construction industry has find ways of substituting recycled concrete aggregate (RCA) for natural aggregate. The technical problems of incorporating RCA into new concrete mixes are well known and have been addressed through research. Recycled aggregates have generally lower densities than the original material used, Although RCA is often considered with suspicion, it may be quite acceptable for many applications, and if higher performance specifications are to be met, a blend of virgin and recycled aggregate may make economic and technical sense. [3]

6.2 Post-consumer glass

Post-consumer glass is another example of a suitable aggregate for concrete. The only technical problem, namely the alkali–silica reaction (or ASR) and other potential problems can be solved. By exploiting the zero water absorption of glass, its high hardness and good abrasion resistance, its excellent durability and chemical resistance, and in particular the aesthetic potential of colored glass, true value is added to the glass. Making commodity products such as paving stones economically viable is a difficult proposition. [3]

6.3 Other recycled materials

In the United States, 100 million tons of sand is used in foundries for the production of steel and other metals. Most of such foundry sands are discarded and available to be recycled. Naik et al. have shown that such foundry sands are suitable for the production of concrete. Another potential source for concrete production is dredged material. The Port Authority of New York and New Jersey needs to dredge about three million cubic meter of sediment each year to keep shipping lanes open and also to deepen them to accommodate the larger new vessels. Since dumping in the open ocean is no longer an option, the material has to be deposited in engineered landfills at great cost, because much of it is highly contaminated with heavy metals, dioxins, PCBs, oils, etc. Similar problems are faced by many other world ports. Treatment methods are already available, which render the material suitable for concrete production, because the heavy metals can be encapsulated chemically such that they cannot leach out. Further research is needed before this technology can be applied in real practice.
Recycled carpet fibers have also been proposed to replace virgin fibers in fiber-reinforced concrete. Millions of tons of old carpets need to be disposed of each year, constituting another sizeable fraction of solid waste. Since carpet fibers are typically made of nylon, recycled fibers have been shown to improve some mechanical properties of cosncrete. [3]

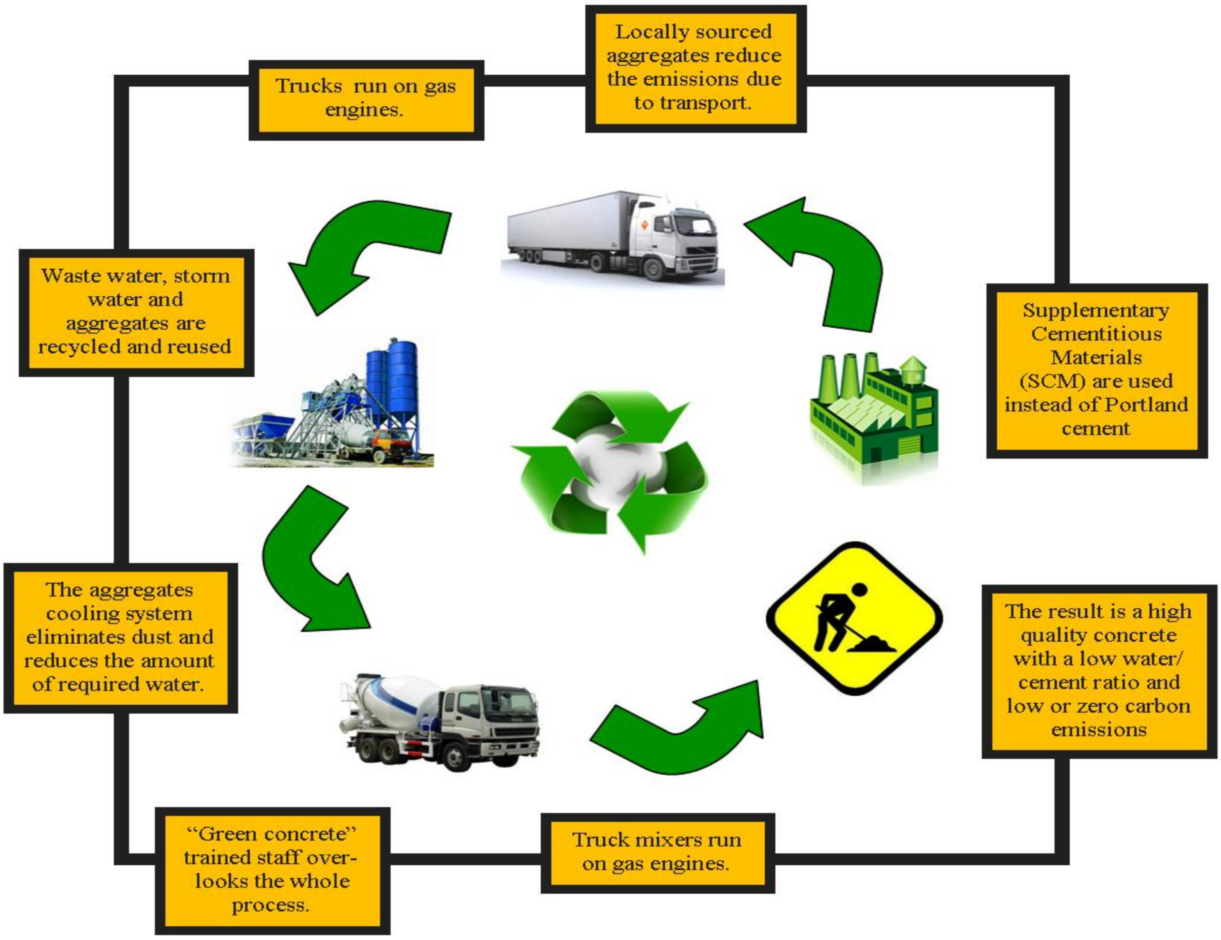
VII. SUITABILITY OF GREEN CONCRETE IN STRUCTURES

a) Reduce the dead weight of a façade from 5 tons to about 3.5 tons.
b) Reduces crane age load, allow handling, lifting flexibility with lighter weight.
c) Good thermal and fire resistance, sound insulation than the traditional Granite rock.
d) Improve damping resistance of building, speed of construction, shorten overall construction period
e) There are numerous advantages in usage of Green concrete in fresh stage such as Enhances the rheology of the mix, workability, Deficiency in sand is corrected by providing sufficient fines, which makes the concrete ideal for pumping, No bleeding & No cold joints
   There are numerous advantages in usage of Green concrete in hardened stage such it, Increases the durability as lower permeability is achieved, Improves the quality of cover to the reinforcement, Protection against sulphate attack and chloride penetration, Safeguard against Alkali-Silica reaction, Decreased thermal cracks due to lower heat of hydration.
f) It helps nation by Substantial saving in power, Decrease in emission of CO_2 – pollution free environment, If all the fly ash generated each year were used in producing concrete, the reduction of carbon dioxide released from cement production would be equivalent to eliminating 25% of the world’s vehicle. By reducing consumption of OPC, the rate of depletion of mineral resources (National Resources) required for production of cement can be reduced. If SCMs are used the problem of disposal will be reduced, thus reducing the environmental hazards and will clear many many acres of land used for disposal.

VIII. Conclusions

Concrete continues to play a pivotal role in overall economic growth both locally and globally. In order to improve the sustainability of all concrete structures, there is a need to understand the interactive effect of the many issues from ‘cradle to grave’ in the design phase, during construction and end-of-life and, most importantly, the energy savings achievable during the use phase. The importance of assessing a building or structure's impact is via a life-cycle assessment. This document has summarized what sustainability is, what it means and why it is important in the provision of sustainable buildings and infrastructure. Most importantly, the document shows that concrete raw materials and repair are the main sources to the CO_2-emission. It also describes the role which Green concrete can play in eliminating the negative impacts of the cement industry, to replace as much Portland cement as possible by supplementary cementitious materials, and use that concrete wisely. The benefits of concrete, save both money and resources during the life of the structure, where and how all these benefits can be used during the design, construction, use and end-of-life phases of a building or structure.

The following steps show in detail, where in the material acquisition, concrete production and final installation processes can be enhanced to make concrete a more sustainable building material. [6]



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