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ENVIRONMENTAL IMPACT OF GREEN CONCRETE IN PRACTICE

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Abstract- *The buildings and other structures in which we live and work have a tremendous impact on our global environment. Concrete is the world's most abundant building material which can be shaped to make roads, bridges, dams, tunnels, buildings etc. Recently, a research study shows that each year more than six billion tons of concrete are produced worldwide which generates a huge amount of carbon dioxide and other green house gases into the environment that leads to global warming. In recent years, global concerns about climate changes have led the researchers to find ways to minimize carbon dioxide and other green house gas emission. 'Green Construction' seeks to balance resource efficiency, health, and social concerns throughout the life cycle of a structure. Among them green concrete has a variety of benefits to offer in achieving this goal. This paper gives an overview of the present state of green concrete that have reduced environmental impact. It is also emphasized here that the use of green concrete embodies low energy costs, lower green house gas emission and low maintenance cost leading to sustainable construction materials. Furthermore, in terms of resource conservation, reuse of post-consumer wastes and industrial byproducts used as a partial replacement for Portland cement clinker, makes concrete more durable and environmentally friendly.*

Keywords: Green Construction, Sustainable construction material, Resource conservation, Portland cement clinker

1. INTRODUCTION

The buildings in which we live and work have a tremendous impact on our global environment. Sustainability or 'green building' seeks to balance resource efficiency, health, and social concerns throughout the life cycle of a structure. Green Concrete has a variety of benefits to offer in achieving this goal. Cement is a gray powder that, when mixed with water, binds sand and stone together to create concrete. Concrete is the world's most abundant building material which is extremely strong and durable. The longevity of concrete means less maintenance and replacement when compared to other building products. This contributes to the environmental value of this versatile building material.

More than six billion tons of concrete are produced annually-about one ton per person on the planet. Concrete is made from cement, water, sand and gravel. The cement is made by heating raw materials such as limestone and clay to very high temperatures until they chemically react. This process uses massive amounts of energy (about five percent of the world's use per year) and releases about a ton of carbon dioxide per ton of cement made. The most important thing is that anything we can do to make concrete more environmentally friendly will have a big impact, simply because it is the world's most used material. (Stated by Maria Juenger, Assistant Professor, Department of Civil engineering, The University of Texas, Austin, US)

Although making cement requires a great deal of energy, cement is only a minor portion (7%–15%) of concrete. The other ingredients, aggregates and water, require very low energy to obtain. The high temperatures needed for cement manufacturing make it an energy intensive process, as compared with the production of other building materials. Both fuel for heating and the chemical reaction from processing raw materials generate carbon dioxide (CO_2) which leads to global warming. This environmental impact can be mitigated by replacing a portion of the cement with fly ash, blast furnace slag, silica fume and rice husk ash etc., thereby reducing carbon emissions created in concrete production. These are the by-products from power plants, steel mills, silicon manufacturing facilities and dehusking of paddy rice respectively. Concrete is also 100% recyclable; it can be crushed and reused as the aggregate in new concrete applications. In reasonable proportions, these by-products confer beneficial properties to concrete.

In 2003, 3 million tons of fly ash was used in the manufacturing of cement and another 12.2 million tons in the production of concrete according to ACAA–2003 data. However, Global concerns about climate changes have led industry researchers to find ways to minimize CO_2 production. The result is a 29% decrease in carbon dioxide output from cement plants during the past three decades. Research has also led to the use of industrial by-products in the manufacturing process of cement. In 2004, about 130 million tires were consumed as fuel in cement kilns (out of 290 million produced), reducing fossil fuel consumption and removing them from the waste stream. In Denmark, partners from all sectors related to concrete production, among these aggregate, cement and concrete producers, a contractor, a consulting engineering company, Danish Technological Institute, the technical universities and the Danish Road Directorate have formed the 'Centre for Green Concrete'. The aim of the centre is to develop new green types of concrete and green structural solutions.

2. ABOUT GREEN CONCRETE

For today, Green Concrete means environmentally friendly concrete. During the production phases of concrete, green concrete is another name for resource-saving concrete. Concrete that has a reduced environmental impact with regard to energy consumption and emissions in its manufacturing, and the amount of CO_2 and other green house gases generated. Green concrete can often also be less expensive to produce, because waste products are used as a partial substitute for cement, landfill taxes are avoided, energy consumption in production is lowered, and durability is improved. In this way in terms of resource and energy conservation, green concrete has become successful to a great extent. In the production of 'Green' concrete, it contains at least 20 percent fly ash, a waste product from coal-burning power plants; its production results in less CO_2 emission. In addition, concrete also can be mixed with blast-furnace slag, silica fume, or recycled crushed concrete and thus giving the manufacturers more eco-friendly options.

3. TYPES OF SUPPLEMENTAL CEMENTITIOUS MATERIALS IN GREEN CONCRETE

Some supplemental cementitious materials (SCMs) are available in large quantities that can be used to replace Portland cement in concrete. These include fly ash, ground granulated blast-furnace slag (GGBS), silica fume, natural pozzolans, rice-husk ash etc.

3.1 Fly ash

Fly ash or pulverized fuel ash (PFA) is a fine residue resulting from the burning of powdered coal at high temperatures. The most common sources of fly ash are electric power-generating stations. Fly ash has become the predominant pozzolan in use throughout the world due to performance and economic factors. Development of fly ash as a constituent of Portland cement concrete was initiated in the U.S. during the early 1930s.The main constituent of fly ash is silica. Glassy noncrystalline forms of silica, alumina, and iron are principally responsible for the pozzolanic reaction with calcium hydroxide (lime). In concrete, lime results from the hydration of Portland cement. Other components of fly ash are calcium, magnesium, sulfur, potassium, and sodium. Class C fly ashes contain less silica, alumina, and iron than the Class F ashes and usually have elevated levels of calcium. The closer view of fly ash particles has been shown in figure 1.

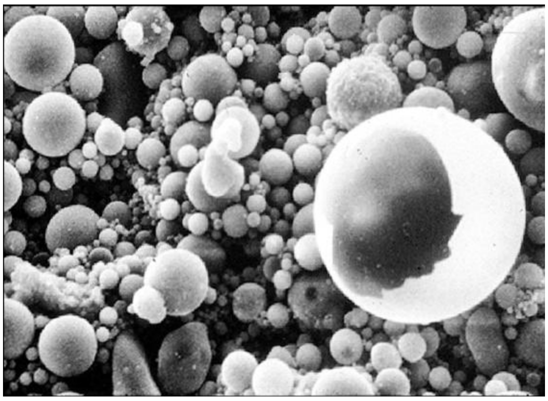

Figure 1: Fly ash particles viewed at 1000x magnification
(Source: ACI Education Bulletin E3-01)

Fly ash is an important pozzolan, which has a number of advantages compared with regular Portland cement. Those advantages of using PFA in concrete have been given below.

Reduced Water demand and improved Workability- Fly ash normally results in improved workability. The reduction in water requirement incorporation PFA in cement is due to the spherical shaped particles and their smooth surface which also roll in fresh paste thereby reduce the frictional resistance of cement particles and improve the fluidity of the mixture.

Higher long-term Strength gain: Fly ash concrete normally results in lower early strength but it continues to combine with free lime, increasing compressive strength over time. Many concrete mixtures containing class C fly ash, up to 35%, have similar 28-days strength gain characteristics as plain cement concrete.

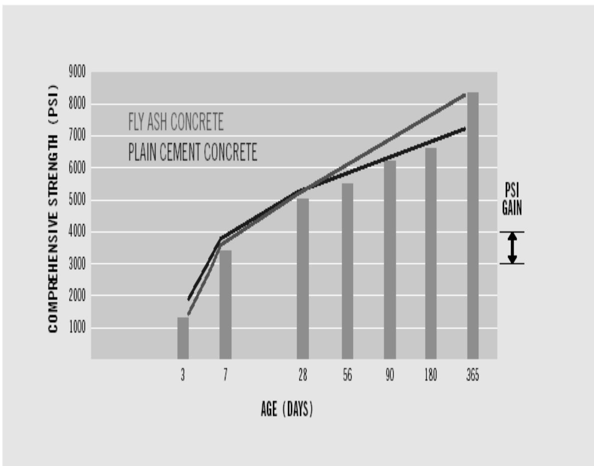

Figure 2: Strength gain of Plain cement concrete and Fly ash concrete

Properly designed concrete mixtures containing fly ash can exhibit higher ultimate compressive strength than Portland cement concrete mixtures which has been illustrated in figure 2. Portland cement continues to hydrate and, the rate of strength gain typically slows down after about 28 days. Fly ash concretes, however, continue to gain strength beyond 28 days at a rate greater than plain Portland cement concrete as a result of continued pozzolanic reaction with available calcium hydroxide inside the concrete. This effect can be seen in the figure-2. Using 28-day strengths for comparison, over time, plain Portland cement concrete generally gains about 30% additional strength whereas Portland cement/ fly ash concrete can gain 50 to 100% additional strength.

Reduced Heat of Hydration: The heat of hydration is lower, which makes fly ash a popular cement substitute for mass structures. The pozzolanic reaction between fly ash and lime generates less heat, resulting in reduced thermal cracking.

Decreased Permeability: Studies have shown that permeability of fly ash concrete is substantially lower than plain Portland cement concrete. This effect is due to the pore refinement that occurs as a result of long-term pozzolanic action of fly ash. Reduced permeability of fly ash concrete can decrease the rates (of entry into concrete) of water, corrosive chemicals, oxygen, and carbon dioxide.

Increased Durability: Durability of concrete refers to its ability to resist physical forces such as repetitive loading, freezing-thawing, abrasion, and chemical attack such as soluble sulfates. Replacing Portland cement with Class F fly ash lowers the tricalcium aluminate content of the concrete and makes it more resistant to sulfates. Fly ash concrete may slow down the rate of attack from acids (because permeability is reduced). Moreover, corrosion of reinforcing steel is also resisted due to lower permeability of fly ash as the intrusion of chlorides which causes the corrosion is reduced. However, Class F fly ash is also effective in reducing destructive expansion from alkali-silica reaction by consuming alkalis in pozzolanic reaction.

Reduced Efflorescence: Fly ash chemically binds free lime and salts that can create efflorescence.

Reduced Shrinkage: The largest contributor to drying shrinkage is water content. The lubricating action of fly ash reduces water demand and as a consequence reduces drying shrinkage.

3.2 Ground Granulated Blast-Furnace Slag

Ground granulated blast furnace slag (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. The use of granulated blast-furnace slag in concrete has increased considerably in recent years, and this trend is expected to continue. The worldwide production of granulated blast-furnace slag, however, is only about 25 million tones per year. The following figure 3 shows the forms of ground granulated blast furnace slag (GGBFS).

Generally, the comparison of ground granulated blast furnace slag (GGBFS) with Portland cement concrete can be summarized as follows:

Figure 3: Slag in Various forms
(Source: ACI Education Bulletin E3-01)

• Concrete with Type IS cement (Pozzolana cement) or with higher dosages of GGBFS added at the mixer usually will have lower heat of hydration;
• Concretes containing slag may show somewhat longer time of setting than straight Portland cement mixtures, particularly for moderate and higher dosages and at lower ambient temperatures;
• Concrete with Type IS cement gains strength more slowly, tending to have lower strength at early ages and equal or higher strength at later ages;
• Increasing slag dosage is associated with lower permeability in concrete;
• Concrete containing GGBFS dosages greater than 35% by mass of cementitious material, have demonstrated an improvement in the resistance to sulfate attack, as well as suppression of alkali-aggregate expansion;

3.3 Silica Fume (SF)

Silica fume, a highly pozzolanic material, is a by-product produced when silicon metal or ferro-silicon alloys are smelted using electric arc furnaces. This finely divided, glassy powder results from the condensation of silicon oxide gas. Silica fume is composed primarily of silicon dioxide (SiO_2). Particles are about 100 times smaller than the typical particles of Portland cement. Silica fume is typically used in quantities ranging from 7 to 12% of the mass of the cementitious material. Worldwide production is estimated to be about 2 million tones. It is generally specified for specialized applications, such as structures exposed to aggressive chemicals. Its primary use is to enhance the durability of concrete by making it less permeable.

Silica fume addition benefits concrete in two ways. First, the minute particles physically decrease the void space in the cement matrix—this phenomenon is known as packing. Second, silica fume is an extremely reactive pozzolan. Silica fume is added to concrete to increase compressive strength or to improve durability. Properly proportioned silica fume concrete can achieve very high early and ultimate compressive strengths. Ready-mixed concrete with compressive strength of nearly 135 MPa (20,000 psi) has been produced in the U.S. using silica fume combined with other admixtures. Silica fume enhances durability primarily by decreasing the permeability of concrete. With its reduced permeability, silica-fume concrete has been extensively used in applications where limiting the entry of chlorides is essential, such as in bridge decks, parking structures, and marine structures. In addition, it enhances the freeze-thaw durability, the vibration damping capacity, the abrasion resistance, the bond strength with steel rebars, the chemical attack resistance and the corrosion resistance of reinforcing steel. Furthermore, it decreases the alkali-silica reactivity, the drying shrinkage, creep rate, coefficient of thermal expansion (Nurdeen, 2010).

3.4 Rice Husk Ash (RHA)

Rice husk ash is not yet commercially available. Along with fly ash and granulated blast-furnace slag, rice husk ash, when it becomes commercially available, will be the most significant supplementary cementitious material for use as a partial replacement for Portland cement in concrete to reduce CO_2 emissions. Rice covers 1% of the earth's surface and is a primary source of food for billions of people. Globally, approximately 600 million tones of rice paddy are produced each year. On average 20% of the rice paddy is husk, giving an annual total production of 120 million tones. In the majority of rice producing countries much of the husk produced from the processing of rice is either burnt or dumped as waste. Rice husk is an external covering of rice, which is generated during dehusking 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. The silica present in the ash is amorphous or crystalline. The burning method and the fineness of the particles are two major factors that primarily affect the reactivity of RHA. The ash gradually loses its pozzolanicity as the temperature of incinerator is increased at a given fineness.

4. GOALS OF PRODUCING GREEN CONCRETE

The main goal of producing green concrete is to make an environment friendly concrete as well as to reduce the harmful residuals produced in different industry and make the concrete economical. To enable this, new technology is developed. The technology considers all phases of a concrete constructions life cycle, i.e. structural design, specification, manufacturing and maintenance, and it includes all aspects of performance, i.e. mechanical properties(strength, shrinkage, creep, static behavior etc.), fire resistance (spalling, heat transfer etc.),workmanship (workability, strength development, curing etc.), durability (corrosion protection, frost, new deterioration mechanisms etc.), environmental aspects (CO_2-emission, energy, recycling etc.).

Goals related to residual reduction and economy are given below:

• Concrete with minimal clinker content.
• Concrete with green types of cement and binders.
• Concrete with inorganic residual products.
• Operation and maintenance technology for green concrete structures.
• Green structural solutions and structural solutions for green concrete.

Environmental Goals are as follows:

• CO_2 emission caused by concrete production must be reduced by at least 30%.
• The concrete industry's own residual products must be used in concrete production.
• New types of residual products, previously land filled or disposed of in other ways, must be used in concrete production.
• CO_2-neutral, waste-derived fuels must replace at least 10% of the fossil fuels in cement production.

5. REDUCING ENVIRONMENTAL IMPACT THROUGH GREEN CONCRETE

The World Earth Summits in Rio de Janeiro, Brazil, in1992, and Kyoto, Japan, in 1997, made it abundantly clear that reducing the rate of greenhouse gas emissions is essential for sustainable development. While greenhouse gases of concern include nitrous oxide (NO_x) and methane (CH_4), their amounts are relatively small compared with that of the primary greenhouse gas, carbon dioxide (CO_2). As a consequence, the developed countries are considering regulations on the emission of these gases. The greenhouse gases allow high-frequency heat waves from the sun to penetrate the atmosphere and heat the surface of earth, but they do not allow the low-frequency heat radiation from earth's surface to escape back into space. The increased quantity of greenhouse gases in the atmosphere increases the temperature of earth's surface. A small increase in the amount of greenhouse gas causes an enhanced response in the global temperature rise. As the manufacture of Portland cement contributes significantly to the CO_2 emissions, this research paper mainly discusses the increased use of large volumes of supplementary cementing materials in the concrete industry and its role in reducing this green house gas emission.

Cement, one chief component of concrete, is a major industrial commodity that is manufactured commercially in over 120 countries Mixed with aggregates and water, cement forms the ubiquitous concrete which is used in the construction of buildings, roads, bridges and other structures. Cement is manufactured from a combination of naturally occurring minerals - calcium (60% by weight) mainly from limestone, silicon (20%), aluminum (10%), iron (10%) and small amounts of other ingredients and heated in a large kiln to over 1500° C (2700° F) to convert the raw materials into clinker. The cement industry contributes to carbon dioxide emissions in two ways. Roughly half of the emitted CO_2 originates from the fuel and half originates from the chemical reaction. An indirect and significantly smaller source of CO_2 is from consumption of electricity assuming that the electricity is generated from fossil fuels. Minor amounts of other green house gases NO_x and CH_4 are also released into the atmosphere.

Ordinary Portland cement results from the calcinations of limestone and silica in the following reaction.

Limestone + silica (1500 °C) = Portland cement + CO_2

$$[5CaCO_3 + 2SiO_2 \rightarrow (3CaO, SiO_2)(2CaO, SiO_2) + 5CO_2]$$

The following table 1 shows the amount of CO_2 emitted from the production of one ton Portland cement in detail.

Table 1: Indicative CO_2 emission from production of 1 ton Portland cement

Source	Indicative CO_2 emitted	Comment
Chemical Composition (Breakdown of limestone)	500kg	The major source of CO_2 and intrinsically unavoidable
Fuel	350kg	Use of waste as fuel can benefit sustainability
Electricity	80kg	The CO_2 is normally emitted offsite, at a power station
Total	930kg	

According to the International Energy Authority World Energy outlook 1995, the worldwide CO_2 production from all sources was 21.6 billion tones of which the worldwide production of cement accounts for almost 7 % of the total world CO_2 production. Most importantly, cement industry is the second fast growing source of CO_2 emissions, and demand for concrete is predicted to double over the next decade (Battelle, 2002).

There are a number of ways that the cement and concrete industry can contribute toward reducing CO_2 emissions. These include:

(i) Using less Portland cement.
(ii) Using more supplementary cementitious materials.
(iii) Incorporating recycled aggregates in concrete.
(iv) Replacing high carbon fuels by low carbon fuels.
(v) Where possible, specifying strength acceptance criteria at 56 or 91 days instead of 28 days.

A reduction in cement use is desirable in energy terms and this can be achieved by using other cementitious materials. These cementitious materials have to show comparable or better properties and costs compared with the existing ordinary Portland cement. The cement industry, realizing the need to reduce carbon emissions, began an initiative to bring down the industry’s contribution to green house gases. There are many steps to get rid of the problems that affect the sustainability as well as to reach the green concrete, including use of supplemental cementitious materials (SCMs) to reduce cement consumption, through the use of lower amounts of cement and reasonable amounts of supplemental cementitious material (SCM). The proportion of 'pure' cement in a cement based mixture can be reduced by replacing some of it with other pozzolanic material (i.e. material which has the ability to act as a cement like binder). Industrial wastes including fly ash, ground granulated blast furnace slag (GGBFS), silica fume and rice husk ash all have the combined benefit of being pozzolana that would otherwise be destined for landfill. In addition to using pozzolanic materials as supplementary materials to reduce the environmental impact that resulting from the use of concrete, there are another various reasons, particularly for reducing the amount of cement required for making concrete which lead to a reduction in construction cost. As well as the benefits from using pozzolanic materials include reductions in energy consumption, greenhouse gas releases and other pollutant emissions from initial mining of limestone, calcination and grinding.

Table 2: Calculated environmental impacts for 1 ton of concrete

Impact	100% PC	50% GGBS	30% Fly Ash
Green house gas (CO_2)	142 kg (100%)	85.4 kg (60%)	118 kg (83%)
Primary energy use	1,070 MJ (100%)	760 MJ (71%)	925MJ (86%)
Mineral extraction	1,048 kg (100%)	965 kg (92%)	1007 kg (96%)

From table 2, it is apparent that replacing 50% of the Portland cement with ground granulated blast furnace slag (GGBFS) results in 40% reduction in the CO_2 emissions and 8% reduction in mineral extraction. Moreover, it is evident that replacing 30% of Portland cement with fly ash causes 17% reduction in the CO_2 emissions and 4% reduction in mineral extraction. If a country can decrease cement production by 50% through replacement of cement by fly ash, slag or other supplementary cementing materials, the country would reduce its CO_2 emissions for the production of cement by about 50%. (Malhotra, 1999)

6. CONCLUSION

A sustainable industrial growth will influence the cement and concrete industry in many respects as the construction industry has environmental impact due to high consumption of energy and other resources. So the important issue is the use of environmental-friendly concrete or ‘green’ concrete to enable world-wide infrastructure-growth without increase in CO_2 emission. Environmental issues associated with the CO_2 emissions – from the production of Portland cement, energy and resource conservation considerations and high cost of Portland cement plants - demand that supplementary cementing materials should be used in increasing quantities to replace Portland cement in concrete. Another, probably even more important issue, is the use of more environmental friendly structural designs incorporating more environmental-friendly maintenance or repair strategies which requires less use of resources, reduce CO_2-emissions at all phases during the entire service life of a concrete structure. So we need high tech to lower the environmental impact of concrete production. Additionally we need to combine the efforts in international projects to benefit the most from the work performed in the field of green concrete. It is hoped that the concrete industry will show leadership and resolve and make contributions to the sustainable development of the industry in the 21st century by adopting new technologies to reduce the emission of greenhouse gases, and thus contribute toward meeting the goals and objectives of the 1997 Kyoto Protocol.

Finally green concrete concept cannot stand alone. It needs to be backed up by a sustainable design concept taking into account the full life-cycle and also the aspects of energy performance of the building and maintenance. Concrete is one of the few building materials offering decades of practically maintenance-free service life but it requires proper design to meet the requirements of the users over a full life-cycle. Therefore, we still have a job to do implementing sustainable design concepts in order to serve the society.

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