Sustainable Development Using Supplementary Cementitious Materials and Recycled Aggregate

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ABSTRACT

Concrete is the most widely used construction material worldwide. Its popularity gives the well-known advantages, such as low cost, general availability, and wide applicability. As well as the applications of concrete in the realms of infrastructure, habitation, and transportation have greatly prompted the development of civilization, economic progress, stability and of the quality of life.

But this popularity of concrete also carries with it a great environmental cost. The billions and billions tons of natural materials are mined and processed each year, by their large volume, are bound to leave a substantial mark on the environment. Most damaging are the huge amounts of energy required to produce Portland cement as well as the large quantities of CO_2 released into the atmosphere in the process.

This paper summarizes the various efforts underway to improve the environmental friendliness of concrete to make it suitable as a "Green Building" material. For most and most successful in this regard is the use suitable substitutes for Portland cement, especially those that are by-products of industrial processes, like fly ash, ground granulated blast furnace slag, cement kiln dust, rice husk ash and wood ash.

The paper discusses some of the economic drivers which determine the degree of commercial success. Simply deposing of waste materials in concrete products is unlikely to succeed except in unusual situations. The emergence of the Green Building movement in india is already changing the economic landscape and the factors that influence resource utilization.

Keywords: Sustainable Development, Green Buildings, Supplementary Cementitious Materials, Recycled Concrete Aggregate.

I. INTRODUCTION

Presently, annual worldwide concrete production is about 12 billion tons, consuming approximately 1.6 billion tons of Portland cement, 10 billion tons of sand and rock, and 1 billion tons of water. The production of one ton of Portland cement generates approximately one ton of carbon dioxide and requires up to 7000 MJ of electrical power and fuel energy. As

Large quantities of waste materials and by-products are generated from manufacturing processes, service industries and municipal solid wastes, etc. As a result, solid waste management has become one of the major environmental concerns in the world. With the increasing awareness about the environment, scarcity of land-fill space and due to its ever increasing cost, waste materials and by-products utilization has become an attractive alternative to disposal. High consumption of natural sources, high amount production of industrial wastes and environmental pollution require obtaining new solutions for a sustainable development. During recent years there has been a growing emphasis on the utilization of waste materials and by-products in construction materials. Utilization of waste materials and by-products is a partial solution to environmental and ecological problems. Use of these materials not only helps in getting them utilized in cement, concrete, and other construction materials, it helps in reducing the cost of cement and concrete manufacturing, but also has numerous indirect benefits such as reduction in landfill cost, saving in energy, and protecting the environment form possible pollution effects. Further, their utilization may improve the microstructure, mechanical and durability properties of mortar and concrete, which are difficult to achieve by the use of only ordinary Portland cement. [1]

II. Sustainable Development

Sustainable building materials are more than recycled or reused materials and components. In order to be truly sustainable, the material must be examined from the time it is harvested as a raw material to the time it will need to be disposed of. When carrying out a Sustainable Development price is of course one consideration but more important is the environmental and health impact of the materials. Energy consumption, waste, emissions, and the resources' ability to renew itself are the most important aspects. The energy consumption of a material during harvesting, transporting, processing, and use are all considered to decide if a material is truly sustainable and therefore suitable in the construction of a Sustainable Development.

These and various related concerns led to the concept of sustainable development, which can be summarized as follows:

1. Remedy the mistakes of the past by cleaning up our contaminated water and soil.
2. Avoid the pollution of our air, water and soil, including the release of greenhouse gases into the atmosphere that are known to contribute to global warming.
3. Utilize natural resources, whether material or energy, at a rate no greater than at which they can be regenerated.
4. Find a proper balance between economic development and preservation of our environment, i.e. improve the living standard and quality of life without adversely affecting our environment. [2]

These goals describe an ideal state and are obviously difficult to achieve. Yet, we do not have much of a choice, lest the live ability of our planet take a rapid turn for the worse. As the World Earth Summits in Rio de Janeiro (1990) and Kyoto (1997) demonstrated very clearly, this worldwide problem can be solved only through concerted international efforts. The industrialized countries are called upon to reduce the emission of greenhouse gases and the wasteful use of natural resources, and the developing countries need to avoid the mistakes made by the industrialized world in the past and develop their economies using technologies that make optimal use of energy and natural materials, without polluting the environment.

It is the purpose of this article to discuss various aspects of the concrete industry, because it has a much larger impact on sustainability than many of us may realize. Concrete is by far the most widely used construction material worldwide. In fact, it is more widely used than any other material, except water. Its huge popularity is the result of a number of well-known advantages, such as low cost, general availability, and adaptability to a wide spectrum of performance requirements. But this popularity of concrete also carries with it a great cost in terms of impact on the environment. [3, 4]

1. Worldwide, over ten billion tons of concrete are being produced each year. In the United States, the annual production of over 500 million tons implies about two tons for each man, woman and child. Such volumes require vast amounts of natural resources for aggregate and cement production.
2. In addition, it has been estimated that the production of one ton of Portland cement causes the release of one ton of CO2 into the atmosphere. CO2 is known to be a greenhouse gas that contributes to global warming, and the cement industry alone generates about 7% of it.
3. The production of Portland cement is also very energy-intensive. Although the North American plants have improved their energy-efficiency considerably in recent decades to the point where this is now comparable to that of plants in Japan and Germany, it is technically next to impossible to increase that energy-efficiency much further below the current requirement of about 4 GJ per ton.
4. The demolition and disposal of concrete structures, pavements, etc., constitutes another environmental burden. Construction debris contributes a large fraction of our solid waste disposal problem, and concrete constitutes the largest single component.
5. Finally, the water requirements are enormous and particularly burdensome in those regions of the earth that are not blessed with an abundance of fresh water. The concrete industry uses over 1 trillion gallons of water each year worldwide, and this does not even include wash water and curing water.

These points and these numbers seem to indicate that the concrete industry has become a victim of its own success and therefore is now faced with tremendous challenges. But the situation is not as bad as it might seem, because concrete is inherently an environmentally friendly material, as can be demonstrated readily with a life-cycle analysis [5]. The challenges therefore reduce primarily to reducing Portland cement's impact on the environment. In other words, we should use as much concrete, but with as little Portland cement as possible. [6]

III. Challenges for concrete and cement industry for sustainable development

There are a number of ways how the concrete industry can increase its compliance with the demands of sustainable development:

1. Increased use of supplementary cementitious material. Since the production of Portland cement is energy intensive and responsible for much of the CO_2 generation, the substitution of other materials, especially those that are byproducts of industrial processes, such as fly ash and slag, is bound to have a major positive impact.
2. Increased reliance on recycled materials. Since aggregate constitutes the bulk of concrete, an effective recycling strategy will lessen the demand for virgin materials.
3. Improved durability. By doubling the service life of our structures, we can cut in half the amount of material needed for their replacement.
4. Improved mechanical properties. An increase in mechanical strength and similar properties leads to a reduction of materials needed. For example, doubling the concrete strength for strength-controlled members cuts the required amount of material in half.

5. Reuse of wash water. The recycling of wash water is readily achieved in practice and already required by law in some countries.

Implementing effective strategies to lessen the environmental impact of the concrete industry by careful use of those tools requires a concerted effort of the industry, starting with well-focused research and development. Even more important for success are economic incentives to convince industry leaders that increased incorporation of sustainable development principles is possible without adversely impacting the industry's profitability. On a less benign parallel track, political developments are underway or imminent which are likely to force the industry to change or lose market share. Bold initiatives are required that are not without risk, yet strict adherence to principles such as "we have always done it this way" is certainly counterproductive, because the world around us will change anyway.

A considerable body of literature exists on methods to improve the mechanical properties and durability of concrete. The emphasis here will be on how to make concrete a "green building material" by use of cement substitutes and recycled materials. [6]

IV. Use of Cement Substitutes for sustainable concrete

Cement is the backbone for global infrastructural development. It was estimated that global production of cement is about 1.3 billion tons in 1996. Production of every tone of cement emits carbon dioxide to the tune of about 0.87 ton. Expressing it in another way, it can be said that 7% of the world's carbon dioxide emission is attributable to Portland cement industry. As we all know that carbon dioxide is one of the significant green house gas and it contribution to the environmental pollution is very high. The ordinary Portland cement also consume natural resources like limestone etc., that is why we cannot go on producing more and more cement and there is a need to economize the use of cement. One of the practical solutions to economize cement is to replace cement with supplementary cementitious materials. [7]

Cement is the key component of concrete that binds the other components together and gives the composite its strength. A considerable amount of work has been reported in the literature on how to use waste products of combustion or industrial processes as supplementary cementitious materials [4, 8, 9]. Because of their cementitious or pozzolanic properties these can serve as partial cement replacement. Ideally, the development of such materials serves three separate purposes simultaneously. On the one hand, waste byproducts have an inherent negative value, as they require disposal, typically in landfills, subject to tipping fees that can be substantial. When used in concrete, the material's value increases considerably. The increase in value is referred to as "beneficiation". As this supplementary cementitious material (SCM) replaces a certain fraction of the cement, its market value may approach that of cement. A second benefit is the reduction of environmental costs of cement production in terms of energy use, depletion of natural resources, and air pollution. Also, the tangible as well as intangible costs associated with landfilling the original waste materials are eliminated.

Finally, such materials may offer intriguing additional benefits. Most concrete mixes can be engineered such that the SCM will give the mix certain properties (mechanical strength, workability, or durability) which it would not have without it. It is the challenge for the concrete technologist when developing a mix design, to combine these three different goals in an optimal way such that the economic benefits become transparent. The key task is to turn waste material with a large inherent negative value into a potentially valuable product. The increase in value should be both real, in terms of converting a liability into a commodity with an increased market value, as well as intangible in terms of reduced environmental costs. The fundamental challenge for the researcher is to identify waste materials with inherent properties that lend themselves to such beneficiation. Below, a few examples shall be mentioned.

A primary goal is a reduction in the use of Portland cement, which is easily achieved by partially replacing it with various cementitious materials, preferably those that are byproducts of industrial processes. The best known of such materials is **fly ash**. Fly ash is finely divided residue resulting from the combustion of powdered coal and transported by the flue gases and collected by electrostatic precipitator. In U.K. it is referred as pulverised fuel ash. Fly ash is the most widely used pozzolanic material all over the world. Fly ash was first used in large scale in the construction of Hungry Horse dam in America in the approximate amount of 30 per cent by weight of cement. Later on it was used in Canyon and Ferry dams etc. In India, Fly ash was used in Rihand dam construction replacing cement up to about 15 percent [7]. As shown in Table 1 [6], the utilization rates vary greatly from country to country, from as low as 3.5% for India to as high as 93.7% for Hong Kong. The relatively low rate of 13.5% in the US is an indication that there is a lot of room for improvement.

Table 1: Coal-Ash Production and Utilization [6]

Country	Million Tons Produced	Million Tons Utilized	%
China	91.1	13.8	15.1
Denmark	1.3	0.4	30.8
Hong Kong	0.63	0.59	93.7
India	57.0	2.0	3.5
Japan	4.7	2.8	59.6

Russia	62.0	4.3	6.9
USA	60.0	8.1	13.5

The use of fly ash has a number of advantages. It is theoretically possible to replace 100% of Portland cement by fly ash, but replacement levels above 80% generally require a chemical activator. We have found that the optimum replacement level is around 30%. Moreover, fly ash can improve certain properties of concrete, such as durability. Because it generates less heat of hydration, it is particularly well suited for mass concrete applications. Fly ash is also widely available, namely wherever coal is being burned. Another advantage is the fact that fly ash is still less expensive than Portland cement. May be most important, as a byproduct of coal combustion fly ash would be a waste product to be disposed of at great cost

In the recent time, the importance and use of fly ash in concrete has grown so much that it has almost become a common ingredient in concrete, particularly for making high strength and high performance concrete. The new Indian Standard on concrete mix proportions (IS 10262-2009) are already incorporated fly ash as a supplementary material to cement. [10]

Extensive research had been done all over the world on the advantage of fly ash as a supplementary cementitious material. High volume fly ash concrete is a subject of current interest across the globe. ASTM broadly classifies fly ash into two classes. Class F and class C. Class F Fly ash normally produced by burning anthracite or bituminous coal and has pozzolanic properties only. Class C Fly ash normally produced by burning lignite or sub-bituminous coal and can possesses pozzolanic as well as cementitious properties. [7]

The employment of fly ash in cement and concrete has gained considerable importance because of the requirements of environmental safety and more durable construction in the future. The use of fly ash as partial replacement of cement in mortar and concrete has been extensively investigated in recent years.it is known that the fly ash is an effective pozzolan which can contribute the properties of concrete. Fly ash blended concrete can improve the workability of concrete compared to OPC. It can also increase the initial and final setting time of cement pastes. Fly ash replacement of cement is effective for improving the resistance of concrete to sulfate attack expansion. The higher is the compressive strength of concrete,the lower is the ratio of splitting tensile strength to compressive strength. Finally, it is knowing that the properties of concrete are enhanced when the substitution of Portland cement was done by fly ash. [10]

Ground granulated blast furnace slag (GGBS) is a by-product of the manufacturing of iron in a blast furnace where iron ore, limestone and coke are heated up to 1500◦C.When these materials melt in the blast furnace, two products are produced i.e molten iron, and molten slag. The molten slag is lighter and floats on the top of the molten iron. The molten slag comprises mostly silicates and alumina from the original iron ore, combined with some oxides from the limestone. The process of granulating the slag involves cooling the molten slag through high-pressure water jets. This rapidly quenches the slag and forms granular particles generally not larger than 5mm in diameter. The rapid cooling prevents the formation of larger crystals, and the resulting granular material comprises some 95% non-crystalline calcium-aluminosilicates. The granulated slag is further processed by drying and then ground to a very fine powder, which is GGBS (ground granulated blast furnace slag) cement It is another excellent cementitious material.[14]

Wainwright and Ait-Aider (1995) examined the influence of the composition of OPC and the addition of up to 70% GGBS on the bleed characteristics of concrete and conclude that the partial replacement of OPC with 40% and 70% of GGBS. GGBS led to increases in the bleeding of the concretes, like fly ash, also GGBS can improve many mechanical and durability properties of concrete and it generates less heat of hydration.[11]

Babu and Kumar (2000) determined the cementitious efficiency of GGBS in concrete at various replacement percentages (10–80%) through the efficiency concept by establishing the variation of strength to water-to-cementitious materials ratio relations of the GGBS concretes from the normal concretes at the age of 28 days. The 28-day compressive strength of concretes containing GGBS up to 30% replacement were all slightly above that of normal concretes, and at all other percentages, the relationships were below that of normal concretes. It was also observed that the variations due to the different percentages of slag replacement were smaller than the corresponding variations in the case of fly ash. The result showed that the slag concretes based on overall efficiency factor (k), will need an increase of 8.6% for 50% replacement and 19.5% for 65% replacement in the total cementitious materials for achieving strength equivalent to that of normal concrete at 28 days.[12]

Rice-husk is an agricultural by-product material. When rice-husk is burnt rice-husk ash (RHA) is generated. RHA is highly pozzolanic material. The non-crystalline silica and high specific surface area of the RHA are responsible for its high pozzolanic reactivity. RHA has been used in lime pozzolana mixes and could be a suitable partly replacement for Portland cement.[13]

RHA concrete is like fly ash/slag concrete with regard to its strength development but with a higher pozzolanic activity it helps the pozzolanic reactions occur at early ages rather than later as is the case with other replacement cementing materials. [14]

The employment of RHA in cement and concrete has gained considerable importance because of the requirements of environmental safety and more durable construction in the future. The use of RHA as partial replacement of cement in mortar and concrete has been extensively investigated in recent years.

RHA blended concrete can decrease the temperature effect that occurs during the cement hydration. RHA blended concrete can improve the workability of concrete compared to OPC. It can also increase the initial and also final setting time of cement pastes. Additionally, RHA blended concrete can decrease the total porosity of concrete and modifies the pore structure of the cement, mortar, and concrete, and significantly reduce the permeability which allows the influence of harmful ions leading to the deterioration of the concrete matrix. RHA blended concrete can improve the compressive strength as well as the tensile and flexural strength of concrete. RHA helps in enhancing the early age mechanical properties as well as long-term strength properties of cement concrete.

Partial replacement of cement with RHA reduces the water penetration into concrete by capillary action. RHA replacement of cement is effective for improving the resistance of concrete to sulfate attack. The sulfate resistance of RHA concrete increases with increasing the RHA replacement level up to 40%. Substitution of RHA has shown to increase the chemical resistance of such mortars over those made with plain Portland cement. Incorporation of RHA as a partial cement replacement between 12% and 15% may be sufficient to control deleterious expansion due to alkali-silica reaction in concrete, depending on the nature of the aggregate. It can be known that the use of rice husk ash leads to enhanced resistance to segregation of fresh concrete compared to a control mixture with Portland cement alone. Also RHA can significantly reduce the mortar-bar expansion.Finally showed that the mechanical properties of concrete are enhanced when the substitution of Portland cement was done by RHA. [13]

Wood ash is the residue generated due to combustion of wood and wood products. It is the inorganic and organic residue remaining after the combustion of wood or unbleached wood fiber. [15]

Abdullahi (2006) reported the compressive strength test results of wood ash (WA) concrete. He used wood ash as partial replacement of cement in varying percentages (0, 10, 20, 30, and 40%) in concrete mixture proportion of 1:2:4. Tests were conducted at the age of 28 and 60 days.The results showed that the specimens containing 0% wood ash had the highest compressive strength. The mixture containing 20% wood ash had higher strength than that containing 10% wood ash at 28 and 60 days. This was due to the fact that the silica provided by 10% wood ash was inadequate to react with the calcium hydroxide produced by the hydration of cement. Increase in wood ash content beyond 20% resulted in a reduction in strength at 28 and 60 days. [16]

Naik et al. (2002) investigated the compressive strength of concrete mixtures made with wood ash up to the age of 365 days. Wood ash content was 5, 8, and 12% of the total cementitious materials. Figure 9.1 shows the compressive strength results. Based on the results, they concluded that: (i) control mixture (without wood fly ash) achieved strength of 34 MPa at 28 days and 44 MPa at 365 days; (ii) strength of concrete mixtures containing wood fly ash ranged from 33 MPa at 28 days and between 42 and 46 MPa at 365 days; and (iii) inclusion of wood fly ash contributed to the strength development of concrete mixtures, even as the cement content was decreased by about 15%. This indicates contribution of wood fly ash to pozzolanic activity. [17]

Udoeyo et al. (2006) determined the compressive strength of concrete made with varying percentages (5, 10, 15, 20, 25, and 30 by weight of cement) of waste wood ash (WWA). They reported that compressive strength generally increased with age but decreased with the increase in the WWA content. Comparisons of the strength of WWA concrete with those of the control (plain) concrete of corresponding ages showed that the strength of WWA concrete was generally less than that of the plain concrete. A possible explanation for this trend is that the WWA acts more like filler in the matrix than as a binder. Thus, increasing the ash content led to an increase in the surface area of the concrete filler to be bonded by the same amount of cement as that of the control. [18]

Cement kiln dust (CKD) is a by-product of cement manufacturing. It is a fine powdery material similar in appearance to Portland cement. EL-Sayed et al. (1991) investigated the effect of cement kiln dust (CKD) on the compressive strength of cement paste and corrosion behavior of embedded reinforcement. They reported that up to 5% substitution of CKD, by weight of cement had no adverse effect on the strength of the cement paste and on reinforcement passivity. Batis et al. (2002) also reported the increase in compressive strength and corrosion resistance of the mix when CKD and blast furnace slag were added in proper ratio in ordinary Portland cement. [15, 19,20]

Shoaib et al. (2000) studied the effect partial substitution of ordinary Portland cement (OPC) and blast furnace slag cement with cement kiln dust (CKD) on the compressive strength of concrete and also determined the optimum quantity of CKD which could be recycled in the manufacture of these types of cements.

Shoaib et al. (2000) studied the effect partial substitution of ordinary Portland cement (OPC) and blast furnace slag cement with cement kiln dust (CKD) on the compressive strength of concrete and also determined the optimum quantity of CKD which could be recycled in the manufacture of these types of cements. The CKD contained the mixture of raw feed, partially calcined cement clinker, and condensed volatile salts.Percentages of replacement of CKD as ratio to cement used were 0, 10, 20, 30, and 40%. The mixes have same mix proportion (1 Cement: 1.9 Sand: 3.52 Gravel and 0.5 W/C ratio), and the cement content used in the mixes was 350Kg/m3. Compressive strength was determined at the age of 1, 3, and 6 months. Based on the test results, they reported that control mix (0% CKD) achieved compressive strength of 27, 28.5 and 32.0MPa at the age of 1, 3, and 6 months, respectively. Compressive strengths of concrete mixes decreased with the increase in CKD percentage at all ages. [21]

V. RECYCLED AGGREGATE

Aggregate constitutes approximately 70% of concrete volume. Worldwide, this amounts to billions of tons of crushed stone, gravel, and sand that need to be mined, processed, and transported every day. [2]
The substitute material that comes to mind first is recycled concrete. Construction debris and demolition waste constitute 23% to 33% of municipal solid waste, and demolished concrete contributes the largest share of this waste material (Recycling Concrete Saves Resources, Eliminates Dumping). [22]

Concrete debris is probably the most important candidate for reuse as aggregate in new concrete. On the one hand, vast amounts of material are needed for aggregate. On the other hand, construction debris often constitutes the largest single component of solid waste, and probably the largest fraction of this is concrete. Using such debris to produce new concrete conserves natural resources and reduces valuable landfill capacity at the same time. In Europe and Japan, such recycling is already widely practiced [23, 24], whereas in the US, it is being accepted only slowly, because the economic drivers are not yet strong enough. But they are improving. The disposal of demolished concrete involves costs, which are likely to go up. Available sources of suitable virgin aggregate are being depleted, such as gravel pits on Long Island, and opening new sources of virgin material is getting increasingly difficult because of environmental concerns. Since the cost of transportation is the main component of the cost of bulk material like sand and gravel, it may not take much of a shift to turn the economics in favor of recycling and reuse.
Turning recycled concrete into useful or even high-quality aggregate poses well-known technical challenges [23]. There are contaminants to be dealt with, high porosity, grading requirements, as well as the large fluctuations in quality. Not all applications require high-strength concrete, though. Recycled concrete aggregate is likely to be quite adequate for some projects, while for others, a blend of new and recycled aggregate may make most economic and technical sense. [6]

VI Changing Political Landscape in India

There are signs that the public attitude towards sustainable development is changing. “Green building design” principles are finding their way into design practice, spearheaded by the architectural community. The Indian Green Building Council has developed a rating system with the help of United States green building council as a guide for green and sustainable design. This system, called “Leadership in Energy & Environmental Design” (LEED), has become a standard adopted by several governmental agencies in its original form or some modified versions of it. It assigns points in seven different categories:

1. Sustainable Sites, 28 possible points
2. Water Efficiency, 10 possible points
3. Energy & Atmosphere, 37 possible points
4. Materials & Resources, 14 possible points
5. Indoor Environmental Quality, 15 possible points
6. Innovation & Design Process, 6 possible points
7. Regional Priority, 4 possible points

In order to become “certified”, a project requires at least 40-49 points. Projects with 50-59 points are “Silver”-rated, those with 60-69 points are “Gold”-rated, and to reach the highest rating of “Platinum”, 80 points and above are required.[24] Means and methods to increase the number of points for a concrete building can be found elsewhere [5]. Several industry-wide efforts are currently underway to develop guides for the industry, to not only increase the number of LEED-points, but also to improve the environmental friendliness of concrete construction across the board. Here it suffices to point out that under the current system, only a rather small number of points can be earned by making concrete more environmentally friendly. For example, in a mix design that contains 15% cementitious material, the replacement of 30% of Portland cement by fly ash will introduce only 4.5% recycled material. The reward in terms of LEED-points in no way reflects the gain in environmental friendliness, as measured by the reduction of CO_2 generation and energy consumption. [6]

VII Conclusion

Virgin materials have a quality control advantage over recycled materials. But the economic feasibility of recycling will increase in time, as virgin materials become more and more scarce and the disposal costs of construction debris and other waste materials keep increasing. The economic feasibility of recycling depends largely on the application. Concrete and cement industry can contribute to sustainable development by adopting supplementary cementitious materials, recycled aggregate to save natural resources, energy, reducing CO_2 emissions, and protect the environment and can improve its record with an increased reliance on recycled materials and in particular by replacing larges percentages of

Portland cement by byproducts of industrial processes. This will help our sustainable and green environment.

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