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Sustainable And Emerging Concrete Materials: Review

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Abstract

The proper use of cement with the beneficial employment of industrial waste products constitutes the backbone of a sustainable concrete technology. The use of fly ash, ground granulated blast furnace slag (GGBFS), rice husk ash, silica fume (SF), metakaolin (MK) and recycled concrete, bricks and other materials are all gaining varying degrees of acceptance from engineers and the society. The proper design that considers long-term durability coupled with the use of 'waste' materials other than cement and natural aggregates can further enhance the sustainability of structures. High performance concrete (HPC) which is becoming the concrete of choice for rapidly emerging new and strong economies, can provide the opportunity for sustainable design and material use. The inclusion of industrial by-products in the production of high-strength-high-performance concrete is a significant contribution to sustainable industry. Cement manufacture is a major contributor to the greenhouse gases. Efforts should be directed to reduce the need for this manufacture.

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1. Introduction

Cement concrete is the most widely used material for various constructions. Properly designed and prepared concrete results in good strength and durability. The main ingredient in the conventional concrete is Portland cement. The amount of cement production emits approximately equal amount of carbon dioxide (CO_2) into the atmosphere. Cement production is consuming significant amount of natural resources. To overcome the above affects the advent of newer materials and construction techniques.

Sustainability is a new dominant paradigm shift in Engineering and is pointing the way of the future. Among major concerns of sustainability is the fragility of the natural environment. Its aim in this regard is to arrest the negative impact of human activity. Sustainability embodies all the provisions necessary for excellent engineering solutions. Such solutions are those that contribute in a balanced measure to profitability, long-term community benefits and low environmental impact. To discuss and then attempt to answer these questions, we need to examine certain facts. These facts relate to the particular concrete industry.

2. Sustainability

Sustainability generally means having no net negative impact on the environment, and this analysis compared the environmental impact of producing concrete.

As used in everyday speech, sustain means to support or to keep a process going, and the goal of sustainability is that life on the planet can be sustained for the foreseeable future. There are three components of sustainability: environment, economy, and society. Sustainable development must provide that these three components remain healthy and balanced. At the moment, the environment is probably the most important component, and an engineer uses sustainability to mean having no net negative impact on the environment. The term sustainable has come to be synonymous with environmentally sound or friendly and green. The environmental component has our attention now because deterioration of our environment is driving the current worldwide focus on sustainable development.

Dictionaries give the meaning of sustainability as the ability to be maintained. Dictionaries further define the term in ecological perspective as 'exploiting natural resources without destroying the ecological balance of an environment.

3. Cement Production

It is estimated that in the year 1900, 10 Mt ($10x10^6$tonnes) of cement were produced globally. Cement production has increased by 170 times. World population has increased by 3.9 times. The average cement consumption of each person on Earth has increased from 6.25 kg per year to 268 kg per year. The average concrete consumption per person increased, by approximately 42 times.

According to the report of the US Department of Energy, concrete production accounts to 12% of the CO_2 emissions associated with cement. From this, it can be concluded that, cement manufacture and concrete production is a major contributor to

GHG (greenhouse gases) emissions and the level of CO_2 emission as contributed by the cement industry is not sustainable.

4. Replacing Cement

Nowadays, there are several powdery materials that fit into this category. To limit the scope of this paper, I focus on a limited number of materials that have gained a great deal of popularity in recent years. These are, silica fume, fly ash, ground granulated blast furnace slag, metakaolin and rice husk ash.

Without going into great details about the properties and characteristics of these materials, I briefly highlight certain points regarding each.

A. Silica Fume

Silica fume is a by-product of the reduction of high-purity quartz with coal in electric furnaces in the production of silicon and ferrosilicon alloys. Silica fume is also known as micro silica, condensed silica fume, or silica dust.

Silica fume particles are extremely small, with more than 95% of the particles finer than 1µm. Silica fume consists of very fine particles with a surface area 13,000–30,000 m^2/kg. On average its particles are approximately 100 times smaller than cement particles. Its extreme fineness and high silica content make it a highly effective pozzolanic material.

It is true that silica fume significantly improves a number of properties in concrete. The main reason why it does this lies in two main facts. Firstly, it's extremely fine size, and secondly, its pozzolanic activity. As to the first fact, the very fine size makes it possible for the particles of silica fume to adhere to the surfaces of aggregates far easier than cement particles. This results in filling up of the weakest part of concrete which is the interfacial zone. Moreover, it efficiently reduces or eliminates bleeding. Thus, it reduces porosity, especially around aggregates. Therefore, its use improves durability. The pozzolanic activity adds the benefit that the particles of silica fume react with the calcium hydroxide product of hydration to form calcium silicate hydrates. Thus adding to the strength of concrete especially in the zones where the concrete is weakest at the paste/aggregate inter-face.

The use of silica fume should not exceed 10% of cement mass because the pozzolanic reaction of silica fume would hinder the normal long term Portland cement hydration development due to the early pozzolanic reaction of silica fume that creates a barrier between the 'still not totally hydrated' cement particles. And the use of silica fume less than 5% is used; there would not be enough particles of the silica fume to cover the aggregates. Silica fume should not exceed 10% of cement mass. Otherwise such use becomes counter-productive. Also the quantity of silica fume, if used, should not be less than 5% of the cement mass otherwise it becomes an inefficient, though expensive material.

B. Fly Ash

The fly ash, also known as pulverized fuel ash, is produced from burning pulverized coal in electric power generating plants. Originally fly ash is a mixture of vegetation, clay and rocks, comprises a wide range of inorganic matters. Physically, fly ash occurs as a very fine spherical particles having diameter in the range from µ to 100µ, low to medium bulk density, high surface area and sandy silt to silty loam texture. Chemically, fly ash is amorphous ferro-alumino silicate mineral with matrix elements like Si, Al, and Fe together with significant amount of Ca, Mg, K, P, and S.Utilization of fly ash in cement and concrete has significant environmental benefits such as, increasing the life of concrete roads and structures by improving concrete durability, reduction in energy use and greenhouse gas and other adverse air emissions when fly ash is used to replace or displace manufactured cement reduction in amount of coal combustion products that must be disposed in landfills, and conservation of other natural resources and materials. It has been proven that fly ash can improve workability and durability. Moreover, because of the improved workability, a lower water demand results in enhancing strength while using less cement and thus producing lower heat at hydration.

So far fly ash has been largely considered as a waste product. However, the attitude towards fly ash has shifted quite significantly from considering it a waste material to-ward considering it as a valuable asset. The reasons behind this important shift are greatly due to continuous research in the area of using this material as a cement replacement.

There is no doubt that if we can substitute cement by large amount of fly ash, we can achieve several environ-mental benefits. Obviously, one benefit is getting rid of the accumulating fly ash that can be a hazard if inhaled or if it contaminates the water table.

C. Ground Granulated Blast Furnace Slag

Ground granulated blast-furnace slag is a glassy material.Ground Granulated Blast Furnace Slag (GGBFS or BFS) is a by-product of the steel industry. The GGBFS is a latent hydraulic material which has chemical composition intermediate between that of pozzolanic material and Portland cement. The GGBFS acts as hydraulic cement when mixed with water in the presence of OPC. GGBFS is being used in the construction of dams and massive projects because of its low heat of hydration.

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Blast furnace slag is a non-metallic product, consisting essentially of silicates and alumina-silicates of calcium and other bases. Slag is made up of both glassy and crystalline phases. The glassy nature is responsible for its cementatious properties.

GGBS can be used as a direct replacement for ordinary cement on one-to-one basis by weight. Replacement rates for GGBS vary from 30% to up to 85%. Generally 50% is used in most applications. Higher replacement rates up to 85% are used in specialist applications such as in aggressive environments and to reduce heat of hydration. GGBS can be used at replacement levels of 70% in lean mix concrete.

The advantage of GGBS in cement and concrete are improved workability and compaction characteristics, low heat of hydration and production of GGBS involves virtually zero CO2 emissions, and no emissions of SO_2 and NOx.

D. Metakaolin

Metakaolin (MK) is a pozzolanic material. It is a de hydroxylated form of the clay mineral kaolinite. It is obtained by calcinations of kaolintic clay at a temperature between 500°C and 800°C. Between 100 and 200°C, clay minerals lose most of their adsorbed water. Between 500 and 800°C kaolinite becomes calcined by losing water through dehydroxylization. The raw material input in the manufacture of metakaolin (Al2Si2O7) is kaolin clay. Kaolin is a fine, white, clay mineral that has been traditionally used in the manufacture of porcelain. Kaolinite is the mineralogical term that is applicable to kaolin clays. Kaolinite is defined as a common mineral, hydrated aluminum silicate, the most common constituent of kaolin.

Metakaolin is produced by calcining kaolinite clays. This results in highly active pozzolanic material that has been found useful as a cement replacement and concrete property enhancer.

Metakaolin is processed to remove non-reactive impurities, producing an almost 100 percent reactive pozzolana. Its particle size is significantly smaller than cement particles. Metakaolin particles are extremely small with an average particle size of 3 µm. Metakaolin has a great potential in concrete as cement replacement at lower cost as compared to traditionally used super pozzolans. Concrete produced with metakaolin shows similar behavior to that with one produced with silica fume.

The advantage of metakaolin in cement and concrete are increased compressive and flexural strengths, reduced permeability, enhance workability and finishing of concrete, reduced potential for efflorescence, increased resistance to chemical attack and increased durability of concrete.

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E. Rice Husk Ash

Rice husk is an agricultural residue obtained from the outer covering of rice grains during milling process. Current rice production in the world is more than 700 million tons. Rice husk constitutes about 20% of the weight of rice. It contains about 50% cellulose, 25–30% lignin, and 15–20% of silica. Rice husk ash (RHA) is generated by burning rice husk. On burning, cellulose and lignin are removed leaving behind silica ash. The controlled temperature and environment of burning yields better quality of rice-husk ash as its particle size and specific surface area are dependent on burning condition. The ash produced by controlled burning of the rice husk between 550°C and 700°C incinerating temperature for 1 h transforms the silica content of the ash into amorphous phase. The reactivity of amorphous silica is directly proportional to the specific surface area of ash. The ash so produced is pulverized or ground to required fineness and mixed with cement to produce blended cement.

Rice husk ash has been used in concrete in its capacity as filler and as a pozzolanic material. Its potential as a partial replacement of cement has been examined and research abounds pointing to advantages and limitations.

Rice-husk ash is a very fine pozzolanic material. The utilization of rice husk ash as a pozzolanic material in cement and concrete provides several advantages such as improved strength, enhanced durability properties, reduced materials costs due to cement savings, and environmental benefits related to the disposal of waste materials and to reduced carbon dioxide emissions.

5. Conclusions

1. Durability of concrete is one of the most important factors, if not the most important, in the attempt to arrive to sustainable stage in concrete construction.
2. Cement manufacture is a major contributor to the greenhouse gases. Efforts should be directed to re-duce the need for this manufacture.
3. Alternative materials that may replace cement include industrial by-products like silica fume, fly ash and blast furnace slag. All of these carry enormous benefits to the concrete industry in general and sustainability in particular.
4. Extracting natural aggregates for the concrete industry cannot be sustainable in the long run. Recycling aggregates, crushed bricks, crushed blocks, crushed concrete and lightweight aggregates made from waste products are alternatives that should be given due importance.
5. New polymer materials that serve to create concrete polymer composites carry the promise to become major building materials in the

future. Such materials provide solutions to durability issues especially when used in repair and pre-cast industries. Though may be expensive, their use may prove to be one good solution to the issue of sustainable building.

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