Research Article

Supplementary Cementitious Materials for Green Concrete

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Abstract

Concrete is the second most used material on the earth, after water. It is considered to be one of environmental-friendly materials of construction. Yet producing the Portland cement which binds concrete together is energy intensive and emits enormous amounts of carbon dioxide (CO_2) which is known to be a greenhouse gas (GHG) that contributes to global warming. During the past few decades, the potential of Portland cement in terms of its effective utility has been realized. As a result, the use of new admixtures has increased significantly within the concrete industry. Properties of concrete can be modified by the use of mineral admixture with partial replacement of cement, to increases long term strength and durability. Green Concrete is capable for sustainable development which characterized by application of industrial waste such as coal fly ash, slag, rice husk ash, etc, to reduce consumption of cement, natural resource, energy and pollution of the environment. In this paper, brief overview is presented related to availability and necessity to use various industrial by-products as supplementary cementitious materials in concrete towards sustainable development.

Keywords: Carbon footprint, Green concrete, Industrial byproducts, Supplementary cementitious materials, Sustainable development

Introduction

Concrete is one of the most widely used construction material in the world. We make more concrete than any other material in the world. It is used in our roads, dams, bridges, and buildings because of its versatility, strength, and durability. Portland cement (PC); an essential constituent of concrete is not an environmentally friendly material. Yet producing the Portland cement that binds concrete together is energy intensive and emits enormous amounts of carbon dioxide (CO_2) which is known to be a greenhouse gas (GHG) that contributes to global warming as well as numerous other pollutants.[2] According to Aitcin, concrete are simply a marvelous material, flexible in its composition, ecological when we take care, and a material still full of unexplored possibilities or even unexploited possibilities.[1] But for a variety of reasons, the concrete construction 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 greenhouse 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.[3] Due to growing environmental concerns of the cement industry, alternative cement technologies have become an area of increasing interest. It is now believed that new binders are indispensable for enhanced environmental and durability performance. Reducing cement production through the use of alternate materials such as coal fly ash, slag, rice husk ash, etc would reduce CO_2 and other GHG emissions. Replacing 15% of cement worldwide by other cementitious materials (e. g. pozzolans) will reduce CO_2 emissions by 250 million tons.[4] In the present paper, an experimental work which helps in developing concrete

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compositions with the lowest possible environmental impact by selecting the type and dosage of supplementary cementitious materials was also discussed.

Ordinary Portland cement is a major construction material worldwide, and will remain so for the foreseeable future. Developing nation is producing more than 300 million cubic meter concrete per annum.[9] Worldwide, concrete production is of 10 billion tonnnes each year. China and India are now producing and using over 50% of the world's concrete and they are now consuming 40 times more cement and concrete than the USA. Total concrete market in India is estimated at 300-350 million cubic meters per annum with third largest concrete industry in the world. India currently produces around 210 million tonnes of cement, second to China at around 2 billion tonnes. India is second largest producer of cement in the world which comprises of 183 large cement plants and over 365 mini cement plants. Cement industry of India has current capacity of 324 million tonnes per annum and expected to add 30-40 million tonnes per annum of capacity in 2013.[12]

Cement is among the most energy intensive construction material whose production released large amount of carbon dioxide during the manufacturing of OPC. The cement industry is the third largest carbon dioxide emitter after housing and transport, not because it is a particular polluting material but because it is so popular and abundant in use. China is now being the largest emitter of CO_2 emissions, overtaken the U.S.A. in 2009. The other big CO_2 emitters are the E.U., India and Russia.[15] Globally, the OPC production contributed to around 7 % of carbon dioxide which is on an increase of 3% annually. The production of one ton of cement liberates about 1 ton of carbon dioxide to the atmosphere. According to Malhotra in Portland cement production, about half of the CO_2 emissions are due to the calcination of limestone, which emits CO_2 during the chemical reaction and the other half are due to the combustion of fossil fuels.[11] The emissions from the calcination of limestone are fairly constant at about 0.54 tonnes of CO_2 per tonne of cement; the emissions from the combustion depend on the carbon content of the fuels being used and the fuel efficiency. The general estimate is about 1 ton of CO_2 emission per ton clinker produced if fossil fuel is used. According to Mehta, the global cement industry has almost doubled its annual rate of direct CO_2 emissions during the last 15 years.[4]

There are three ways to reduce emission of carbon dioxide

- Reduce the amount of cement used,
- Reduce the quantity of water use in mixing which will reduce the cement use in the mix and can achieve the same strength
- Reduce the total amount of concrete used in the structures and still achieve the same or better performance of the structures

Likewise, McCaffrey suggested that the amount of carbon dioxide (CO_2) emissions by the cement industries can be reduced by decreasing the amount of calcined material in cement, by decreasing the amount of cement in concrete, and by decreasing the number of buildings using cement.[5]

Problems in disposal

Waste is the one of the main challenges to dispose and manage. It has become one of the major environmental, economical and social issues. Recycling is the most promising waste management process for disposal of waste materials. Agricultural or biodegradable materials have played a major role in human life. Hence, this plays an important role in producing sustainable concrete with partial replacement of cement by waste.

According to Singh Y, more than 175 million tones of fly ash are expected to be generated in India by the year 2012.[6] This would require about 40000 hectares of land for the construction of ash ponds. The wet slurry system downgrades the pozollanic property of fly ash. It has high water requirements also and fails to recognize the utility of bottom ash. Generally, one acre land is needed for disposal of fly ash generated from per M.W. of power production. In coming year (2016-17), it is expected that India will produce 300- 400 Million Tons per year fly ash which is approximately double the quantity it is produced now, so the consumption should be increased subsequently. The major use of fly ash is in building material as a cement raw material and have many advantages like it reduces Green House gases emission, solve serious waste disposal problem faced by power generation industry, reduces energy requirement. The World Bank has cautioned India that by 2015 disposal of coal ash would require 1000 square km or one meter square of land per person.[13]

Use of fly ash is one of the measures from low level applications such as landfill to high strength concrete due to its engineering characteristics. The physical and chemical properties of fly ash enhance most of the properties of concrete as long term availability. Successful application of this waste will have great advantages and minimize the land being used for disposal of this waste.[14,15]

Various Supplementary Cementitious Materials

Replacement materials that react with calcium hydroxide are commonly termed "Supplementary Cementitious Materials", (SCMs). To minimizing the environmental impact of Portland cement, the green building community is trying to replace as much as possible with a number of alternative materials: supplementary cementitious materials (SCMs), mineral admixtures, or pozzolans. Use of these materials lowers the embodied energy of the concrete and offsets almost one ton of carbon emissions for every ton of Portland cement replaced. There are two main types of SCMs: hydraulic materials that react with water to form cementitious compounds, and pozzolanic materials that react with calcium hydroxide in cement mixes to form additional cementitious compounds.[16,17]

There are large numbers of alternative binders and many options to improve the energy and emissions associated with their manufacture. Fly ash as a substitute for portland cement utilization has great potential to lower green house gas emissions by decreased mining activities and reducing carbon dioxide production during manufacture of Portland cement.[8] Fly ash can substitute up to 66% of cement in the construction of dams. It is also used as a pozollanic substitute for cement in Roller Compacted Concrete dams-an innovative dam technology developed as a result of efforts to design more economical concrete dams that could be constructed rapidly with designed performance. Fly ash in R.C.C. is used not only for saving cement cost but also for enhancing strength and durability.[10] Fly ash is one promising material which can be used as both supplementary cementitious materials as well as to produce light weight aggregate. The use of cost effective construction materials has accelerated in recent times due to the increase in the demand of light weight concrete for mass applications.

In addition to fly ash, other supplementary cementing materials that are available in large quantities and can be used to replace Portland cement in concrete include granulated blast furnace slag, natural pozzolans, rice husk ash, silica fume, metakaolin, etc. The worldwide production of granulated blast furnace slag is about 25 million tonnes per year. The use of granulated blast furnace slag in concrete has increased considerably in recent years, and this trend is expected to continue.[11] Rice husk ash is not yet available commercially, although the worldwide potential is about 20 million tonnes annually. India is a major rice producing country, and the husk generated during milling is mostly used as a fuel in the boilers for processing paddy, producing energy through direct combustion and / or by gasification. This RHA is a great environment threat causing damage to the land and the surrounding area in which it is dumped. Rice husk ash, when it becomes available commercially, will along with fly ash and granulated blast-furnace slag, be the most significant supplementary cementing material for use as a partial replacement for Portland cement in concrete to reduce CO_2 emissions.[7,8] The use of natural pozzolans is rather limited because of their high water demand when incorporated in concrete, and the need for calcination. Silica fume, a highly pozzolanic material, is a byproduct of when silicon metal or ferro silicon alloys are produced in smelters using electric arc furnaces. The world-wide production is estimated to be between 1.5 to 2 million tonnes. Its primary use is to enhance the durability of concrete by making it less permeable. Thus it also used as a supplementary sementitious materials to contribute to reduce CO_2. The performance of metakaolin in concrete is like that of silica fume, but as metakaolin is a manufactured product, unlike silica fume which is a by-product, its use in concrete contributes very little to reduction of greenhouse gas emissions.

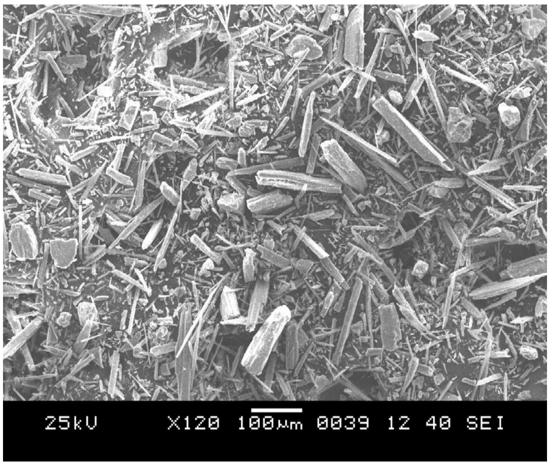
In addition to these, agricultural wastes such as rice husk ash, wheat straw ash, and sugarcane bagasse ash are also being used as pozzolanic materials and hazel nutshell used as cement replacement material. India being one of the largest producers of sugarcane in the world produces 300 million tons per year and large quantity of sugarcane bagasse is available from sugar mills. Sugarcane bagasse is partly used as fuel at the sugar mill. Sugarcane baggase ash is a byproduct of sugar factories and it is produced by burning sugarcane baggase where it is formed by the extracting all sugar from sugarcane. SCBA was found that it improves the properties of concrete such as compressive strength and water tightness in some percentage of replacement and fineness. The main parameter responsible for this improvement was higher silica content. SCBA is a valueless agricultural waste product but it has a pozzolanic property which can be used to replace cement in concrete and mortar, first reaction is the hydration reaction which takes place after addition of water in cement to form calcium hydroxide (CH) and calcium silicate hydrate (C-S-H). The second reaction is pozzolanic reaction which takes place between CH from hydration reaction and SiO_2 a pozzolona from SCBA and produced second phase of CSH which increase the compressive strength.[18]

The use of wollastonite as a cementitious material is widely reported in the literature.[19] Wollastonite is a naturally occurring calcium inosilicate mineral that has the chemical formula $CaSiO_3$ and is formed by approximately equal proportions of CaO and SiO_2. In some cases, wollastonite may contain small amounts of iron, magnesium, and manganese substituting for calcium. Wollastonite is a naturally occurring, acicular, inert, white mineral (calcium meta-silicate [β-CaO-SiO_2]), which is less costly than steel and carbon microfibers. It contains nearly equal proportions of lime and silica; up to 45% each respectively. Therefore it is self cementitious too, in addition to being a pozzolan; also called as class C pozzolan. Wollastonite is mined commercially for use in refractory ceramics and as filler in paints. The processed granular material is of high purity, inexpensive, and readily available. The mineral is named after William Hyde Wollaston (1766 – 1822), a noted English chemist and mineralogist. Originally trained as a physician, in 1793 Wollaston left the practice of medicine to focus his efforts on scientific pursuits. Wollastonite forms when impure limestone or dolostone is subjected to high pressure and temperature. It is usually white in colour, but may sometimes appear to have a cream, grey, or very pale green colour. Wollastonite has a triclinic crystal structure, and a melting point of 1540˚C. In 2011, the world production of wollastonite was 617,000 tonnes, which increased by 6% as against previous year. China (300,000 tonnes) and India (181,000 tonnes) were the major producers.

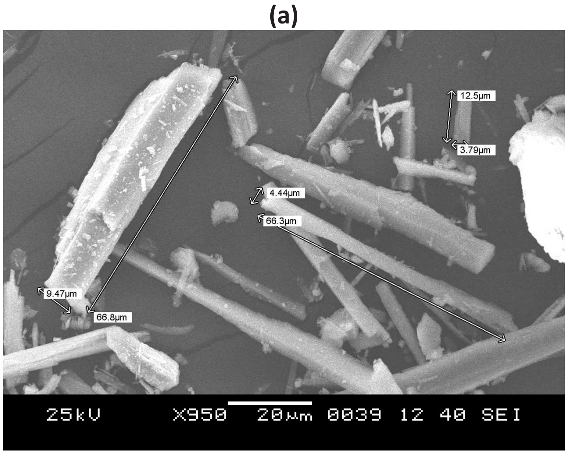
Extensive deposite of Wollastonite is located near village khilla and Kheraupala in Pali, Sirohi and Udaipur district where 56 million tones of reserves have been estimated. Low grade Wollastonite was also found near village Gola ali pura, Rupnage in Ajmer district having 1.66 million tones preserves. Wollastonite also can crystallize directly from a magna that has unusually high carbon content, but this is a rare occurrence.

The SEM morphology of the wollastonite was illustrated in figure 1 which indicates maximum tubular structures along with acicular or needle shape, with particle size ranging from 1um to about 100um.

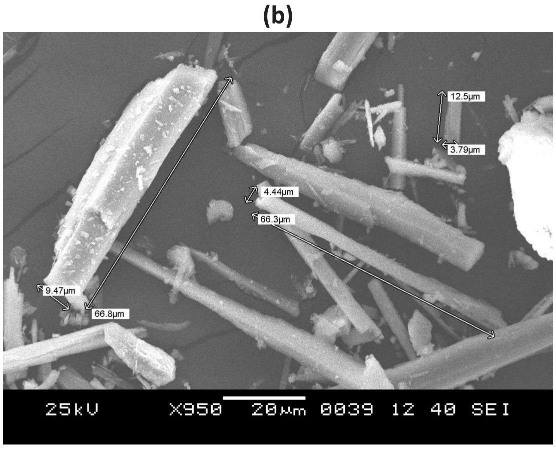
These tubular micro fibres are responsible for gaining and enhancing the mechanical properties of wollastonite reinforced concrete.



(a)



(b)



(c)

Figure 1.Microscopic Analysis of Wollastonite

Scanning Electron Microscopy (SEM) showing the particle sizes at 950X and 500X.

Make Concrete Greener with Ternary Blend of Fly Ash and Rice Husk Ash

In order to produce environmentally friendly concrete, Mehta PK, suggested the use of fewer natural resources, less energy, and minimize carbon dioxide emissions.[14] He categorized these short-term efforts as 'industrial ecology'. The long-term goal of reducing the impact of unwanted by-products of industry can be attained by lowering the rate of material consumption.

The detailed experimental work was done by author to produce green concrete using industrial byproducts [combination of fly ash (FA) and rice husk ash (RHA)] for 30% partial replacement of cement.[7,8] In this work, combination started from 30% FA and 0% RHA mix together in concrete by replacement of cement with the gradual increase of RHA by 2.5% and simultaneously gradual decrease of FA by 2.5%. Last proportion was taken 15% FA and 15% RHA. The tests on hardened concrete were destructive in nature which includes compressive test on cube at 7,14,28,56 and 90 days of curing as per IS: 516 1959, Flexural strength on beam at 28 days of curing as per IS: 516 1959 and split tensile strength on cylinder at 28 days of curing as per IS: 5816 1999. The work reports the effects on the behavior of concrete produced from partial replacement of cement with combination of FA and RHA at different proportions on the mechanical properties of concrete such as compressive strength, flexural strength, and split tensile strength. Investigation reported that compressive strength increases by 30.15% in compared with control concrete at 28 days, flexural strength increases by 4.57% compared with control concrete at 28 days, split tensile strength decreases by 9.58% compared with control concrete at 28 days, were obtained at combination of 22.5% FA and 7.5% RHA. Through Rice husk ash is harmful for human being and the cost of rice husk ash is zero and thus we preferred RHA use in concrete as compare to silica fumes and it is also economical. The workability of RHA concrete was found to decrease but the FA increases the workability of concrete. Rice Husk Ash can be used with admixtures, plasticizers, and super plasticizers, for increasing the workability and strength of concrete with partial replacement of cement. The strength parameters such as compressive strength, flexural and tensile strength have been significantly improved with the addition of RHA. Durability studies carried out in the investigation through acid attack test and chloride test with 1% H_2SO_4 and 3% NaCl revealed that 22.5% FA+ 7.5% RHA concrete is more durable in terms of durability factors than control concrete. It is observed that rice husk ash concrete will have higher life compared to control concrete. The work concluded that partial replacement of FA and RHA in concrete help to reduce greenhouse gas emissions produces economical solution and eco-friendly concrete.

Conclusions

The discussion presented in this paper deals with use of industrial waste as a construction material and its proper disposal since it is hazards. Much more discussions and work to be needed in the way of use and utilization of waste materials as a construction materials and its proper disposal.

The best solution related to sustainable issue is to find a way to reduce the consumption of cement in concrete, which is resulted in decrease energy consumption and CO_2 emission. Less cement means less greenhouse gas produced. Now we have to focus on less cement, more waste in concrete. The above discussion throws a light on various environmental issue and emission of green house gas due to production of Portland cement along with suitability, necessity to use various industrial by-products (waste) as a supplementary cementitious materials and there proper disposal since it is hazards. This paper also summarizes efforts to improve the environmental friendliness of concrete to make it suitable as a "Green Building" material with use of suitable substitutes for Portland cement, especially those that are byproducts of industrial processes, like fly ash, ground granulated blast furnace slag, silica fume, etc.

Author suggested that environmental friendliness of concrete can be considerably enhanced if the rate of fly ash utilization by the concrete industry is accelerated in the ash production countries and countries where large amounts of blast furnace slag is available as a by-product can similarly benefit from the use of high volumes of granulated slag either as a concrete admixture or as an additive in the manufacture of Portland slag cements.

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