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Reducing the use of cement usage in construction Industry – Need of the hour

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Abstract: — **Concrete is a versatile building material that has been used extensively for infrastructure development since past many decades. However cement, the key ingredient that is used to bind the other ingredient is not a ecofriendly material, since the manufacturing of cement releases harmful greenhouse gases. This paper represents state of the art on alternative materials that can be used as replacement to cement. The paper also highlights potential of alternative materials that can be used as an alternative to cement as a binder. Compressive strength being the major requirement of the concrete, the paper focuses on strength development of various alternative binders. Durability cannot be neglected although, the durability aspect of the binders ae also mentioned herewith.**

Index Terms—**About four key words or phrases in alphabetical order, separated by commas.**

I. INTRODUCTION

Concrete being the most popular among the building materials, rightly deserves to be so because of its properties such as mouldability, high compressive strength. Yet another feature of concrete is that the properties of the concrete tailored to suit any aggressive environments, by addition of various pozzolanic materials and chemical admixtures. Cement is the key binding ingredient that goes into the making of concrete. The production of cement, however, releases greenhouse gas emissions both directly and indirectly: Heating of limestone releases CO2 directly, while the burning of fossil fuels to heat the kiln indirectly results in CO2 emissions[1-4].

The direct emissions of cement occur through a chemical process called *calcination*. Calcination occurs when limestone, which is made of calcium carbonate, is heated, breaking down into calcium oxide and CO_2[5-7]. This process accounts for ~50% of all emissions from cement production.

Indirect emissions are produced by burning fossil fuels to heat the kiln. Kilns are usually heated by coal, natural gas, or oil, and the combustion of these fuels produces additional CO2 emissions, just as they would in producing electricity. This represents around 40% of cement emissions. Finally, the electricity used to power additional plant machinery, and the final transportation of cement, represents another source of indirect emissions and account for 5-10% of the industry's emissions.

Use se of pozolanic materials in concrete

The utilization of pozzolanic materials (also known as supplementary cementitious material) in concrete as partial replacement of cement has been the interest of researchers, mainly on account of the improvements in the long-term durability of concrete combined with ecological benefits. Fly

ash, Ground Granulated Blast Furnace Slag (GGBS) and High Reactive Metakaolin (HRM) are the pozzolanic materials, which conform to these requirements and largely available in India.

A.Ground granulated Blast furnace slag

Although GGBS is a hydraulically latent material, in presence of lime contributed from cement, a secondary reaction involving glass (Calcium Alumino Silicates) components sets in. As a consequence of this, cementitious compounds are formed. They are categorized as secondary C-S-H gel. The interaction of GGBS and Cement in presence of water is described as below:

Product of hydration of OPC

$OPC(C_3S/C_2S) + H2O \longrightarrow C\text{-}S\text{-}H + CH$

Product of hydration of GGBS

$GGBS(C_2AS/C_2MS) + H2O \longrightarrow C\text{-}S\text{-}H +$

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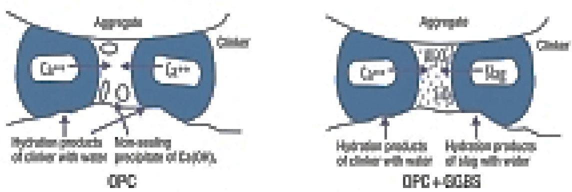
SiO_2

Reaction of pozzolanic material

SiO_2+ CH + H_2O ——————————————>C-S-H

The generation of secondary gel results in formation of additional C-S-H, a principal binding material. This is the main attribute of GGBS, which contributes to the strength and durability of the structure. The diagrammatic representation of secondary gel formation is shown below.



Formation of Secondary Gel

B.flyash

Fly ash is finely divided residue that results from the combustion of coal and transported by flue gas. India is a resourceful country for fly ash generation with an annual output of over 110 million tonnes, but utilization is still below 20% in spite of quantum jump in last three to four years. Availability of consistent quality fly ash across the country and awareness of positive effects of using fly ash in concrete are pre- requisite for change of perception of fly ash from 'A waste material' to 'A resource material'. Now a days due to strict control on quality of coal and adopting electrostatic precipitators, fly ash of consistent quality is separated and stocked, and it is gaining popularity as a good pozzolanic material for partial replacement of cement in concrete[5-10].

Majority of the fly ash available in India are silicious type (ASTM C 618 Type-F) which contains reactive calcium oxide less than 10% and posses no hydraulic properties. It does not react with water directly. The silica present in the fly ash reacts with calcium hydroxide (CH), produced during the hydration of cement, and the principal product of reaction is calcium silicate hydrate (C-S-H). The reaction of fly ash depends largely upon breakdown and dissolution of the glossy structure by the hydroxide ions and the heat generated during early hydration of Portland cement fraction. Reaction of fly ash and water in the presence of water is described as below:

Product of hydration of OPC

OPC (C_3S/C_2S) + H2O————————> C-S-H + CH

Reaction of pozzolanic material

CH + S ——————————————> C-S-H

The reaction of fly ash continues to consume calcium hydroxide to form additional C-S-H as long as calcium hydroxide is present in the pore fluid of cement paste.

C. Metakaolin

Metakaolin[9-13] is a pozzolana that readily reacts with free calcium hydroxide to form stable, insoluble, strength-adding, cementitious compounds.

When Metakaolin- HRM (AS2) reacts with calcium hydroxide (CH), a cement hydration byproduct, a pozzolanic reaction takes place whereby new cementitious compounds, C2ASH8 and CSH are formed. These newly formed compounds contribute to cementitious strength and enhance durability properties to the system in place of the otherwise weak and soluble calcium hydroxide.

Product of hydration of OPC

OPC(C3S/C2S) + H2O ————————> CSH + CH

Reaction of pozzolanic material

AS2 + CH + H2O ————————> C2ASH8 + CSH

Unlike other commercially available pozzolanic materials, Metakaolin is a quality-controlled, manufactured material. It is not a byproduct of an unrelated industrial process. Metakaolin has been engineered and optimized to contain a minimum of impurities and to react efficiently with cement's hydration byproduct, the calcium hydroxide.

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D. Silica Fume (micro silica)

Silica fume, or microsilica or condensed silica fume, is a byproduct material that is used as a pozzolan. This byproduct is formed as a result of the reduction of high-purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy.

Silica fume rises as an oxidized vapor from the furnaces that deals with temperatures of the range 2000°C. When it cools it condenses and is collected in huge cloth bags. The condensed silica fume is then processed to remove impurities and to control particle size. Composition of silica fume is essentially silicon dioxide (usually more than 85%) in an amorphorous form. It is extremely fine with particles less than 1 µm in diameter and with an average diameter of about 0.1 µm, about 100 times smaller than average cement particles.

Condensed silica fume has a surface area of about 20,000 m^2/kg (nitrogen adsorption method). For comparison, tobacco smoke's surface area is about 10,000 m2/ kg. It is used in applications where a high degree of impermeability is needed (Fig. 3-9) and in high strength concrete. Silica fume that meets the ASTM C 1240 specifications is usually used on commercial basis for high strength concrete.. ACI 234 (1994) and SFA (2000) provide an extensive review of silica fume[14].

II. ALTERNATIVES TO USE OF CEMENT

An excellent review article[15] highlights the research in terms of use of alternative or new age cements that can replace the traditional cement in order to reduce the carbon emissions in the environment. The environmental issues surrounding binders used in construction as a whole, and, especially, to provide a certain amount of elementary information on alkaline activation technology and alkaline cements.

In particular, recent researches [16-19] have stressed that such technology may shortly reach a stage of development in which it will serve as a link in the necessary transition from Portland cement to the cements of the future. No attempt has been made in this text to reflect different lines of opinion about specific issues of questionable importance. For these reasons, in an attempt to introduce formal innovation, the present conclusions do not contain a summary of the most significant data discussed above.

Problem associated with alternative cements is gaps in the knowledge base hindering to progress in the technological development of alkaline binders and to the aforementioned transition from Portland and traditional to new, more sustainable cements.

Technical gap in alkali activation procedures is the lack of a systematic and orderly study of the mechanisms governing the effect of the known alkali activators (sodium and potassium hydroxides, silicates, carbonates and sulfates) on silico-aluminous materials. The relationship between "reaction mechanisms, the chemistry of alkaline activating solutions and end product properties" needs to be explored, along with the decisive effect of calcium (with enormous technological implications) on such mechanisms. While alkaline silicate solutions have likewise been widely used in alkaline activation, essential aspects of the reactive process are still poorly understood, such as the effect of the various chemical species present in the solution on reaction kinetics or the composition of the end product.

Finally, working with solid activators instead of alkaline solutions would afford an enormous technological advantage, for the former would emulate one of the most estimable properties of Portland cement: its conversion from a dehydrated solid state into an effective binder by mere mixing with water. In pursuit of such activators, some authors have proposed using cementitious formulas (with silicoaluminous materials) that contain sodium and/or potassium carbonates or even sodium and/or potassium sulfates. In any event, the literature on alkaline activation with these products is scant, and primarily geared to obtaining cementitious products. Nothing, or barely anything, has been published that would relate the interaction of silicoaluminous materials with concentrated sodium or potassium carbonate or sulfate solutions to the formation of N–A–S–HorK–A–S–H type cementitious gels. And nothing has been written to date that would indicate (in formulas with carbonates or sulfates) the structural destination of carbonate or sulfate anions if they are taken up into the three-dimensional cementitious skeleton of Si/Al binders. Another understudied area is the formation of other phases not generally found in these cementitious systems.

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Prime materials also constitute a further sizeable gap in the understanding of these cements. The institution of a universal, standardized, economical and sustainable system for processing raw materials (such as is in place for Portland cement) and activating the resulting products would be extremely beneficial.

Lastly, a word is in order on hybrid cements. Work is needed on hybrids with a low Portland clinker content and high proportion of aluminosilicates, especially on their behavior in alkaline environments. Setting, rheology, mechanical strength development and durability in this type of hybrids must also be studied.

III. HIGH VOLUME FLYASH CONCRETE

Use of pozzolanas such as flyash, as mentioned in above section has many benefits including the improvement of concrete properties in fresh and hardened state, which otherwise is a waste material from thermal power plants. If not disposed efficiently, it would cause serious environmental hazards. The use of High Volume Fly Ash (50% or more of cement content)[4] concrete in construction is a solution to environmental degradation being caused by cement industry. The concept very much fits into the era of sustainable development. As cement industry, itself, is responsible for 7% of world's carbon dioxide emissions, responsible for global warming, attention needs to be drawn by construction industry to solve the problem [20].

Recent concerns about the environment degradation and global warming has driven the attention of concrete technologists towards the use of high volume flyash concrete. High volume flyash concrete is the concrete in which at least 50% of cement content is replaced by flyash. HVFA concrete is usually associated with low water to cementitious material ratio of 0.4 or less. HVFAC has excellent workability, low heat of hydration, adequate early-age and high later-age strengths, reduced drying shrinkage, reduced micro cracking, excellent durability characteristics while being more economical and environment-friendly when compared to conventional concrete. Due to its superior performance and engineering properties the development of HVFAC has opened new doors to sustainability of modern concrete construction.

HVFA concrete with high flyash content reduces the compressive strength considerably, especially at earlier ages as compared to OPC concrete. At 7 days, compared to the control mixture the cylinder compressive strength was reduced by 29% in average for a 30% FA replacement, and by 70% for a 70% FA replacement. While at 28 days, the strength of the 30% FA containing SCC mixtures was only slightly lower (12% in average) than the control mixture, though a 70% FA replacement still resulted in a 46% average strength reduction. At later ages, the contribution of FA to compressive strength became more pronounced. At 90 and 180 days the differences between compressive strength of the control mixture and the mixtures containing FA are reduced, especially for the mixtures with low-lime FA. The reason behind this observation was the slower activity of the low-lime FA. Moreover, the 90, 180 and 365-day compressive strengths were higher for the low-lime FA when compared to the high-lime FA because of the reduced W/CM ratio for those mixtures. At the end of 365 days, the compressive strength of SCC mixtures with 30% and 40% low-lime FA replacement were equal (75.6 MPa) and higher than the control mixture (74.1 MPa)[19-23].

IV. CONCLUSION

Although significant has been made in the field of applying waste materials that can be reused in concrete, the commercial applications however remains limited. Supplementary cementitious materials can be used as partial replacement. However for structural concrete purpose the replacement levels remain limited to about 20-25%. Pozzolanas such as microsilica has been used in manufacturing of high strength concrete and high performance concrete, shows improved performance in terms of strength and durability, however the cement usage again not reduced significantly.

High volume flyash concrete which replaces about 50% or more of the cement content, the problem associated with high volumes is lower early strength and longer setting times. Research in terms of reducing setting time is required in order to commercialize the use of high volumes of flyash.

Alternative binding material need to be researched as as to bridge the gap in the knowhow of alkaline activators. For commercial and large scale use of alternative binding

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material, supplementary cementations materials could be combined with alkaline activators, the mechanism however need to be explored. This still remains a challenge to the research community.

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