Impact of SCMs on Concrete

Dr. M. N. Bajad, Kothawade Ashwini Shirish
[#]*Department of civil engineering, SavitribaiPhule Pune University*
Sinhgad College of Engg,Pune,Maharashtra,India
mnbajad@sinhgad.edu
ashkothawade@gmail.com

***Abstract*-The influence of supplementary cementations material namely sugarcane bagasse ash & lime kiln dust on the engineering properties of high strength concrete has been reviewed in this study. This paper reviews the possible use of industrial wastes as a supplementary cementations material in the production of concrete. This provides a summary of existing knowledge about the successful use of industrial wastes in concrete industry. Workability, compressibility, elastic modulus, porosity and pore size distribution were assumed in order to quantify the effects of different materials. It aim to reveal the idea of utilizing these wastes by elaborating upon their engineering, physical & chemical properties. Thus the impact of using supplementary cementations materials in concrete are discussed in this paper.**

***Keywords*— Lime kiln dust, Supplementary cementations materials, sugarcane bagasse ash.**

I. Introduction

In 21st growing century, concrete is used as a building material in the construction industry. The other important characteristics of concrete, besides its strength are its ability to be easily moulded into any form. It is an engineered material that can meet almost any desired specification & it is also adaptable, incombustible, affordable & easily obtained. At present situation concrete is widely used with more than 10 billion tons production annually in industrial society. It has been estimated that by 2050, the rate of world's population will grow satisfactorily from 1.5 to 9 billion, and, thus, will cause an increase in the demand for energy, housing, food and clothing as well as for concrete, which is forecast to increase to approximately 18 billion tons annually by 2050.

The use of building materials is increasing rapidly due to high demand for construction materials, their transportation costs, reducing natural resources, environmental restrictions etc. The manufacturing processes of conventional materials like cement consumes lot of energy & lot of natural resources & also its demand is significantly increasing. World cement demand was 2282 million tonnes (MT) in 2005, with china being the first leading producer at1, 063 MT (46% of total world production) and India in the second place in the production of cement. In 2010, total production of hydraulic cement rapidly increased to3301 MT.

India is the second largest cement producing country in the world, accounting for 6-7 % of global cement production with an effective capacity of 235 million tonnes/year. The cement manufacturing process leads to large CO2 emissions and rapid depletion of limited natural resources. It is estimated that the cement industry contributes about 6-7 % of global CO2 emissions in the world. CO2 emission from the Indian cement industry is predicted to reach 834 MT by 2050 (510 % increase compared to present CO2 emissions). It is imperativeto use alternative supplementary cementations materials to achieve sustainability in concrete construction.

Several studies have focused on finding alternatives that can be used as replacement to cement, such as, the disposable and less valuable wastes from industry and agriculture, whose potential benefits can be realized through recycling, reuse and renewing programmes. Hence, researchers have been investigating the effectiveness, efficiency and availability of waste materials that are pozzolanic in nature as a cement replacement. The required materials should be a by-product from an original source that is rich in silicon (Si) and aluminium (Al). The framework for utilizing industrial waste material for building applications has a successful history, which includes fly ash, slag, and silica fume. Consequently, land filled waste materials that are normally disposed of and land filled is now deemed to be valuable for enhancing the desired properties of concrete.

Proper estimation of availability and evaluation of characteristics of sugarcane bagasse ash are imperative to achieve appropriate use of this material instead of disposal as waste. This study reports a detailed estimation of availability of sugarcane bagasse ash in India. Performance evaluation of SCBA in previous research studies to assess the potential of SCBA and lime kiln dust for use as an alternative supplementary cementitious material in concrete is also reviewed in this paper.

II. Supplementary Cementitious Materials

A substantial quantity of waste materials are produced globally as by-products from different sectors, such as industrial, agricultural, and wastes from rural and urban society. These waste materials, if not deposited safely, it may be hazardous. The type and amount of sewage produced increases with the growth in population. These wastes remain in the environment for a longer duration since they are unused. The waste disposal crisis has arisen due to the formation of decomposed waste materials. The solution to this crisis lies in the recycling of wastes into useful products. Research into the innovative uses of waste materials is continuously advancing day by day. Waste and by-product materials, such as bagasse ash, silica fume, ground granulated blast slag, rice husk ash, and palm oil fuel ash have been successfully used in concrete for decades . The successful usage as a partial or whole replacement of Portland cement, contributes to the resolution of the landfill problem and reduction in the cost of building materials, provides a satisfactory solution to the environmental issues and problems associated with waste management, saves energy, and helps to protect the environment from pollution. Agricultural wastes, such as rice husk ash, wheat straw ash, and sugarcane bagasse ash, hazel nutshell ash which constitute pozzolanic materials can also be used as a replacement for cement.Today, supplementary cementing materials are widely used as pozzolanic material in high-strength concrete, reduce permeability and improve the durability of the concrete. Many types of pozzolans are used worldwide, and are commonly used as an addition or replacement for Portland cement in concrete. It is renowned that pozzolanic concrete contributes to the compressive strength in two ways: as the filler effect and the pozzolanic reaction. Thus, the pozzolanic material will reduce the demand or usage of cement at that time. A pozzolan comprises siliceous materials, and when combined with calcium hydroxide, exhibits cementitious properties depending on the constituents of the pozzolan. On the other hand, the ‘‘high early strength’’ concrete can be produced by the highly reactive silica in pozzolans. The basis of the pozzolanic reaction is a simple acid-based reaction between calcium hydroxide, also known as Portlandite (Ca(OH)2) and silicic acid (Si(OH)4). This reaction is reprepresented as follows:

$$Ca(OH)_2 + (Si(OH)_4) \rightarrow Ca_2 ++ H_2SiO_4^{2-} + 2H_2O$$
$$\rightarrow CaH_2SiO_4 \,.\, 2H_2O$$

And is the same as the abbreviated notation below:

CH + SH → CSHC-S-H

As the density of CSH is lower than that of Portlandite and pure silica, a consequence of this reaction is a swelling of the reaction products. This reaction, which is also known as alkali–silica reaction may occur over time in concrete between the alkaline cement pore water and poorly-crystalline silica aggregates.

Basically, concrete is a combination of cement, water, fine and coarse aggregate. As consequence of the greenhouse gas emissions (GHG), most concrete mixtures utilize supplementary cementitious materials (SCMs) either in blended cements or added separately in the mixer. The utilization of SCMs, such as rice husk ash, which is a by-product from agriculture, represents a viable solution to the partial cement substitution. This is divided into natural and artificial materials. The usage of SCMs without the additional process causes a significant decrease in CO2 emissions per ton in the atmosphere. These materials are also referred to as mineral admixtures or pozzolans, and when used in concrete and combined with Portland cement form cementitious particles, however by themselves, they do not possess any cementitious compounds. They should meet the requirements of the established standards. The structural advantage of SCMs is that they enable the producer to modify the mixture and calculate the proper design of the desired application. In addition, it can be used to improve the performance of concrete, either in fresh or hardened mixtures. In economic terms, using alternative waste materials can reduce the cost of construction while providing comparable performance. This cost includes the source and transportation of the alternative material, controlled combustion process, and savings through diversion, such as disposal management. Subsequently, the environmental benefits will decrease the sizeable needs and demands of Portland cement per unit volume of concrete as well as the impact on the enormous deflation range of GHG emission.

III. Industrial Wastes As SCM

Nowadays, global environmental warming is considered to be the most important worldwide issue. Solid waste materials are found everywhere, such as in the urban and rural society, industry and agriculture. As industrial wastes effect of the environment, the use of these waste materials in construction will realize the many benefits previously mentioned. Research has determined that concrete that produced using industrial wastes presents improved thermal properties, which can result in significant points being gained in the atmosphere and energy category of Leadership in Energy and Environmental Design (LEED) rating system. Moreover, due to the high cost constraints and limited availability of the main material in concrete, particularly in developing countries, industrial wastes used as SCMs in concrete production can contribute to the environmental friendliness and economic effectiveness of structures worldwide.

A. Sugarcane Bagasse Ash

The by-products generated from the cogeneration and combustion process at certain temperatures of sugar cane bagasse, is called as bagasse ash (BA). Huge quantities of bagasse ash are being formed annually in developing countries, such as India, Thailand, Brazil, Pakistan, Columbia, the Philippines, Indonesia and Malaysia, and are going to be destroy Nowadays, global environmental warming is considered to be the most important worldwide issue. Solid waste materials are found all over, such as in the urban and rural society, industry and agriculture. As industrial wastes influence of the environment, the use of these waste materials in construction will realize the many benefits previously mentioned. Research has determined that concrete that produced using industrial wastes presents improved thermal properties, which can result in significant points being gained in the atmosphere and energy category of Leadership in Energy and Environmental Design (LEED) rating system. Moreover, due to the high cost constraints and limited availability of the main material in concrete, particularly in developing countries, industrial wastes used as SCMs in concrete production can contribute to the environmental friendliness and economic effectiveness of structures worldwide, oyed and disposed of into the environment.

Material description and performance assessment are needed to evaluate new substitute for supplementary cementitious materials for use in concrete. This process includes chemical, physical, mineralogical and microstructural characterization. Chemical is imperative to find major, minor, and trace elements in the alternative materials. Special attention is needed for the compounds which influence the hydration of cement or properties of the concrete. If such compounds are present, then suitable test should be carried out to find the availability of these compounds to participate in hydration reactions**.** Characterization and performance evaluation of sugarcane bagasse ash in the previous research studies have been reviewed in this paper. Raw bagasse ash is composed mainly of silica – SiO2 (60-75 %), CaO, K2O and other minor oxides including Al2O3, Fe2O3, and SO3.

In some studies, raw bagasse ash has been burnt to higher temperature to reduce coarse fibrous particles as well as to achieve better properties. Burning temperature varies widely from 500 ºC -1000 ºC. In one study, raw bagasse ash was directly burnt to 560 ºC for one hour to reduce carbon content from 11.2 % to 3.8 %. Another study involved the evaluation of the performance of bagasse as fuel. In this study carbon was observed as a main constituent in the floating coarse fraction of bagasse ash. This floating fraction in the bagasse ash was collected and pelletized as gasifier feed material. It is interesting to note that bagasse ash was sieved by using large industrial scale sieves and coarse particles were separated and fed to boiler again as fuel because of high carbon content. High surface area and presence of micropores in the coarse particles help to achieve fuel with activated carbon source. Bagasse ash is rich in silica and insoluble matter is very less. Because of this the separation of coarse particles from bagasse with floating process was recommended.

From the review of literature presented in this section, it is clear that better performance was observed in strength, heat of hydration, permeability and other durability parameters in bagasse ash blended concretes as compared to plain concrete. From the above discussion, it is marked that bagasse ash has the potential to be used as supplementary cementitious material in concrete. Proper classification and handing out methodology of bagasse ash need to be studied to achieve a high level of utilization in concrete.

- Sugarcane bagasse ash is generated as by-product from sugar industries in large quantity in India. Disposal of this ash is a critical issue for sugar industries due to environmental constraints and land requirement. Rapid implementation of new cogeneration plants in sugar industries are further expected to increase bagasse ash generation significantly.
- Sugarcane bagasse ash has reactive silica content in its compostion and can be used as supplementary cementitious material in concrete. Proper characterization of SCBA needs to be conducted to achieve maximum pozzolanic activity with minimum energy inputs. Suitable processing methodology must be developed to attain its appropriate use in concrete.
- Utilization of bagasse ash as supplementary cementitious material in concrete strives to achieve durable as well as sustainable concrete and can tackle the disposal problem significantly.

B. Lime Kiln Dust

Lime Kiln Dust (LKD) is the by-product of Quick Lime (QL) production. QL used as a material in purification of steel, manufacturing of Calcium Carbide, effluent treatment for waste water and many more. QL is white in color and granular. QL production requires lime stone as its raw material. The process involves using natural gas to heat the lime stone (CaCO3) to the temperature of 800°C to 1000°C to turn CaCO3 into QL (CaO) as shown in the given equation.

$$CaCo_3 + \Delta \rightarrow CaO + CO_2$$

The heating process is a continuous process throughout the lime kiln. This also generates CO2 gases with dust or particulate matter (PM). The gas is filtered using fabric dust filter collector. The PM that is captured is called LKD. LKD chemical compositions may vary for different plants, because it is influenced by type of lime stones, kiln, fuel used, and also the kiln operating parameters. However, it generally contains relatively high percentage of CaO. It has been estimated that about 2.7 million metric tons of LKD produce in United States annually and a single factory in Malaysia produces about 1.4 tons per day but there is still very few published research on the use of LKD as a cement replacement material. Globally, massive quantity of LKD is produced. Therefore, the need to research about the performance of mortars containing LKD is increasing. The aim of this study is to experimentally investigate the potential benefits of replacing Ordinary Portland Cement (OPC) by up to 60% wt. with LKD in cement mortar. This was achieved by studying its specific gravity, Blaine fineness, particle size, standard consistency, setting time, density and strength for LKD mortar.

Materials

Ordinary Portland cement (OPC) Type 1, LKD, manufactured silica sand and normal tap water were used in the investigation. LKD was collected from a factory in Taiping, Perak, Malaysia. The factory produces 270 tonnes/day QL and discharge approximately 1.6tonnes LKD per day which is disposed in landfill. In 2005, there was approximately 167 landfills area in Malaysia and 80% of them were filled and closed. The collected LKD was stored in air tight container to avoid contacts with moisture and air because it can cause LKD to becomeagglomerate. In order to study the effect of LKD incorporation on the strength of cement mortar, OPC was replaced with LKD from 5% to 65% by cement weight.

Physical properties of OPC and LKD are summarized in Table

Materials	Specific Gravity	Mean particle size, d_{50} (micron)	Blaine fineness(cm^2/g)
OPC	3.16	29.67	3600
LKD	2.54	40.29	1747

Chemical Compositions of OPC and LKD

Bruker S8 Tiger, X-Ray Efflorescence (XRF) was used to analyse the chemical compositions of OPC and LKD presented in Table. The XRF was carried out 3 times for the same sample and the average is reported. The results show that, the main composition of LKD is CaO and SiO2. LKD has lower compositions in terms of CaO in comparison with OPC. LKD has 55.67% content of CaO while OPC has 63.87% CaO. The trend is the same for SiO2, Al2O3, Fe2O3, MgO and K2O with lower compositions for LKD compared to OPC. However, MgO content in LKD still conforms to BS12:1996 standard. LKD has 0.28% SO3 which is less than 3.3% as stated in BS12:1996. This indicates that LKD has potential to be used partial OPC replacement as it has pozzolanic property. The LKD loss of ignition (L.O.I) is 37.63 which are significantly higher than OPC L.O.I (2.32). Therefore LKD has exceeded the maximum L.O.I which is less than 3% as the limit stated in BS12:1996. This is similar with Najim (2014) research on Cement kiln Dust (CKD) replacement of OPC whereby the CKD L.O.I exceeded the limit too.

Chemical Properties of OPC and LKD.

Oxides	CaO	SiO_2	AlO	SO	FeO	MgO	KO	NaO	TiO	PO	LOI
OPC	63.78	18.72	4.44	3.28	3.22	2.97	0.19	0.14	0.13	0.13	2.32
LKD	51.86	0.67	0.68	0.3	0.38	0.95	0.85	0.01	0.01	0.01	38.59

Standard Consistency and Setting Times

LKD mixes standard consistency and the setting times were done according to the ASTM C19. It can be seen that when LKD is increased, the water content required increases. It shown that in parallel with the increasing content of LKD, more water was needed to be added. This indicates that in order, to obtain standard consistency cement paste the water/cement (W/C) ratio needs to be increased. LKD absorbs more water compared to OPC probably because LKD particles are porous and bigger in size. This increased W/C ratio accelerates the mixes initial and final setting time and vice versa. As such, the LKD mixes initial and final setting times conforms to ASTM C150-81 standards, even at 60% LKD replacements.

In this research, the rate of early strength decreased with increased of LKD content. However, the strength increased with age. Replacement of LKDabove 20% reduced the compressive strength of the mixes significantly. However, at 28 days, mixes with 5%, 10%,15% and 20% LKD replacement reduced the strength only about 20% when compared to the control. Many researchers have observed the same trend of strength reductions with pozzolans reaction in paste when OPC is substituted. In this research, at age 28 days, almost all LKD mixes obtained strength above 50 MPa. The normalized compressive strength value indicated that LKD can be use as cement replacement up to 50%. Mortar mix with the same B/S ratio and W/B ratio while increasing the LKD replacement ratio generally reduces the compressive strength of LKD mortar.

Addition of LKD reduces the mortar strength.

- Strength of above 50 MPa for 28days age can be achieved by replacing cement with LKD up to 50%.
- Increase of LKD increases water demand.
- Addition of LKD significantly accelerates the initial and final setting times.
- LKD also reduced the density of the mortar.

IV. Conclusions

Recent interest focused on sustainable development and the recognition of eco-concrete with the population growth around the world. Researchers are becoming increasingly concerned about concept of a green economy, which is important to the environment and society. Since Portland cement, the main principal binder used in concrete, is the product of an industry that is not only energy-intensive, but is also responsible for the huge emissions of CO2, often referred to as green-house gas. The production of cement significantly contributes to global warming, which leads to climate change. The utilization of agricultural waste can be the break-through needed to make the industry more environmentally friendly and sustainable. Many types of industrial and agricultural waste can be used as a partial replacement of cement, such as rice husk ash, palm oil fuel ash, bamboo leaf ash, lime kiln dust, wood waste ash, and sugar cane bagasse ash. Therefore, the enhancement of the existing knowledge and investigation of other useful agricultural waste to be used as supplementary cementitious material (SCM) in concrete mixture will be a valuable contribution and a viable solution for sustainable construction as well as to produce greening in respect of the environment.

Acknowledgment

The author gratefully acknowledge to the guide Dr. M. N. Bajad Sir for the full support and guidance during study of review paper.

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