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Research Paper

Engineering

KEYWORDS : SCMs (Supplementary Cementitious Materials), Fly Ash (FA), Ground Granulated Blast Furnace Slag (GGBFS), Silica Fume (SF), Rice Husk Ash (RHA)

A Study of Future Trend for Sustainable Development by Incorporation of SCM's

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ABSTRACT

The key area of interest of present era is about the preservation of environment and sustainable development in each and every sector of engineering. This paper comprises of detailed study of major supplementary cementitious materials commonly used and new emerging materials as a replacement of natural resources used for construction activity in Indian context. In its most basic form, concrete is a mixture of portland cement, sand, coarse aggregate and water. The principal cementitious material in concrete is portland cement. Today, most concrete mixtures contain supplementary cementitious materials that make up a portion of the cementitious component in concrete. These materials are generally byproducts from other processes or natural materials. They may or may not be further processed for use in concrete. Some of these materials are called pozzolans, which by themselves do not have any cementitious properties, but when used with portland cement, react to form cementitious compounds. For use in concrete, supplementary cementitious materials, sometimes referred to as mineral admixtures, need to meet requirements of established standards. They may be used individually or in combination in concrete.

INTRODUCTION

The use of SCMs dates back to the ancient Greeks who incorporated volcanic ash with hydraulic lime to create a cementitious mortar. The Greeks passed this knowledge on to the Romans, who constructed such engineering marvels as the Roman aqueducts and the Coliseum, which still stand today. Early SCMs consisted of natural, readily available materials such as volcanic ash. Nowadays, most concrete mixture contains supplementary cementitious material that forms part of the cementitious component. These materials are majority byproducts from other processes or natural materials. The major benefits of SCM is its ability to replace certain amount of Portland cement and still able to display cementitious property, thus reducing the cost of using Portland cement. More recently, strict air-pollution controls and regulations have produced an abundance of industrial byproducts that can be used as supplementary cementitious materials such as fly ash, silica fume and ground granulated blast furnace slag. The use of such byproducts in concrete construction not only prevents these products from being land-filled but also enhances the properties of concrete in the fresh and hydrated states. The SCMs can be divided into two categories based on their type of reaction: hydraulic or pozzolanic. Hydraulic materials react directly with water to form cementitious compounds, while pozzolanic materials which by themselves do not have any cementitious property but when used with Portland cement, react to form cementitious combination. It chemically reacts with calcium hydroxide (CH), a soluble reaction product, in the presence of moisture to form compounds possessing cementing properties. Types of SCM that will be discussed further in this context are fly ash, ground granulated blast furnace slag, silica fume and natural pozzolanas.

DEFINITION OF SCMs

Some of the supplementary cementitious materials are called pozzolana, which by themselves do not have any cementitious proper- ties, but when used with Portland cement, react to form cementitious compounds whereas other materials, such as slag, do exhibit cementitious properties. Thus SCM can be defined as:

"The materials that, when used in conjunction with Portland or blended cement, contribute to the properties of the fresh as well as hardened concrete through hydraulic or pozzolanic activity or both."

TYPES OF SCMs

The most commonly used supplementary cementitious material at present stage in India is fly ash and hence it has been emphasized more in this paper. Other supplementary cementitious materials used are Ground Granulated Blast Furnace Slag (GGBFS), Silica Fume (SF) and Metakaolin where as other which are still in a research phase and has a scope of utilization are Hypo-sludge and Rice Husk Ash.

FLY ASH

Fly Ash is a finely divided residue resulting from the combustion of ground or powdered bituminous coal or sub bituminous coal (lignite) and transported by the flue gases of boilers fired by pulverized coal or lignite. Fly ash is a fine, glass powder recovered from the gases of burning coal during the production of electricity. These micron-sized earth elements consist primarily of silica, alumina and iron. Fly ash is by far the most widely used supplementary cementitious material in the manufactured concrete products industry because of low cost (about half that of cement), availability and property-enhancing characteristics.

In India, it is estimated that 230-250 million tones of fly ash is generated by more than 70 major thermal power plants of which only 6-10 % is utilized by cement, construction and road industries.

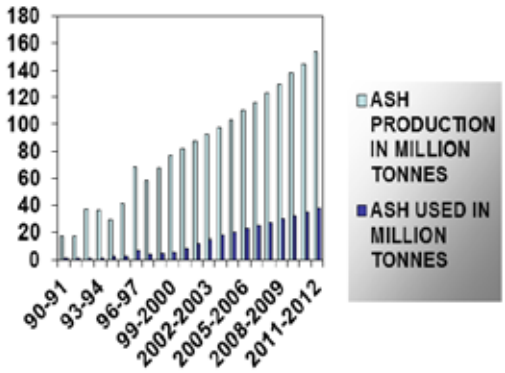

Figure-1 Production of flyash
(Source: info.flyash.in)

PROPERTIES OF FLY ASH

TABLE 1
PHYSICAL PROPERTIES OF FLY ASH

Physical Properties	value
Shape	Spherical
Size	10 and 100 micron
Color	Dark gray to black color
Air content %	7
Specific surface,m2/kg	392
Autoclave expansion,%	0.02

(Source:info.flyash.in)

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TABLE 2
CHEMICAL PROPERTIES OF FLY ASH

Content	Portland cement (% by mass)	Fly ash (%by mass)
CaO	64.01	0.37-27.68
SiO2	20.13	27.88-59.40
Al2O3	5.78	5.23-33.99
Fe2O3	2.35	1.21-29.63
MgO	1.19	0.42-8.79
SO3	0.11	0.20-6.90
Na2O	0.77	0.64-6.68
K2O	0.37	0.24-1.73
TiO2	1.63	0.21-28.37

(Source:info.flyash.in)

ADVANTAGES OF FLY ASH

- Fly ash is still less expensive than Portland cement.
- Fly ash is also widely available, namely wherever coal is being burned.
- Fly ash can improve certain properties of concrete, such as durability.
- It generates less heat of hydration, well suited for mass concrete applications.
- The amount of water can be reduced by 2 to 3 percent for every 10 percent of fly ash used to replace cement.
- Depending on how fine the fly ash and the content of unburnt carbon, the water reduction can reach up to 6-10 % with a 25 % cement replacement.
- It's possible to replace 100% of Portland cement by fly ash theoretically, but it requires chemical activator. Optimum replacement level is 30%.
- Since fly ash is spherical in shape, it greatly improves the workability of fresh concrete acting like small ball bearings during the mixing and placing process.

DISADVANTAGES OF FLY ASH

- There is the relatively slow rate of strength development. But this is irrelevant in applications where high early strength is not required.
- More significant is the wide variability of its chemical composition and quality, which is the main reason for the low utilization rates.
- Customers generally prefer a consistently uniform color. One concrete manufacturer had to discontinue the use of fly ash, because he could not control the color of his product.

APPLICATIONS OF FLY ASH

- **Building components:** Clay fly ash bricks/blocks/tiles (flooring/roofing/ walling); fly ash-{Lime-gypsum)/cement-sand bricks/blocks/tiles; pavement blocks/ tiles; precast housing elements; CLC/ACC blocks/insitu casting etc.
- **Cement and concrete:** Manufacture of fly ash based cement; use of fly ash based cement and site mixing of fly ash for production and use of concrete of different grades for various applications, including all types of concretes: mass concrete, high strength, pre-stressed, self-compacting, roller compacting etc.
- **Roads, embankments and bridges:** Rural roads, urban roads, state highways, national highways, embankments, flexible pavement, rigid pavement, roller compacted roads, repair/conversion of bitumen roads into fly ash concrete roads, bridges, foundations of bridges and structures, all types and grades of concretes in use of bridges, culverts and allied structures.
- **Flyover embankments:** Reinforced and conventional, stabilization of problematic soils, construction of embankments over weak soils, construction of embankments in flood zone areas/earthquake prone areas and in the vicinity/over water bodies.

GROUND GRANULATED BLAST FURNACE SLAG (GGBFS)

Ground granulated blast-furnace slag also called slag cement, is made from iron blast-furnace slag; it is a nonmetallic hydraulic cement consisting essentially of silicates and aluminosilicates of calcium developed in a molten condition simultaneously with iron in a blast furnace. The molten slag at a temperature of about 1500°C (2730°F) is rapidly chilled by quenching in water to form a glassy sand like granulated material. The granulated material, which is ground to less than 45 microns, has a surface area fineness of about 400 to 600 m2/kg. The relative density (specific gravity) for ground granulated blast furnace slag is in the range of 2.85 to 2.95. The bulk density varies from 1050 to 1375 kg/m3. The rough and angular-shaped ground slag in the presence of water and an activator, NaOH or CaOH, supplied by portland cement, hydrates and sets in a manner similar to portland cement. However, air-cooled slag does not have the hydraulic properties of water-cooled slag. Granulated blast furnace slag was first developed in Germany in 1853. Ground slag has been used as a cementitious material in concrete since the beginning of the 1900s. GGBFS can be substituted for cement on a1: 1 basis. In the absence of mix specific data, the substitution of GGBFS should be limited to 50 percent for areas not exposed to deicing salts and to 25 percent for concretes which will be exposed to deicing salts. While substitution of GGBFS for up to 70 percent in a mix has been used, there appears to be an optimum substitution percentage which produces the greatest 28 day strength. This is typically 50 percent of the total cementitious material but depends on the GGBFS used. The present production of GGBFS in Indian is as shown in figure2.

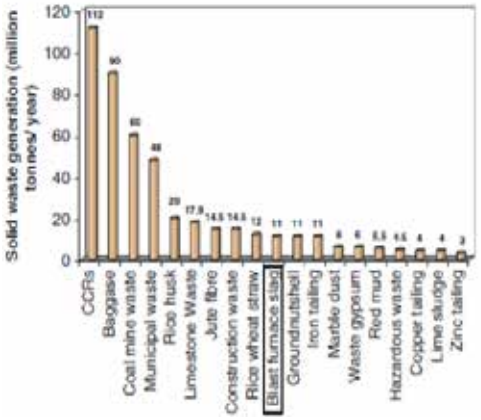

Figure 2 Productions of GGBFS
(Source: www.elsevier.com/locate/buildenv)

PROPERTIES OF GROUND GRANULATED BLAST FURNACE SLAG (GGBFS)

TABLE 3
CHEMICAL PROPERTIES OF GGBFS

Chemical Constituent	Portland	GGBS
CaO	65%	40%
SiO2	20%	35%
Al2O3	5%	10%
MgO	2%	8%

(Source: www.scirp.org)

TABLE 4
PHYSICAL PROPERTIES OF GGBFS

Physical Properties	value
Colour	Off-white powder
Bulk density (loose)	1.0–1.1 tonnes/m3
Bulk density (vibrated)	1.2–1.3 tonnes/m3
Relative density	2.85–2.95
Surface area	400–600 m2/kg Blaine

Source: www.scirp.org

ADVANTAGES OF GROUND GRANULATED BLAST FURNACE SLAG (GGBFS)

- Reduce expansion caused by alkali-aggregate reaction.
- Like fly ash, GGBFS improve mechanical and durability properties of concrete and generates less heat of hydration.
- The rate and quantity of bleeding is less because of the relatively higher fineness of slag.
- GGBFS improves workability and decreases the water demand due to the increase in paste volume caused by the lower relative density of slag.
- Flexural strength is usually improved by the use of slag cement, which makes it beneficial to concrete paving application.
- Significant reduction in permeability is achieved as the replacement level of the slag increases from 40 to 65% especially by mass.
- Air-entrained slag concrete specimens performed excellently in freeze- thaw tests, with relative durability factors greater than 91%.

DISADVANTAGES OF GROUND GRANULATED BLAST FURNACE SLAG (GGBFS)

- Scaling resistance of concretes decreases with GGBFS substitution rates greater than 25 %.
- The necessity of proper curing should be emphasized with the use of ground granulated blast furnace slag.
- Concretes containing ground granulated blast furnace slag may be more susceptible to cracking caused by drying shrinkage.
- At low temperatures, the strengths are substantially reduced up to 14 days, and the percentage of slag used is usually reduced to 25-30%.
- Setting times of concretes increases when the slag content increases.
- Increase of slag content (35 to 65%) can extend the setting time by 60 minutes.

APPLICATION OF GROUND GRANULATED BLAST FURNACE SLAG (GGBFS)

- GGBS is used to make durable concrete structures in combination with ordinary portland cement and/or other pozzolanic materials. GGBS has been widely used for its superiority in concrete durability, extending the lifespan of buildings from fifty years to a hundred years.
- Two major uses of GGBS are in the production of quality-improved slag cement, namely Portland Blast furnace cement (PBFC) and high-slag blast-furnace cement (HSBFC), with GGBS content ranging typically from 30 to 70%; and in the production of ready-mixed or site-batched durable concrete.
- Use of GGBS significantly reduces the risk of damages caused by alkali–silica reaction (ASR), provides higher resistance to chloride ingress — reducing the risk of reinforcement corrosion — and provides higher resistance to attacks by sulfate and other chemicals.

SILICA FUME (SF)

Silica fume (SF) is a byproduct of the smelting process in the silicon and ferro-silicon industry. The reduction of high-purity quartz to silicon at temperatures up to 2,000°C produces SiO2 vapours, which oxidizes and condense in the low-temperature zone to tiny particles consisting of non-crystalline silica. By-products of the production of silicon metal and the ferrosilicon alloys having silicon contents of 75% or more contain 85-95% non-crystalline silica. The by-product of the production of ferrosilicon alloy having 50% silicon has much lower silica content and is less pozzolanic. Therefore, SiO2 content of the silica fume is related to the type of alloy being produced.

Silica fume is available in two conditions: dry and wet. Dry silica can be provided as produced or densified with or without dry admixtures and can be stored in silos and hoppers. Silica Fume slurry with low or high dosages of chemical admixtures are available. Slurried products are stored in tanks.

PROPERTIES OF SILICA FUME (SF)

TABLE 5
PHYSICAL PROPERTIES OF SILICA FUME

Physical Property	Value
Particle size (typical)	<1µm
Bulk density	130-430 kg/m3
Specific gravity	2.22
Surface area (BET)	13,000-30,000 m2/kg

Source: www.springer.com/978-3-642-17865-8

TABLE 6
CHEMICAL PROPERTIES OF SILICA FUME

Chemical Properties	Value
Silicon dioxide, SiO2	92.1
Aluminum oxide, Al2O3	0.5
Ferric oxide, Fe2O3	1.4
Calcium oxide, CaO	0.5
Magnessium oxide, MgO	0.3
Potassium oxide, K2O	0.7
Sodium oxide, Na2O	0.3
Loss on Ignition	2.8

Source: www.springer.com/978-3-642-17865-8

ADVANTAGES OF SILICA FUME (SF)

- It improves both strength and durability of concrete to such an extent that modern designs rule call for the addition of silica fume.
- Silica fume can be used to increase the compressive strength of lightweight concrete as well as conventional concrete.
- It reduces the wall thickness or other dimensions product and overcome transportation limitations.
- Silica fume particles pack around the aggregate more efficiently, modifying the paste structure and preventing bleeding.
- Silica fume ultimately reduces the porosity of the hydrated cement matrix through improved particle packing.
- Silica fume fills the voids between cement particles just as cement fills the voids between sand and coarse aggregate.

DISADVANTAGES OF SILICA FUME (SF)

- Silica fume is typically more expensive than cement.
- The material is difficult to handle because of its extreme fineness.
- It's easy to become airborne, thus raising health issue concerns.
- Silica fume concrete is slightly darker in color and has been reported being "sticky" during finishing.
- Due to its small size and high surface area (20,000 m2/kg), silica fume minimizes bleeding, which may lead to plastic shrinkage cracking.
- Water demand is higher because of its high surface area.

APPLICATION OF SILICA FUME (SF)

- **High Performance Concrete (HPC) containing silica fume—**for highway bridges, parking decks, marine structures and bridge deck overlays which are subjected to constant deterioration caused by rebar corrosion current, abrasion and chemical attack. Silica fume will protect concrete against deicing salts, seawater, road traffic and freeze/thaw cycles. Rebar corrosion activity and concrete deterioration are virtually eliminated, which minimizes maintenance expense.
- **High-strength concrete enhanced with silica fume—** provides architects and engineers with greater design flexibility. Traditionally used in high-rise buildings for the benefit of smaller columns (increasing the usable space) high-strength concrete containing silica fume is often used in precast and prestressed girders allowing longer spans in structural bridge designs.

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- **Silica-fume Shotcrete—**delivers greater economy, greater time savings and more efficient use of sprayed concrete. Silica fume produces superior shotcrete for use in rock stabilization; mine tunnel linings, and rehabilitation of deteriorating bridge and marine columns and piles. Greater bonding strength assures outstanding performance of both wet and dry process shotcreting with less rebound loss and thicker applications with each pass of the shotcrete nozzle.
- **Oil Well Grouting—**whether used for primary (placement of grout as a hydraulic seal in the well-bore) or secondary applications (remedial operations including leak repairs, splits, closing of depleted zones); the addition of silica fume enables a well to achieve full production potential. Besides producing a blocking effect in the oil well grout that prevents gas migration, it provides these advantages such as (i) Improved flow, for easier, more effective application; (ii) dramatically decrease permeability, for better control of gas leakage; and (iii) lightweight
- Repair Products—silica fume is used in a variety of cementitious repair products. Mortars or grouts modified with silica fume can be tailored to perform in many different applications—overhead and vertical mortars benefit from silica fume's ability to increase surface adhesion. Silica fume significantly improves cohesiveness making it ideal for use in underwater grouts, decreases permeability in grouts used for post-tensioning applications and increases the resistance to aggressive chemicals.

METAKAOLIN

Metakaolin is an artificial pozzolan obtained by the calcination of kaolinitic clays over a specific temperature range. It is a material with pozzolanic properties and can be added to lime mortar mixes to provide improved mechanical and water behaviour characteristics for use in conservation mortars. For this particular application cement mortars are inadequate, due to their excessive brittleness, low plasticity and high elastic modulus and high content in soluble salts.

A further advantage of lime/pozzolan mortars is their lower environmental impact, when compared to cement mortars, due to lower energy consumption during production and CO2 absorption by carbonation. The addition of metakaolin to mortars and concretes also has a positive effect in terms of durability.

PROPERTIES OF METAKAOLIN

TABLE 7
PHYSICAL PROPERTIES OF METAKAOLIN

Physical properties	OPC Cement	Metakaolin
Color	Grey	White
Average particle size μm	12	1
Specific gravity	3.09	2.50
Specific surface area m2/kg	373	12000
Nitrogen Absorption m2/g	-	16.8

(Source: presentation of Lauren McCormick)

TABLE 8
CHEMICAL PROPERTIES OF METAKAOLIN

Chemical properties	OPC Cement	Metakaolin
Silicon dioxide, SiO2	20.1	51.34
Aluminum oxide, Al2O3	4.51	41.95
Ferric oxide, Fe2O3	2.50	0.52
Calcium oxide, CaO	61.3	0.34
Loss on Ignition	2.41	0.72

(Source: presentation of Lauren McCormick)

ADVANTAGES OF METAKAOLIN

- Reduced permeability (including chloride permeability)
- Increased compressive and flexural strengths
- Reduced potential for efflorescence, which occurs when calcium is transported by water to the surface where it combines with carbon dioxide from the atmosphere to make calcium carbonate, which precipitates on the surface as a white residue.
- Increased resistance to chemical attack
- Increased durability
- Reduced effects of alkali-silica reactivity (ASR)
- Enhanced workability and finishing of concrete
- Reduced shrinkage, due to "particle packing" making concrete denser
- Improved color by lightening the color of concrete making it possible to tint lighter integral color.

APPLICATION OF METAKAOLIN

- High performance, high strength, and lightweight concrete
- Precast and poured-mold concrete
- Fibercement and ferrocement products
- Glass fiber reinforced concrete
- Countertops, art sculptures (for example the free-standing sculptures of Albert Vrana)

HYPO-SLUDGE

Over 300 million tones of industrial wastes are being produced per annum by chemical and agricultural process in India. These materials pose problems of disposal and health hazards. The wastes like phosphogypsum, fluorogypsum and red mud contain obnoxious impurities which adversely affect the strength and other properties of building materials based on them. Out of several wastes being produced at present, the use of phosphogypsum, flurogypsum, lime sludge, hypo sludge, red mud, and mine tailing is of paramount significance to protect the environment.

Paper making generally produces a large amount of solid waste. Paper fibers can be recycled only a limited number of times before they become too short or weak to make high quality paper. It means that the broken, low- quality paper fibers are separated out to become waste sludge. All the inks, dyes, coatings, pigments, staples and "stickies" (tape, plastic films, etc.) are also washed off the recycled fibers to join the waste solids. The shiny finish on glossy magazine-type paper is produced using a fine kaolin clay coating, which also becomes solid waste during recycling. This paper mill sludge consumes a large percentage of local landfill space for each and every year. Worse yet, some of the wastes are land spread on cropland as a disposal technique, raising concerns about trace contaminants building up in soil or running off into area lakes and streams. Some companies burn their sludge in incinerators, contributing to our serious air pollution problems. To reduce disposal and pollution problems emanating from these industrial wastes, it is most essential to develop profitable building materials from them.

PROPERTIES OF HYPO-SLUDGE

TABLE 9
CHEMICAL PROPERTIES OF RAW HYPO SLUDGE

Sr. No	Constituent	Cement (In %)	Hypo Sludge (In %)
1.	Lime(CaO)	62	46.2
2.	Silica(SiO2)	22	9
3.	Alumina	5	3.6
4.	Magnesium	1	3.33
5.	Calcium sulphate	4	4.05

Source: R.Srinivasan paper

ADVANTAGES OF HYPO-SLUDGE

- It provides most economical concrete.
- It should be easily adopted in field.
- Using the waste in usefull manner
- It reduces the cost of the construction
- It promotes the low cost housing to economical weaker section(EWS) group people
- It minimize the maximum demand for cement
- Minimize the maximum degradation in environment due to cement and safeguard ozone layer from greenhouse gases.

DISADVANTAGES OF HYPO-SLUDGE

- It contains high amount of chlorine so it is difficult to handle.
- At this stage it is difficult to collect it in a bulk quantity.
- It is generally found in slurry form hence in order to mix with cement one has to remove water from it and make it dry.

APPLICATION OF HYPO-SLUDGE

- Low cost all-weather roads for rural areas.
- Soil improvisation treatment.
- Housing for slum migration.
- Solution for low cost housing with fair strengths.
- Manufacturing of building components such as bricks, paver blocks, etc.

RICE HUSK ASH

Rice husk is an agricultural residue which accounts for 20% of the 649.7 million tons of rice produced annually worldwide. The production detail in India is as shown in figure3. The ash produced partially burnt husk from the milling plants when used as a fuel also contributes to pollution and efforts are being made to overcome this environmental issue by utilizing this material as a supplementary cementing material. The chemical composition of rice husk is found to vary from one sample to another due to the differences in the type of paddy, crop year, climate and geographical conditions.

Rice milling industry generates a lot of rice husk during milling of paddy which comes from the fields. This rice husk is mostly used as a fuel in the boilers for processing of paddy. Rice husk is also used as a fuel for power generation. Rice husk ash (RHA) is about 25% by weight of rice husk when burnt in boilers. It is estimated that about 70 million tons of RHA is produced annually worldwide. This RHA is a great environment threat causing damage to the land and the surrounding area in which it is dumped.

During milling of paddy about 78 % of weight is received as rice, broken rice and bran .Rest 22 % of the weight of paddy is received as husk. This husk is used as fuel in the rice mills to generate steam for the parboiling process. This husk contains about 75 % organic volatile matter and the balance 25 % of the weight of this husk is converted into ash during the firing process, is known as rice husk ash (RHA). This RHA in turn contains around 85 % - 90 % amorphous silica. So for every 1000 kgs of paddy milled, about 220 kgs (22 %) of husk is produced , and when this husk is burnt in the boilers , about 55 kgs (25 %) of RHA is generated.

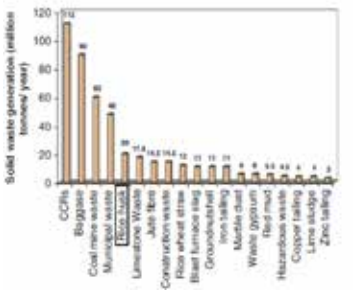

Figure 3

Production of GGBFS
(Source: www.elsevier.com/locate/buildenv)

PROPERTIES OF RICE HUSK ASH

TABLE 10
PHYSICAL AND CHEMICAL PROPERTIES OF RICE HUSK ASH

Chemical & Physical properties	OPC Cement	RHA
Silicon dioxide, SiO2	20.99	88.32
Aluminum oxide, Al2O3	6.19	0.46
Ferric oxide, Fe2O3	3.86	0.67
Calcium oxide, CaO	65.96	0.67
Magnesium oxide, MgO	0.22	0.44
Specific gravity	2.94	2.11
Loss on Ignition	1.73	5.81

Source: D.V.Reddy paper

ADVANTAGES OF RICE HUSK ASH

- Considerable reduction in alkali-silica and sulfate expansions.
- Higher frost resistance of non-air entrained RHA concrete compared to similar mixtures of silica fume concrete.
- Higher compressive strength.
- Higher resistance to chloride ion penetration of RHA concrete with 10% cement replacement compared to normal concrete.
- Reduction in the heat of hydration,
- Higher resistance to carbonation.
- Higher abrasion compared to control mortar specimens

APPLICATION OF RICE HUSK ASH

- Green concrete
- High performance concrete
- Insulator
- Waterproofing chemicals
- Oil spill absorbent
- Specialty paints
- Flame retardants

CASE STUDY

This research work was experimentally carried out to investigate the effects of partially replacing Ordinary Portland cement (OPC) with our local additive Rice Husk Ash (RHA) which is known to be super pozzolanic in concrete at optimum replacement percentage which will help to reduce the cost of housing.

Rice Husk Ash was burnt for approximately 72hours in air in an uncontrolled burning process. The temperature was in the range of 400-600 0 C. The ash collected was sieved through BS standard sieve size 75µm and its colour was grey. It was then measured by volume to replace the cement at 10%, 20% and 25% in M20 grade concrete. The compressive strength of RHA concrete was investigated at 7, 14, 21 and 28days curing age.

TABLE: 11
COMPRESSIVE STRENGTH (MPA) OF CONCRETE WITH RHA

% replacement with RHA	Avg. Compressive Strength, (MPa)			
	7 days	14 days	21 days	28 days
10	12	14	18	22
20	11	13	18	20
25	10	12	14	19

Source: Maurice E. Ephraim, Godwin A. Akeke and Joseph O. Ukpata

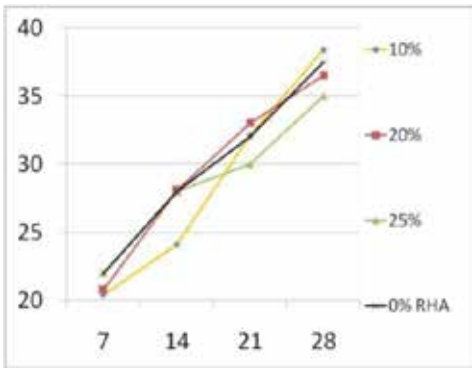

Figure 4 Graphical Representation of the Relationship between Compressive Strength and Age

Source: Maurice E. Ephraim, Godwin A. Akeke and Joseph O. Ukpata

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CONCLUSIONS

The use of RHA in civil construction works will reduce environmental pollution, improve the quality of concrete, and reduce its cost of production as well as solving the problem of agro-waste management by putting into use this locally found additive (RHA). Adding RHA to concrete resulted in increased water demand, increase in workability and enhanced strength compared to the control sample. This results show that an addition of RHA from 5-10% will increase the strength and a further addition up to 15-25% RHA will have a slight reduction in strength of 15% and a decreasing in strength values is pointed out when the levels of RHA are increasing. So, we can say that up to 20% RHA utilized for economical and sustainable development of concrete. Uses of RHA in concrete can save the agro-waste disposal costs and produce a 'greener' concrete for construction. An innovative supplementary Construction Material is formed through this study.

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