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Development of High Performance Concrete

Faizan Abid
PG Student, Civil Engineering, Department, SORT, People's University, Bhopal, M.P.

R C Patil
Assistant Professor, Civil Engineering Department, SORT, People's University, Bhopal, M.P.

Rakesh Sakale
Head of Department, Civil Engineering Department, SORT, People's University, Bhopal, M.P.

ABSTRACT

Making of High Performance Concrete, which is chiefly used as a building material in the major and mega infrastructure and projects, is a very big task. Though the recent advancements have dominated the barriers of the preparation of high performance concrete, the use of green materials such as Meta-kaoline, Silica Fume, Fly Ash and Rice Husk Ash is limited. Apart from the green materials, numerous conventional and mineral admixtures are available in the current market, which enhances the quality and performance of the concrete such as Metakaoline, Alccofine and Silica Fume etc. The quality of concrete mixture is evaluated through various mechanical properties like compressive strength, flexural strength and split tensile strength and various durability tests like rapid chloride penetration test (RCPT), sorptivity test, chloride resistance test, accelerated corrosion test and sea water attack test are carried out to analys the performance of HPC.

The prime objective of this research study is to evaluate the structural strength of high performance concrete by utilizing green and pozzolanic material as supplementary cementitious material. This research study primarily focuses on the development of empirical correlations for estimating the 7 days and 28 days compressive strength with sufficient workability diverse range of water/cement ratio for concrete mixes. Detailed laboratory investigations are performed covering almost all available supplementary cementitious materials like Meta-kaoline, Silica Fume, Fly Ash and Rice Husk Ash nearby area of Madhya Pradesh state of India.

This Research study helps in identifying the influence of Meta-kaoline, Silica Fume, Fly Ash and Rice Husk Ash on the strength characteristics of HPC. The use of alternative material of Portland Cement leads to reduction of emission of harmful gases and impact on production capacity of cement manufacturing plant.

This research work will enhance and accelerates the decision making process in the pre construction as well as post construction stages of any infrastructure projects. Further the above developed empirical model can be applied for all manufacturing of high performance concrete using supplementary cementitious material. These developed correlations can offer excellent engineering judgment and assist in decision making process for the structural evaluation of the HPC during pre-construction and post construction stages.

I. INTRODUCTION

1.1 Conventional Concrete:

Cement concrete is most widely used construction material in the world. Cement concrete is a composite material formed by the combination of cement (binding material), aggregate and water in proper proportion in such way that the concrete produce meets the requirement of the construction activity on hand particularly as regards its workability, durability, strength and economy. In our country the concrete is generally prepared at the sites and consequently need to be carefully supervised and controlled in order that it performs the way it's precisely expected to perform. Bunch of care is to be taken in every phase of manufacturing of the concrete.

The various stages of manufacturing concrete are:
a) Batching
b) Mixing
c) Transporting
d) Placing
e) Compacting
f) Curing
g) Finishing

1.2 Special type Concrete:

1.2.1 High Performance Concrete:

It's mistaken to consider that the supplementary cementitious materials were used in the concrete only just because of their availability and just for the economic concerns. These materials present some unique advantageous properties which can't be met by using the Ordinary Portland Cement only **(Neville, 1995)**. For producing high performance concrete (HPC), it is well known fact that the use of supplementary cementitious materials (SCMs), such as Silica Fume (SF), Alccofine and Fly Ash (FA) are essential. The concept of HPC has definitely developed with time. Initially it was equated to high strength concrete (HSC), which definitely has some merits, but it doesn't show a complete and real picture. There is a need to consider other properties of the concrete as well which sometimes, could even take main concern over the strength criterion. Various authors and researchers proposed different definitions for High Performance Concrete (HPC). High Performance Concrete (HPC) is a concrete which made with suitable materials, combined according to a selected mix design, properly mixed, transported, placed, consolidated and cured so that the resulting concrete will provide an excellent performance in the structure in which it's placed, in the environment to which it's exposed and with the loads to which it will be subjected for its design. Thus, High Performance Concrete is directly related to the long-lasting concretes.

1.2.2 Polymer Concrete:

In the constructions industry new building materials with improved properties are required for satisfying the latest utilization domains for modern construction or for repairing works. The application of polymer on concrete has significantly progressed in the last few decades. Polymers are either incorporated in a cement-aggregate mixture or used as single binder. The composites made by using polymer along with cement and aggregates are called polymer modified mortar or polymer modified concrete, while composites made with polymer and aggregates are called polymer mortar or polymer concrete, depending on the maximum size of the aggregate granule.

In the composition of polymer concrete there is not cement: the aggregates are bonded by the resins. Function of the type of polymer it can obtain concretes with synthetic resin, concretes with plastic resin or simple concrete with resin. The composite doesn't contain hydrated cement paste. Polymer concrete presents some advantages compared to the Portland cement concrete such as rapid hardening, high mechanical strengths, improved resistance to the chemical attack, durability, etc. One of the most significant disadvantages is the high cost of resin that limited the use domains of polymer concrete. The performances of polymeric concrete depend on the polymer properties, type of filler and aggregates, curing temperature, components dosage, etc. The aggregates can be silicates, quartz, crushed stone, gravel, limestone, calcareous, granite, clay, etc. Near the aggregate, the filler is very important. Different types of fine materials can be used such as fly ash, silica fume, phosphor-gypsum, cinder, etc.

1.2.3 Fibre Reinforced Concrete:

Fibre reinforced concrete (FRC) is concrete containing fibrous material which improves its structural integrity. It contains short discrete fibres that are uniformly distributed and randomly oriented. Fibres include steel fibres, synthetic fibres and natural fibres. Within these different fibres that character of fibre reinforced concrete changes with varying concretes, geometries, distribution, fibre materials, orientation and densities.

The concept of using fibres as reinforcement material is not new. Fibres have been used as reinforcement since ancient times in so many places. Historically, horsehair was used in mortar and straw in mud bricks. In the early 1900s, asbestos fibres were used in making of concrete, and in the 1950s the concept of composite materials came into consideration and fibre reinforced concrete was one of the topics of attention. There was a need to find a replacement for the asbestos used in concrete and other building materials once the human health risks associated with the substance were discovered. By the 1960s, steel, glass and synthetic fibres such as polypropylene fibres were used in concrete, and research into latest fibre reinforced concretes (FRC) continues today.

The different ingredients used for casting the concrete are as follows:

1.3 Waste material:

Because of sustained pressure of industrial and developmental activities, there are considerable disturbances in the ecological balance of the nature. As with most large manufacturing industries, by-product materials are produced. These industrial by-product and waste materials must be managed responsibly to assure a clean and safe environment. The concept of environmental geo-techniques has emerged as an answer to the requirement to understand the ecological problems, connected with Fly ash, Quarry fines and Silica fines.

1.3.1 Fly ash:

Fly ash is one of the residues generated in combustion and comprises the fine particles that rise with the gases. In an industrial circumstance, fly ash usually refers to ash produced during the combustion of coal. It is having a fineness of about in the range between 4000-8000 cm^2 /g. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reaches the chimneys of coal-fired power plants Depending upon the source and constitute of the coal being burned, the components of fly ash vary considerably.

It may include one or more of the following elements or substances in quantities from trace amounts to several beryllium, boron, cadmium, chromium, chromium VI, cobalt, lead, manganese, mercury, molybdenum, selenium, strontium, thallium, and vanadium, along with dioxins.

1.3.2 Cement Kiln Dust (CKD):

Cement manufacturing is a critically important industry in the whole world, worldwide production accounted for about 2.5 billion metric tons. Over the past several years impressive advances have been achieved in the management and use of cement kiln dust (CKD), thus reducing its dependency on landfill disposal. Sustainability is the foundation stone of the cement industry, not only in the products that use cement, but also in its manufacturing process. Many of the older, inefficient plants are being replaced by more modern plants or being renovated with new technologies to be more efficient as well as more environments friendly.

The majority of cement kiln dust (CKD) is recycled back into the cement kiln as raw material. Additionally, new technology has allowed the use of previously land filled cement kiln dust (CKD) to be used as raw feed stock. Recycling this by-product back into the kiln not only reduces the amount of cement kiln dust (CKD) to be managed outside the kiln, but also it reduces the need for limestone and other raw materials, which saves natural resources and helps conserve energy.

1.3.3 Quarry fines:

In the year 2005, approximately 200 million tonnes of saleable aggregate was produced; corresponding 50 million tonnes of quarry fines and 25 million tonnes of quarry waste were also produced. The need to minimize fines production is driven by the Aggregates Levy and the Landfill Tax (which has made it expensive to dispose of fines). Future developments are likely to be driven by the need to respond to climatic change. New crusher designs will be more automated, offer improved energy efficiency, have a greater production capacity and improved reliability.

1.4 Supplementary cementing materials (S.C.M.):

Supplementary cementing materials (SCMs) such as Meta-kaolin, Alccofine and GGBS are increasingly used in the recent years as cement replacement material. They help to obtain both higher performance and economy. These materials increase the long term performance of the concrete through the reduced permeability resulting in the improved durability.

1.4.1 Meta-kaolin:

The requirement of the high strength high performance concrete is increasing because of demands in the construction industry. Efforts for enhancing the characteristics of concrete over the past few decades suggest that cement replacement materials along with chemical admixtures can improve the durability and corrosion characteristics of the cement concrete. High Reactive Meta-kaolin (HRM), is a pozzolanic material that can be utilized to produce highly durable concrete composites. However, information to understand the behaviour of this mineral additive in concrete mixture is insufficient. Some of the recent information is discussed in this paper highlighting the role of meta-kaolin in high strength high performance concrete.

1.4.2 GGBS:

Grinding Granulated Blast Furnace Slag (GGBS) is non-metallic product consist of silicates and aluminates of calcium and other bases. The molten slag is rapidly chilled by quenching in water to form glassy sand like grains, further these grains ground to fineness less than 45μ. IS146:2000 suggest, Grinding Granulated Blast Furnace Slag (GGBS) obtained by grinding granulated blast furnace slag conforming to IS 12089 may be used as part replacement of OPC provided uniform blending with cement is ensured.

1.4.3 Alccofine:

ALCCOFINE is a specially processed product based on slag of high glass content with high reactivity obtained through the process of controlled granulation. The raw materials are composed chief of low calcium silicates. The processing with other select ingredients results in the controlled particle size distribution (PSD). The computed blain value based on particle size distribution (PSD) is around 12000cm^2/gm and is truly ultrafine. Due to its unique chemistry and ultrafine particle size, ALCCOFINE 1203 provides reduced water demand for a given workability, even up to 75% replacement level as per requirement of concrete performance. ALCCOFINE 1203 can also be used as a high range water reducer to improve compressive strength or as a super workability aid to improve flow.

1.4.4 Micro-Silica:

The surplus amount of foundry dust was treated as a partial replacement for sand. Use of foundry dust in self consolidating concrete (SCC) resulted in high air content (7% - 10%) and low density of concrete due to reaction between the foundry dust and the particular brands of chemical admixtures used. Further, with the increase in foundry dust content containing steel, the colour of concrete changed from dark gray to black. For the foundry silica-dust content of 20% and above, the requirement for high range water reducing admixture increased; however, the amount of viscosity-modifying admixture decreased up to 33 % up to the silica-dust content of 30%. It was concluded that the foundry industry silica-dust material can be used for partial replacement of cement, fly ash and sand in SCC. More extensive work is in progress.

1.4.5 Rice Husk Ash:

In India, rice production has increased rapidly during last few years, becoming the most important crop. Rice Husks are residue produced in significant quantities. At the same time in some regions of the country, they are utilized as a fuel in the rice paddy milling process, in our county they are treated as waste material, causing pollution of the environment and disposal issues. Due to increasing environmental related concern, and the need to save energy and resources, efforts have been made to burn the rice husks under the controlled conditions and to utilize the resultant ash as a supplementary binding material. In addition, rice husks are capable to be an ideal fuel for power generation.

II. LITERATURE REVIEW

Concrete has a number of advantages as the main material for the construction in comparison to the other construction materials. It's the most easily available material everywhere in the world and it possesses the excellent resistance to water as comparison to wood and steel. Therefore, concrete has become a more durable and long-lasting material. In addition, the plastic consistency of the fresh concrete makes it easier to be formed into a range of shapes and sizes using prefabricated formwork **(P. Kumar Mehta, 1986)**.

The rapid development of the construction industry has led to an increase in the demand for tall and long span concrete structures and this demand can be fulfilled by High Strength Concrete (HSC), a type of concrete with compressive strength greater than 6,000 psi (41 MPa). It is because of the fact that high strength concrete (HSC) can carry loads more economically than normal concrete, reduce the total amount of material required and reduces overall cost of the structure. Concrete can certainly not be made sustainable since it's based on non-renewable mineral resources. However, the concrete can be made more sustainable by replacing cement with supplementary cementing materials based on industrial by-products like slag and fly ash. Greater amount of fly ash can be used if loss in early strength is counteracted by the help of finer grinding or special grinding or accelerators.

Muthu, K. U., M. S. Ramaiah (2008) Self Compacting Concrete technology is broadly accepted as a quality product and investigations show that Nan Su's method is simple to apply and can be used for producing high strength self-compacting concrete (HSSCC). The investigation of SCC under fatigue loading is in a very few cases. In the near future new concrete like Basalt fibre concrete, Bacterial concrete, Geopolymer concrete and Nano composites will find suitable applications in the construction industry. The investigations related to the Light weight concrete applications in structural concrete are in progress and a rational method of mix design of Foam Concrete (FC) is required. The application high volume Fly ash technology to the construction of rigid pavements is found to be appropriate for sustainable developments. The above application would help to solve the many environmental issues.

Several investigations were reported in the study of shear strength of concrete beams. A data base of about 400 tests indicates a wide scatter between the theoretical and computed ultimate shear strength of the beams. In the recent past, the Arching action on the slabs has been revisited and methods are proposed together with the same.

The concrete industry circumstances in India and the current practice of specifying the concrete. The research paper provides some definitions of performance specifications and things to see their advantages. The basic elements of performance specifications such as sampling, testing methods, development of the acceptance criteria and the bonus-penalty system are briefly described. It is suggested that some pilot projects demonstrating the benefits of the performance specifications may be taken up in India in the upcoming future.

Patel., Vatsal, Shah., Niraj (2013) effect of Mineral and Chemical Admixtures used to improve the performance of concrete. High Performance Concrete (HPC) can be prepared to provide optimized performance characteristics for a given loading and exposure conditions along with the requirements of cost, service life and durability. The success of High Performance Concrete (HPC) requires more consideration on proper Mix Design, Production, Placing and Curing of Concrete. For each of these operations controlling parameters should be achieved by concrete producer for an environment that a structure has to face and survive against them.

Brooks et al. (2000) after studying the effect of silica fume, metakaolin, fly ash and ground granulated blast furnace slag on setting times of high strength concrete (HSC), they concluded that there was increase in the retarding effect up to 10% replacement of the cement by supplementary materials like Metakaolin and as the percentage replacement is increased, the retarding effect is reduced.

1) Meta-kaoline:

M. Frias, M. I. Sanchezderojas, J. Cabrera (2000) In their experimental work, the influence of the pozzolanic activity of the Meta-kaolin (MK) on the hydration heat has been studied in the comparison to the behaviours of other traditional pozzolanic materials such as fly-ash and silica fume. The results revealed that Meta-kaolin (MK) mortars produce a slight heating increase when compared to a 100% Portland cement mortar, due to the high pozzolanic activity of Meta-kaolin (MK). With respect to the hydration heat, MK-blended mortar showed closer behaviours to silica fume than to fly-ash.

Xia Oquian and Zongjinli (2001) studied and presented the stress–strain relationships of concrete containing 0% to 15% of Meta-kaolin (MK) at an incremental rate of 5%. They concluded that incorporation of Meta-kaolin up to 15% has increased the compressive strength and tensile strength, also peak strain is increased at increasing rate of Meta-kaolin up to the range about 15%. Incorporation of Meta-kaolin has slightly increased the compressive strength and elasticity modulus.

Poon et al (2001) investigated the rate of the pozzolanic reaction of Meta-kaolin in high performance cement mortars (HPCM). They studied the hydration progress of Meta-kaolin in terms of its compressive strength, porosity and pore size distribution (PSD). They concluded that the higher pozzolanic reactivity results in a higher rate on strength development and its pore structure modification for the cement pastes at the earlier ages.

Jamal M. Khatib, Roger M. Clay (2003) in their experimental investigation, the amount of water absorption (WA) by total immersion and by capillary rise of concrete containing the Meta-kaolin (MK) is studied. Cement was partially replaced with up to 20% Meta-kaolin. The results show that the presence of Meta-kaolin (MK) is greatly advantageous in reducing the amount of water absorption by capillary action. There is a systematic reduction in the water absorption by capillary action with the increase in Meta-kaolin content in the concrete. Between 14 and 28 days curing, there is slight increase in the absorption by total immersion and by capillary rise for all Meta-kaolin concretes.

Lu Courard et al. (2003) studied the durability of mortars containing meta-kaolin (MK). The studies on chemical behaviours and transport by means of chloride diffusion tests and sulphate immersion were carried out. They concluded that 10% to 15% replacement of cement by Meta-kaolin lead to low decrease of the workability and greatest mechanical performance and inhibition effect on chloride diffusion and sulphate attack for 20% meta-kaolin (MK).

2) Silica Fumes:

Silica Fume (SF) is an extremely reactive pozzolanic material as compared to other materials. It's a by-product obtained from the manufacturing of silicon or ferrosilicon. It is extracted from the flue gases from electric arc furnaces. Silica Fume particles are very fine with particle sizes about hundred times smaller than those of average size of Ordinary Portland Cement particles. It is a very dense powder or is in the form of water slurry. The standard specifications of Silica Fume are defined in ASTM - 1240. It is generally used at a replacement level of 5% to 12% by the total mass of cementitious materials. It can be used successfully for the structures where high strength is needed and significantly reduced permeability to water is the chief concern. Extraordinary procedures are required to be adopted for handling, placing and curing concrete with these very fine silica fume particles.

Memona., Radin and Zainc (2002) is recommended compressive strength at the age of 28 days, 0 %, 30% & 70% replacement achieved 54 Mpa ,63 Mpa & 64 Mpa. Concrete mixes (30% and 70%) exhibited better performance than the NPC concrete in seawater exposed to the tidal zone. The pore size distribution (PSD) of both high-strength concrete (MSS-0 and MSS-40) was significantly finer at the age of 6 months were reduced about 3 times compared to NPC concrete.

Shannag (2000) designed and studied very high compressive strength of 65 Mpa to 110 MPa along with the incorporation of locally available natural pozzolana and silica fume. He concluded that 15% replacement of the cement with silica fume along with 15% natural pozzolana gave comparatively higher strength than without natural pozzolana.

3) Fly Ash:

Global production of the coal combustion products is estimated around 1300 million tonnes per year by the cement and concrete industry. To attain a sustainable development of the concrete industry, the rate of the use of pozzolanic and cementitious by products will have to be accelerated **Malhotra & Mehta, (1996)**. Reusing larger amounts of Fly Ash (FA) in the concrete mix and replacing higher quantities of cement will certainly help to reduce a major problem of the environmental impact. Incorporating high volumes of Fly Ash in the concrete mix is one of the best possible ways for making green concrete. Design requirements related to the mechanical characteristics will be absolutely fulfilled and with this type of concrete it will be possible to build more durable structures while contributing the significantly to the construction sustainability.

The following characteristics are typical for HVFAC: a minimum of 50 to 60% Fly Ash by mass of cementitious materials, low water content, usually less than 130 kg/m^{3}of concrete; cement content not more than 200 kg/m^{3}of the cement concrete mixture, but normally about 150 kg/m^3; low water/cementitious material ratio, in general less than 0.35. It's usually approved that class F fly ashes delays setting and reduces the early strength of concrete significantly, the effect increasing with replacement level.

Majko and Pistilli (1984), Class C fly ashes have mixed effects on setting time and early strength gaining. Frequently these have been shown to delay the setting time, as much as 4 hours to 6 hours at high replacement levels. However, some class C ashes have been shown to reduce setting times or have no effect on these properties.

Roongta., Dewangan & Dr. Usha (2004), IS 1489:1969 for Portland Pozzolana Cement was introduced in India the addition of Fly Ash (FA) was limited from 10% – 25% only and now in IS 1489:1991 the range of Fly Ash addition in Portland Pozzolana Cement (PPC) is 15% – 35%. This research and development work was carried out in Quality Control (QC) Department of Cement Manufacturing Company Limited Meghalaya India in the laboratory level, to identify the impact of higher addition of Fly Ash beyond IS limit (up to 50%), with respect to the clinker quality, fineness and Indian Specification IS 1489:1991 for Portland Pozzolana Cement (PPC). At 0%, 40%, 42%, 45%, 47%, 50% replacement of Fly ash, they found compressive strength (28 days) 69 MPa, 58 MPa, 58 MPa, 52 MPa, 52 MPa, 48 MPa respectively.

S. Gopalakrishnan (2006), M30 grade concrete was casted using Fly Ash at 50% cement replacement level. A slump of about 100 mm was to be achieved for the workability. The strength value levels were almost similar at the age of 28 days and High Volume Fly Ash Concrete exhibited higher strength at the later ages. The flexural strength was found to be higher for HVFAC. High Volume Fly Ash Concrete showed very low chloride permeability and low water absorption and reduced water permeability compared to that of OPC based concrete. The abrasion resistance of High Volume Fly Ash Concrete was found to be slightly better compared to Ordinary Portland Cement based concrete.

Vanita Agarwal (2008) found that the proportions of Fly Ash (FA) in Concrete can vary from 30% - 80% for different grades of concrete. It is observed that the later age strength of the concretes having more than 40% replacement of cement by FA suffers adversely though water/ cement ratio is gradually decreased. For concretes with less than 40% replacement level of cement, the characteristic strength at 28 days is on the higher side. Whereas, for concrete with 40% replacement level of cement, the 28 days Compressive strength is at par with that of plain concrete.

4) Rice Husk Ash

Zhang and Malhotra (1996), in the published literature demonstrate that the hardened properties of cement concrete are improved in the presence of Rice Husk Ash.

For example, RHA provided significant improvements in the compressive as well as tensile strengths, ultrasonic pulse velocity and transport properties of high strength and high performance concretes (HPC).

The utilization of Rice Husk Ash (RHA) in the concrete was patented in the year 1924. Till the year 1978, all the researches were concentrated to utilize ash derived from uncontrolled combustion process. Mehta published several papers dealing with Rice Husk Ash (RHA) utilization during this period. He established that the burning rice husk under controlled temperature - time conditions produces ash containing the silica in amorphous form **(Gastaldini et. al., 2007)**.

Depending on the production method, the utilization of RHA as a pozzolanic material in cement and concrete provides several advantages, such as improved compressive strength and durability. Some researcher reported that mortars and concrete mixture containing RHA have compressive strength values inferior or superior to that of Ordinary Portland Cement Concrete. **(Karim. M, 2012)** mortars and concrete containing Rice Husk Ash improve durability of the concrete at various ages. Normally, there are two types of Rice Husk Ash in concrete. The type of RHA which is suitable for the pozzolanic activity is amorphous or shapeless rather than crystalline. Therefore, substantial researches have been carried out to produce the amorphous silica. The results have shown that Rice Husk Ash quality depends on the temperature and burning time.

III. MATERIALS USED AND METHODOLOGY

This chapter reviews the constituent materials, properties and deterioration mechanisms of the structural concrete. This was done in order to firstly categorize the most significant properties of the structural concrete which should be investigated in this research work before setting or establishing the ranges within which supplementary cementitious materials (SCMs) can be used as a cement replacement material in structural concrete. The second important reason was to achieve a good understanding of the factors which affect various properties of concrete, so that the experimental programme can be designed to investigate the comparative influence of supplementary cementitious materials on the properties of concrete.

Materials used

1) Meta-kaoline:

MetaCem is a High Reactivity Metakaolin (HRM) enhances the compressive strength and durability of concrete mix to make concrete even more suitable for sustainable construction. Mineral admixtures have changed the concept of making durable and special concretes in the world. Now use of Pozzolanic material have become a traditions for high strength, high performance concrete **(Tiwari A.K. et al, 2004)**. Along with other Pozzolanic Material Meta-kaolin has been researched worldwide and have been found to be a product equivalent to the silica fume in almost all the aspect. India has large reserves of kaolin and knows how to produce Super Quality Metakaolin (SQM) for use as cement replacement in the construction industry. A good amount of research work is also reported on the applications leading to beginning of use of meta-kaolin in the cement mortar and concrete. The paper details the behaviour of Meta-kaolin for various grades of concrete, concrete durability and comparative study with Silica Fume Concrete.

MetaCem grades of Calcined clays are reactive allumino silicate pozzolana formed by the calcining very pure hydrous China clay. Chemically MetaCem combines with Calcium Hydroxide $CA(OH)_2$ to form Calcium Silicate and Calcium Alluminate Hydrates. The particle size of MetaCem is significantly smaller than cement particles. IS: 456-2000 recommends use of Metakaolin as Mineral admixture.

2) Silica Fume:

Silica Fume (SF) is an extremely reactive pozzolanic material. It is a by-product obtained from the manufacturing of silicon or ferro-silicon. It is extracted from the flue gases from electric arc furnaces. Silica Fume particles are very fine with particle sizes about hundred times smaller than those of average size of Ordinary Portland Cement particles. They are not cementitious but highly pozzolanic material. ASTM C 1240 (ASTM, 2008) defines the requirements of silica fume that can be used in concrete.

The American Concrete Institute (ACI) defines silica fume as “very fine non-crystalline silica produced in electric arc furnaces as a by-product of the production of elemental silicon or alloys containing silicon” (ACI 116R). It is usually a gray coloured powder, somewhat similar to Ordinary Portland Cement or some fly ashes.

3) Fly-Ash:

Fly Ash class F, known also as pulverized- fuel ash, is the by-product obtained by electrostatic and mechanical precipitator from flue gases of power station furnaces fired with pulverized coal. The similarity of Fly Ash to natural pozzolanas of volcanic origin has encouraged the use of Fly Ash in the conjunction with Ordinary Portland cement in making the concrete.

According to the American Concrete Institute (ACI) Committee 116R, fly ash is defined as ‘the finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gasses from the combustion zone to the particle removal system’ (ACI Committee 232 2004). Fly ash is removed from the combustion gases by the dust collection system, either mechanically or by using electrostatic precipitators, before they are discharged to the atmosphere. Fly ash particles are typically spherical, finer than Portland cement and lime, ranging in diameter from less than 1mm to no more than 150 μ

Fly ash is the most commonly used SCM. Fly ash is the residue collected from the flue gases exiting the boiler of a pulverized coal generating station. The fly ash particles are collected in electrostatic precipitators or bag houses and then transferred to a storage silo or sluice pond. Fly Ash has a spherical morphology and exhibits a rather wide range of bulk chemical compositions. This wide range of chemical composition has resulted in the creation of two classes of fly ash in ASTM specifications and three classes of fly ash in Canadian Standard Association (CSA)ASTM specifications break fly ash in two classes based on $SiO_2+Al_2O_3+Fe_2O_3$ content.

Class F fly ash has a $SiO_2+Al_2O_3+Fe_2O_3$ content of 70% or more. Class C fly ash has a $SiO_2+Al_2O_3+Fe_2O_3$ content between 50% and 70%. Class F fly ashes are typically pozzolanic however; some authors have noted that they may occasionally exhibit some self-cementitious properties. Class C fly ashes may exhibit self-cementitious properties.

4) Rice Husk Ash:

Non Crystalline RHA was used as a supplementary cementitious material (SCM). It was available in the form of very fine powder with a grey colour. RHA was tested for relative density, accelerated pozzolanic activity, Blaine specific surface area, particle size distribution (PSD) and chemical composition. The accelerated pozzolanic activity was determined according to the procedure used for Silica Fume (SF).

The hydrometer method, as mentioned in ASTM D 422 (2004) was applied for the particle size analysis of RHA. The borate fusion whole rock analysis by XRF spectrometry was used to determine the oxide composition and loss on ignition ((LOI) of Rice Husk Ash. The rice husk ash (RHA) used in this study was obtained from rice processing mill. The properties of Rice Husk Ash are presented in table below.

Methodology

Various test in this research to check the various properties of material used as well as the properties of the complete mixture. Tests like:

I) AIV
II) Sieve Analysis Test
III) Slump Cone Test
IV) Water Absorption
V) Compressive Strength

IV. MIX DESIGNING

Based on the detailed literature review, it's proved that the use of supplementary cementitious materials in the cement concrete has double advantages in the supporting green environment as well as improving some of the concrete properties. The utilization of green materials as Meta-kaoline, Silica Fume, Fly Ash and RHA reduces the waste from the various industrial production activities and reduces CO2 emissions due to the utilization of Portland Cement in concrete industry. Hence, in this experimental research it was decided to use supplementary cementitious material to improve the strength of HPC. As high performance concrete not only depends on its strength but also on other physical properties, the physical/mechanical properties of high performance concrete integrated with supplementary cementitious materials were also investigated i.e. properties of fresh concrete, properties of hardened concrete and the durability of concrete. Test for fresh concrete consists of setting time and slump cone test. In addition, test for hardened concrete consists of compressive strength.

1) BIS Mix Design Method

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required strength, workability and durability as economical as possible, is termed as the concrete mix design. In our study mix design was done by BIS mix design method which is based on Bureau of Indian Standards **(14) BIS: 10262-2009**.

The basic steps involved in the concrete mix design process can be summarized as follows:

i. Based on the level of quality control the target mean strength is estimated from the specified characteristic strength.
ii. The water/cement ratio is selected for the target mean strength and checked for the requirements of durability.
iii. The water content for the required workability is determined by slump cone test.
iv. The cement content can be determined from the water/cement ratio determined by slump cone test and water content obtained in step (ii) and (iii) respectively and is checked for the water requirements.
v. The relative proportion of fine aggregate and coarse aggregate is selected from the characteristic of coarse and fine aggregates.
vi. The trial mix proportions are determined.
vii. The trial mixes are tested for verifying the compressive strength and suitable adjustments are made to get there the final mix composition.

A) Target Mean Strength of The Concrete Mix:-

Target strength for mix proportioning

$f'ck = fck + 1.65\,\sigma$

Where,

$f'ck$ = target average compressive strength at 28 days

fck = characteristic compressive strength at 28 days and

σ = standard deviation

From Table-1, Standard Deviation, $\sigma = 4$ N/mm^2

Therefore, target strength = 20 + 1.65 x 4 = 26.6 N/mm^2

Table-1 Assumed Standard Deviation According To IS 456: 2000 (Table-8)

Grade of Concrete	Assumed Standard Deviation in N/mm^2
M-10	3.5
M-15	3.5
M-20	4.0
M-25	4.0
M-30	5.0
M-35	5.0
M-40	5.0
M-45	5.0
M-50	5.0

B) Selection of Water/Cement Ratio For The Concrete Mix:-

Minimum cement content, maximum water-cement ratio and minimum grade of concrete for different exposures with normal weight aggregates of 20 mm nominal maximum size **(Table 5 of IS:456-2000)**.

Table-2 Minimum Cement Content and Maximum W/C Ratio With Exposure Condition With Their Grades

S. No.	Exposure	Reinforced Concrete		
		Minimum Cement Content kg/m3	Maximum Free Water-Cement Ratio	Minimum Grade of Concrete
1	Mild	300	0.55	M-20
2	Moderate	300	0.50	M-25
3	Severe	320	0.45	M-30
4	Very Severe	340	0.45	M-35
5	Extreme	360	0.40	M-40

From Table-2, maximum water-cement ratio is 0.55 for M 20 grade concrete. Hence we will adopt water/cement ratio = 0.55.

C) Selection of Water Cement Ratio for The Concrete Mix:-

Maximum water content per cubic meters of concrete for nominal maximum size of aggregate according to IS code **(Table-3 of BIS: 10262-2009)**.

Table-3 Maximum Size of Aggregate With Maximum Water Content

S. No.	Maximum Size Of Aggregates (mm)	Maximum Water Content (kg)
1	10	208
2	20	186
3	40	165

From Table-4.3, maximum water content for 20 mm size aggregate is 186 litres (for 25 to 50 mm slump range) and for 10 mm aggregate is 208 litres. Hence we adopt an average quantity of water i.e. $\frac{186}{2} + \frac{208}{2} =$ **197 litres**.

D) Calculations of Cement Content For The Concrete Mix:-

Water/Cement ratio = 0.55

Cement content = (197 / 0.55) = 358.18 say 359 kg/m^3

From Table-3, minimum cement content for mild exposure condition = 300 kg/m^3.Our calculated cement content is 358.18 kg/m^3 i.e. more than 300 kg/m^3. Hence it is OK.

E) Proportion of Volume of Coarse Aggregate And Fine Aggregate Content:-

Table-4 Volume of Coarse Aggregate Per Unit Volume of Total Aggregate For Different Zone of Fine Aggregate (Table 4 of BIS: 10262-2009)

S. No.	Nominal Maximum Size Aggregate (mm)	Volume of Coarse Aggregate per unit Volume of total Aggregate for Different Zones of Fine Aggregate			
		Zone I	Zone II	Zone III	Zone IV
1	10	0.44	0.46	0.48	0.50
2	20	0.60	0.62	0.64	0.66
3	40	0.69	0.71	0.73	0.75

From Table-4, volume of coarse aggregate corresponding to 20 mm size aggregate and fine aggregate (Zone II) for water-cement ratio of 0.50 is 0.62. In our case W/C ratio is 0.55. Therefore, volume of coarse aggregate is required to be decreased to decrease the fine aggregate content. As water/cement ratio is higher by 0.05, the proportion of volume of coarse aggregate is decreased by 0.01 (at the rate of -\+ 0.01 for every +\- 0.05 change in W/C ratio). Therefore, corrected proportion of volume of coarse aggregates for 0.55 W/C ratio is 0.61.

Mix Design Calculations Results:-

Table-5 Proportion of Different Materials In Our Mix

Cement	Fine Aggregate	Coarse Aggregate	Water
359	730.89	1113.77	197 liters
1	2.036	3.102	0.55

Preparation of Trial Mixes:-

Based on the concrete mix design by Bureau of Indian Standard (BIS) method, four trials mixes were prepared. Two trials mixes were prepared with W/C ratio of 0.55 and other two mixes were prepared with W/C ratio of 0.50. The 6 cubes were casted for each mix and were tested at 7 and 28 days. The mix proportions for various constituents have been summarized in Table-6.

Table-6 Quantities Per Cubic Meter For Trial Mixes (M20)

Mix No.	W/C Ratio	Slump (mm)	Water (l/m^3)	Cement Kg/m^3	Sand Kg/m^3	Coarse Aggregate Kg/m^3	Average Cube Strength at 7 Days (MPa)	Average Cube Strength at 28 Days (MPa)
Mix-A	0.55	50	186	338	749.7	1142.4	15.30	25.48
Mix-B	0.55	100	197	359	730.89	1113.77	15.50	26.75
Mix-C	0.50	50	186	372	724.6	1143.4	14.45	24.55
Mix-D	0.50	100	197	394	700.8	1113.9	14.98	25.90

The Mix-B was selected as the design mix because its average cube strength is very close to the target mean strength of the concrete with appropriate content of cement among all the mixes.

Prepared Mixes For Testing of The Compressive Strength:-

We prepared the various mixes of concrete for the testing of compressive strength with the variable percentage of supplementary cementitious material i.e. (5%, 10% and 15%) of Meta-kaoline, Silica Fume, Fly Ash and Rice Husk Ash.

Table-7 Prepared Mixes for Tests of Compressive Strength of Concrete with Meta-kaoline

Mix No.	W/C Ratio	Meta-kaoline Content in % of Cement Wt	Water (l/m^3)	Cement Kg/m^3	Sand Kg/m^3	Coarse Aggregate Kg/m^3
Mix-I	0.55	5 %	197	359	730.89	1113.77
Mix-II	0.55	10 %	197	359	730.89	1113.77
Mix-III	0.55	15 %	197	359	730.89	1113.77

Table-8 Prepared Mixes for Tests of Compressive Strength of Concrete with Silica Fume

Mix No.	W/C Ratio	Silica Fume Content in % of Cement Wt	Water (l/m^3)	Cement Kg/m^3	Sand Kg/m^3	Coarse Aggregate Kg/m^3
Mix-I	0.55	5 %	197	359	730.89	1113.77
Mix-II	0.55	10 %	197	359	730.89	1113.77
Mix-III	0.55	15 %	197	359	730.89	1113.77

Table-9 Prepared Mixes For Tests of Compressive Strength of Concrete with Fly-Ash

Mix No.	W/C Ratio	Fly-Ash Content in % of Cement Wt	Water (l/m^3)	Cement Kg/m^3	Sand Kg/m^3	Coarse Aggregate Kg/m^3
Mix-I	0.55	5 %	197	359	730.89	1113.77
Mix-II	0.55	10 %	197	359	730.89	1113.77
Mix-III	0.55	15 %	197	359	730.89	1113.77

Table-10 Prepared Mixes for Tests of Compressive Strength of Concrete with RHA

Mix No.	W/C Ratio	RHA Content in % of Cement Wt	Water (l/m^3)	Cement Kg/m^3	Sand Kg/m^3	Coarse Aggregate Kg/m^3
Mix-I	0.55	5 %	197	359	730.89	1113.77
Mix-II	0.55	10 %	197	359	730.89	1113.77
Mix-III	0.55	15 %	197	359	730.89	1113.77

V. EXPERIMENT RESULTS AND DISCUSSION

1) Workability Test Results:-

After performing the number of slump cone tests on the prepared mixes with variable percentage of supplementary cementitious materials are mentioned below. The workability of cement concrete test results indicates a slight decreasing trend of workability when the percentage of supplementary cementitious increased. Table-5.1, Table-5.2, Table-5.3 and Table-5.4 shows the average slump recorded during the test.

Table-11 Slump Cone Test Results with Meta-kaoline

% Content of Meta-kaoline in the Concrete mix	Slump (mm)
5	95
10	95
15	90

Table-12 Slump Cone Test Results with Silica Fume

% Content of Silica Fume in the Concrete mix	Slump (mm)
5	95
10	90
15	90

Table-13 Slump Cone Test Results with Fly Ash

% Content of Fly Ash in the Concrete mix	Slump (mm)
5	90
10	85
15	85

Table-14 Slump Cone Test Results with RHA

% Content of RHA in the Concrete mix	Slump (mm)
5	90
10	80
15	80

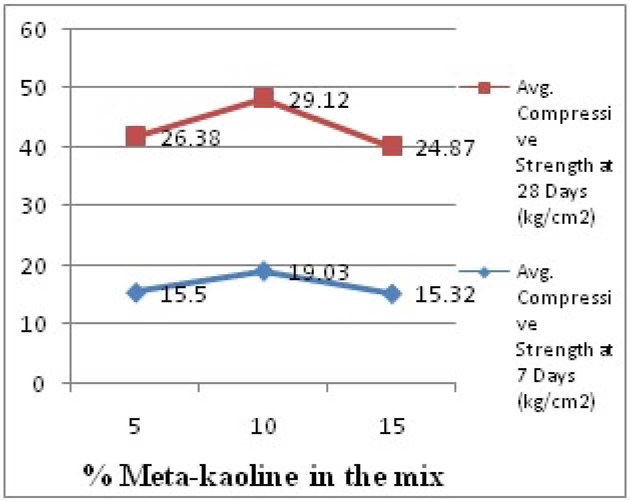
2) Compressive Strength of HPC:-

The compressive strength of all the prepared mixes was determined at the ages of 7 days and 28 days for the various replacement levels of Meta-kaoline, Silica Fume, Fly Ash and Rice Husk Ash with cement concrete. The values of average compressive strength for different mixes prepared by replacement of cement by supplementary cementitious materials in the range 5 %, 10% and 15 % at the completion of different curing periods (7 days and 28 days) are given in the various Tables below.

Table-15 Combine Table for Compressive Strength of HPC with Meta-kaoline

S. No.	Meta-kaoline (%)	Avg. Compressive Strength at 7 Days (kg/cm^2)	Avg. Compressive Strength at 28 Days (kg/cm^2)
1	5	15.50	26.38
2	10	19.03	29.12
3	15	15.32	24.87

By these test results we can say that the compressive strength of HPC can be increased up to approximately 9 % by replacing cement with 10 % Meta-kaoline as compared conventional concrete mixture.

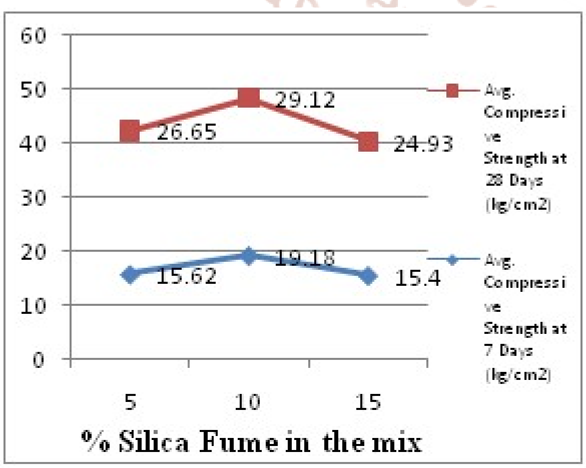


Graph-1 Combine Graph for Compressive Strength of HPC with Meta-kaoline

Table-16 Combine Table for Compressive Strength of HPC with Silica Fume

S. No.	Silica Fume (%)	Avg. Compressive Strength at 7 Days (kg/cm^2)	Avg. Compressive Strength at 28 Days (kg/cm^2)
1	5	15.62	26.65
2	10	19.18	29.12
3	15	15.40	24.93

By these test results we can say that the compressive strength of HPC can be increased up to approximately 9 % by replacing cement with 10 % Silica Fume as compared conventional concrete mixture.

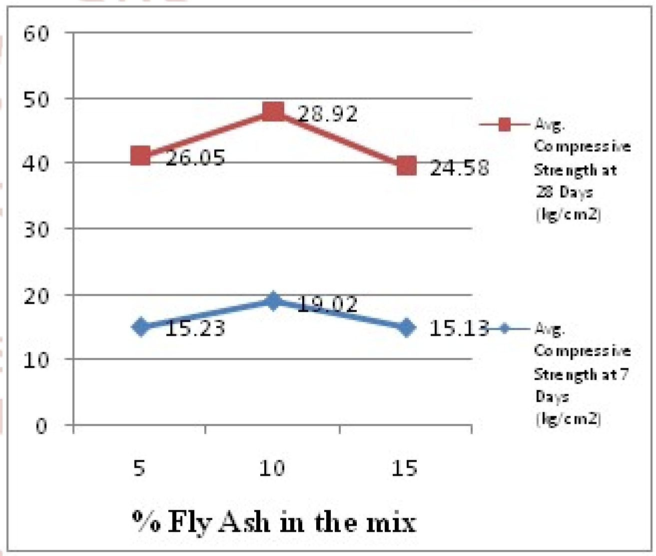


Graph-2 Combine Table for Compressive Strength of HPC with Silica Fume

Table-17 Combine Table for Compressive Strength of HPC with Fly Ash

S. No.	Fly Ash Content (%)	Avg. Compressive Strength at 7 Days (kg/cm^2)	Avg. Compressive Strength at 28 Days (kg/cm^2)
1	5	15.23	26.05
2	10	19.02	28.92
3	15	15.13	24.58

By these test results we can say that the compressive strength of HPC can be increased up to approximately 9 % by replacing cement with 10 % Fly Ash as compared conventional concrete mixture.

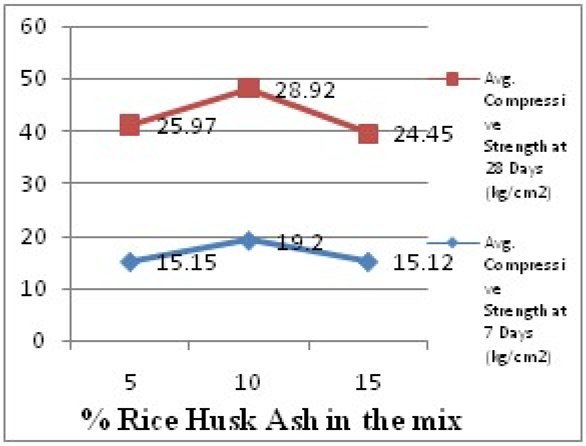


Graph-3 Combine Graph for Compressive Strength of HPC with Fly Ash

Table-18 Combine Table for Compressive Strength of HPC with RHA

S. No.	RHA Content (%)	Avg. Compressive Strength at 7 Days (kg/cm^2)	Avg. Compressive Strength at 28 Days (kg/cm^2)
1	5	15.15	25.97
2	10	19.20	28.92
3	15	15.12	24.45

By these test results we can say that the compressive strength of HPC can be increased up to approximately 8 % by replacing cement with 10 % RHA as compared conventional concrete mixture.



Graph-4 Combine Graph for Compressive Strength of HPC with RHA

increases the strength of concrete mix for all curing ages up to a certain point. After that there is an abrupt reduction in the compressive strength of the High performance Concrete (HPC), because at higher dosage of SCMs, concrete loses its ability to make a proper bond between the all ingredients of concrete.

4. The concrete mix which was prepared with the replacement of cement by Meta-kaoline, Silica Fume, Fly Ash and Rice Husk Ash (RHA) in the range 10 % with 0.55 W/C ratio posses the maximum compressive as well as good workability. Therefore this mix is recommended for maximum compressive strength.

VI. CONCLUSION AND RECOMMENDATION FOR FUTURE WORK

A) Conclusion

After the detail analysis and consideration of the test results we surely can say that the replacement of cement by supplementary cementitious material (SCM) in our case Meta-kaoline, Silica Fume, Fly Ash and Rice Husk Ash (RHA) significantly affects the 7 days and 28 days compressive strength of the High Performance Concrete (HPC). From the significant difference, it can be evidently seen that the replacement of cement by supplementary cementitious material (SCM) in certain amount i. e. 10 % of the weight of cement increases the compressive strength up to 8 % to 10 % approximately than conventional concrete specimen. Experimental test results also show the similar trend. Hence, the results of the statistical analysis are equivalent to the experimental results. From the experimental investigation this research work can be concluded as follows:-

1. The replacement of cement by Meta-kaoline, Silica Fume, Fly Ash and Rice Husk Ash (RHA) does not affect very much the workability of the cement concrete mixture.
2. The gradual increase seen in the compressive strength of High Performance Concrete (HPC) at the 7 days and 28 days curing age with 5 % and 10 % replacement of cement by Meta-kaoline, Silica Fume, Fly Ash and Rice Husk Ash (RHA) but after that it starts reducing the compressive strength with increase of the replacement level.
3. The replacement of cement by Meta-kaoline, Silica Fume, Fly Ash and Rice Husk Ash (RHA)

B) Recommendation for future work

Further researches and investigations were highly recommended and should be carried out to understand more mechanical properties of High Performance Concrete. Several recommendations for future studies in this field are mentioned below:-

1. Furthermore investigations and laboratory testing should be done to study on the various mechanical properties of High Performance Concrete (HPC). Such application of these supplementary cementitious materials was recommended in testing on concrete slabs, beams and walls.
2. Conducting more tests such as abrasion value, shear test, impact value, blasting or creeping of concrete on theses concrete mixes.
3. The combination of two or more supplementary cementitious materials may tend to provide more efficient mechanical properties of a structure, so further investigation can be carried out by the combination of different types supplementary cementitious material into the concrete mixture.
4. The mechanical properties of High Performance Concrete may be different in various temperatures. So the tests on freeze-thawing conditions were recommended for future study.
5. The effect of various admixtures on the properties of High Performance Concrete can also be checked in future.

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