A major project report
on

Production and Utilisation of Rice Husk Ash in Concrete and its Comparison with Silica Fume

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Master of Technology
in
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(Structure Engineering)

under the supervision of
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CANDIDATE'S DECLARATION

I do hereby certify that the work presented in this report entitled "**Production and Utilisation of Rice Husk Ash in Concrete and its Comparison with Silica Fume**" in partial fulfilment of the curriculum of fourth semester of Master of Technology in Structural Engineering, submitted in the Department of Civil Engineering, DTU is an authentic record of my own work under the supervision of Dr. Awadhesh Kumar, Associate Professor Department of Civil Engineering.

I have not submitted this matter for the award of any other degree or diploma.

Date: July 18, 2014

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

In this report, the detailed experimental investigation was done to study the effect of partial replacement of cement by Rice Husk Ash (RHA) and silica fume (SF) in various proportions starting from 15% RHA to 30% RHA and 5% SF to 10% SF. The tests on hardened concrete were destructive in nature which includes compressive strength test on cube of size (150 x 150 x 150 mm) at 7,28,56 and 90 days of curing as per IS: 516 1959, Flexural strength tests on beams of size (100 x 100 x 500 mm) at 7,28,56,90 days of curing as per IS:516 1959 , compressive strength test on cylinders of size (150 mm ø x 300mm height) at 7,28,56,90 days of curing as per IS: 516 1959 and Drop weight impact test on disc of sizes (150 mm ø x 60mm) as per ACI 544. The work presented in this report reveals the effects on the behaviour of concrete produced from cement with combination of SF and RHA at different proportions on the mechanical properties of concrete such as compressive strength, flexural strength, and impact strength. From this study it is found that 25% replacement of RHA and 7.5% replacement of cement with SF are the optimum level of replacement.

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Chapter 1
Introduction

1.1 High-Performance Concrete (HPC)

Despite its wide spread use now in the developed countries, it has been difficult to define high-performance concrete (HPC) in a unified way and no simple and consensus definition exits to date. American Concrete Institute (ACI) defines HPC as the concrete that meets special performance and uniformity requirements that may not always be obtained using conventional ingredients, normal mixing procedures and typical curing practices [1] and these requirements may include enhancement of ease of placement without segregation, long term mechanical properties, early age strength, toughness, volume stability and life in severe environments. Brandt reports that HPC is the one, which gives 28 days compressive strength greater than, or equal to 60 MPa and very high performance concrete (VHPC) has 28 days compressive strength in the range of 120 MPa or greater [2]. He states that HPC differs from ordinary concrete in terms of high strength, lower W/C, increased fractions of fine and very fine grains and use of super plasticizer (SP) to get higher flow of around 180-250 mm slump with the retention time of 1-1.5 hours and smaller fraction of coarse aggregates and smaller maximum grain dimensions. Similarly there are numerous definitions of HPC coined by various practitioners.

1.2 Criterion of HPC

Enhancement of ease of placement without segregation has been considered as the criterion of high performance of the cementitious systems in this thesis. Ease of placement without segregation is a special characteristic of self-compacting cementitious systems (SCCS) which do not require any mechanical vibration fort their compaction. It is a desirable feature of concrete in heavily reinforced sections. This is why that many research papers call self- compacting concrete (SCC) as high performance concrete [3, 4, 5, and 6]. Because of the importance of the role of the paste component on the overall response of mortars and concretes, the response of HP self-compacting paste (SCP) systems was studied in detail in order to start the research work. These are the one component primary cementitious systems and it is very well known that the mechanical properties, volume stability and durability of mortars and concretes depends to a great extent on the durability of their paste component. Durable or high performance paste components systems are obtained by incorporating secondary raw materials.

1.3 Advantages of Using Secondary raw materials (SRM's)

The use of supplementary cementing materials can significantly improve the transport properties and durability of concrete. However different dosages and combinations of supplementary cementing materials can yield dramatically different response [7].The use of SRM's in concrete may bring lots of benefits like reduced water demand (WD), increased flow and strength and reduced shrinkages etc. but some problems may also be caused. One has to be careful regarding the selection of type and amount of SRM's to be used in an application. The uniformity of these materials may be questionable in some cases [8]. The effects of fly ash, and, to a lesser degree, that of slag and condensed silica fume on the properties are well documented. In general SRM's have both positive and at times negative effects on water demand(WD), temperature rise, strength development, freeze-thaw resistance, chemical attack resistance, alkali-silica reaction, alkali- carbonate reaction control[8]. They also have effect on volume stability and microstructure etc. necessitating their careful selection for an application. With continuously graded aggregates, the use of SRM's in the presence of super-plasticizer usually results in minimizing the voids, paste and hence the cement requirement. They also add to the stability of the system. This could result in increased economy, high performance and increased durability.

1.4 Advantages of HPC

High performance concrete offers many advantages. Some of these are as follows:

- Requires fewer laborers for transport and placement of concrete, and thus becomes more economical.
- Reduces the volume of excavation and shoring involved in foundation trenches.
- Saves a large quantity of concrete due to the reduced section of structural

components.

- Provides good finishing without any surface pores and improves the aesthetical appearance of concrete.
- Results in greater strength due to enhanced compactness and reduced porosity.
- Confers high early strength, allows a quicker reuse of formwork, and thus enhances the production rate.
- Imparts improved water-tightness, and thus offers reduced transport properties and enhanced durability.

1.5 Need of the research

Rice milling generates a by-product known as husk. This surrounds the paddy grain. 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. 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 kg of paddy milled, about 220 kg (22 %) of husk is produced and when this husk is burnt in the boilers, about 55 kg (25 %) of RHA is generated.

India is a major rice producing country, and the husk generated during milling is mostly used as a fuel in the boilers for processing paddy, producing energy through direct combustion and / or by gasification. Due to the low nutritional properties of rice-husk, it is not appropriate for use as a feed for animals. Moreover, its siliceous composition is resistant to natural degradation, which can produce a large environmental load. About 20 million tons of RHA is produced annually .This RHA is a great environment threat causing damage to the land and the surrounding area in which it is dumped. Lots of ways are being thought of for disposing them by making commercial use of this RHA. Earlier this RHA was used in landfills. The use of RHA decreases the demand for cement in the construction industry, reduces the cost of concrete production, and reduces the negative environmental impact that CO_2 emissions represent in the production of cement. The world data of milled production of rice is given in table 1.1.

Table1.1 Milled production of Rice (Quantity in 1000 MT) [11]

Countries	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14May
Brazil	8570	7929	9300	7888	8160	8500
Burma	11200	11642	10528	10816	10666	11000
Cambodia	3992	4056	4233	4268	4600	4900
China	134330	136570	137000	140700	143000	144000
Egypt	4673	4564	3100	4250	4675	4850
India	**99180**	**89090**	**95980**	**105310**	**104000**	**108000**
Indonesia	38310	36370	35500	36500	37500	37700
Japan	8029	7711	7720	7646	7756	7720
Korea South	4843	4916	4295	4224	4006	4220
Nigeria	2632	2234	2818	2877	2370	3100
Pakistan	6900	6800	5000	6200	6000	6200
Philippines	10755	9772	10539	10700	11350	11700
Thailand	19850	20260	20262	20460	20200	21100
Vietnam	24393	24993	26371	27152	27650	27850
Others	33298	35598	37360	37251	37952	38183
Subtotal	442155	433505	441706	459942	463885	473223
United States	6546	7133	7593	5866	6334	6038
World Total	448701	440638	449299	465808	470219	479261

1.6 Objective of the project

In some papers it has been published that the Rice husk ash is used only up to 70 MPa but they have also published that it depends on the burning condition of the Rice husk and on the quality of rice Husk. The silica content of the RHA is dependent on the burning condition. The more will be the silica content; the better will be RHA. In this report RHA having silica content of 94% is produced.

The particular aim of this project is to investigate the possibility of using RHA to produce HPC. With this aim, the research focuses on the following aspects:

- Production of high silica content RHA with minimum cost.

- Development of high strength concrete with RHA.
- Development of high strength concrete with silica fume.
- To carry out economic feasibility study.
- To look into the possibility of using rice-husk ash (RHA), as a suitable replacement of silica fume (SF) in HSC.

1.7 Scope of the Report

The contents of the report are given in six chapters.

- Chapter 1 introduces HPC with a short overview of the present research and gives the research objectives and briefly presents the scope of the report.

- Chapter 2 presents a background of HPC, highlights the major issues of HPC, describes various constituent materials of HPC including their key aspects and identifies several research needs

- Chapter 3 gives an overview of the research program and procedures for experimental investigation, testing of materials and mixture design.

- Chapter 4 gives the test conducted on concrete and their results.

- Chapter 5 gives the discussion on the results supported by some of the photographs throughout the project work.

- Chapter 6 gives the conclusion of the research work carried out and scope of future work

Chapter 2
Literature review

2.1 Historical Development

In early 1940's concrete strength at construction sites was around 25 MPa which rose to about 34 MPa in 1950's. In the early 1970's, experts predicted that the practical limit of ready mixed concrete would be unlikely to exceed a compressive strength greater than 43 MPa. The compressive strength of concrete largely depends on the water-cement ratio and the degree of internal packing as reflected by porosity of the system. Porosities could be minimized by continuous grading of aggregate as well as of binder phases which required large amounts of fines and hence higher water demand (higher w/c ratios) resulting in lower strength and reduced durability. Lower concrete strength also meant larger sizes of horizontal (beams and slabs) and vertical (columns and shafts) structural systems for a given load and this was not acceptable for certain functional requirements of a high-rise structure. For a given allowable bearing capacity of the supporting foundation system, increased dead loads mean reduced occupancy loads and hence reduced number of stories of a high rise building. However after the invention of super plasticizers in Germany and Japan in early 1980's the water-cement ratios could be reduced even with considerable and essential fine powder incorporations in HPC.

It can be seen that increased concrete strength is more effective in reducing the column sizes than reducing the sizes of horizontal structural sub-systems. In practice higher concrete strength is specified for columns than for beams and slabs in a high rise structure.

Increased concrete strength without durability is not very desirable and is a waste of costly materials. Steps must be taken to enhance the durability of concrete. Various options are available including the use of SP, low w/c ratio and using suitable fillers. In fact pozzolanic fillers along with SP and low w/c ratio are the hallmarks of HPC systems. In HPC high amounts of fine fillers and super plasticizers are essentially used for meeting the desired workability, strength and durability requirements. This minimizes the fluid transport within concrete mass and would result in higher strength as well. It was therefore decided to have an improved microstructure of cementitious systems by the joint application of SP and fillers in the investigations reported herein. The fillers with pozzolanic properties were found more efficient. In the lines to follow these items are discussed. [11]

2.2 Basic Information on SRM's used in HPC

The environmental aspects involved in the production and use of cement, concrete and other building materials are of tremendous importance. The manufacture of Portland cement is a highly energy intensive and environment unfriendly process requiring about 4 G J of energy per ton of the finished product in addition to producing 0.8-1.3 ton of CO_2 per ton of cement produced. In an energy hungry world, considerable efforts are being made to find substitutes of cement which are called secondary raw materials (SRM's), supplementary cementitious materials or sometimes waste materials in the literature. But calling them waste material does not sounds appropriate. These SRM's are used to replace a part of cement, an expensive material in ready mixed concrete in mortars and concretes. Reduction of cement translates into reduced shrinkage and heat of hydration. [12] These SRM's are industrial by-products that are easily available, require little or no pyro-processing, and have inherent or latent cementitious properties. Use of Fly Ash in concrete is on increase. SRM's used in this research work included SF and RHA.

Fillers are generally added to HPC systems to reduce water demand, to increase paste volume and stability, to improve finished surface, to improve pumping etc. and to reduce shrinkage. Appropriate choice of the filler is very important for the material engineer at the site for a given placement. Kronlof [13] states that traditionally, very fine particles were believed to increase the water requirement of concrete and therefore harmful to concrete. Mathematical particle packing theories, however, show the opposite. In concrete fine powder particles comprising binder and mineral powders (MP) fill the spaces between aggregate particles. The space remaining between fine powder particles is then filled with water and to a lesser extent with air also. For workability some excess water is needed for particle mobility. The role of plasticizers and super plasticizers is to disperse the particles into spaces within their size range. In mixes without plasticizer, fine particles are flocculated and cannot fill spaces of their own class size, which is why they often require more water. The first condition that must be met for high density is the use of super plasticizers to break flocculation and hence achieve uniform packing.

Crushed aggregate particles are irregular in shape and pack more poorly together than naturally formed gravel. The space between them being comparatively large requires more water and cement to meet workability and strength requirements. In order to reduce cement quantity mineral powders (MP) looks like a possible solution. The function of MP particles derives from their filler and binder effects and for this, the particles have to be extremely fine. In practice MP's are mainly industrial bye-products. The filler effect includes particle packing and involvement in chemical reactions as nucleation sites. The binder effect results from reaction products of true chemical hydration and pozzolanic reactions. However separating these while researching chemically reactive particles is extremely difficult.

It has been suggested that the moduli of elasticity of rocks is the controlling factor of the modulus of elasticity of resulting concrete. In other words, concrete with higher modulus is only obtained with rocks of higher modulus from which aggregates are made. The increase of 172.5% in the modulus of elasticity of rocks may result in corresponding 48% increase in the modulus of elasticity of concrete [14].

2.3 Role of SRM's in Strength Enhancement

Inert and pozzolanic mineral admixtures modify the physical and chemical properties of mortars and concretes and the compressive strengths can be separated into fractions of strength related to physical and chemical effects of mineral admixtures. When mineral admixtures are added, three effects can be quantified including, dilution, heterogeneous nucleation (physical) and pozzolanic reaction (chemical) depending on the amount and solubility of amorphous silica. Heterogeneous nucleation is a physical process leading to a chemical activation of hydration of cement such that mineral admixture particles act as nucleation centers for the hydrates thus enhancing cement hydration. A smaller amount of powder has an optimum efficiency and results in a large increase in compressive strength while the use of large amount of powder has a smaller effect [12]. Incorporation of FA in cement based materials generally reduces the water demand, increases the setting times and reduces the early shrinkage due to the delayed hydration. Packing effect is dominant for FA systems during 3-28 days [14] and pozzolanic effect becomes more pronounced thereafter and that the pozzolanic reaction of FA decreases with increase in its particle size. Quantification of SF in concrete systems has shown that up to an age of 7 days, physical effects contribute to the compressive strength while beyond that chemical effects become significant [15]. Increase in the strength of a cementitious system brought about by the inclusion of amorphous RHA in a replacement mode is due to its packing effect, pore refinement effect, reduction of effective w/c ratio due to absorption of water in internal porosity of RHA particles, improvement of cement hydration and to the pozzolanic reaction between silica and $Ca(OH)_2$ [16]. By virtue of its reduced pozzolanic activity, crystalline RHA shows lesser strength enhancement than amorphous RHA and its filler effect dominates the pozzolanic one.

2.4 Super plasticizers

Super plasticizers (SP) are chemical admixtures which increase the workability of cementitious systems at low mixing water contents and are therefore considered to be essential for durability of structures made with HPC. By the addition of super plasticizer, the cementitious material is dispersed into small pieces. Concrete pumping is also very much facilitated by using super plasticizers because it decreases the friction at the interface of pipe and pumped concrete. They can however, show greater slump loss at times especially if the mixing water content is less than the water demand of the system or due to incompatibility problems. The HRWRs improve the flowing ability of HPC by their liquefying and dispersing actions. They reduce the yield stress and plastic viscosity of concrete by their liquefying action [17], and thus provide a good flowing ability in HPC. In addition, the HRWRs deflocculate the cement particles and free the trapped water by their dispersing action [18], and hence enhance the flowing ability of concrete. In dispersing action, the inter-particle friction and thus the flow resistance are also decreased; therefore the flowing ability of concrete is improved.

By definition an admixture influences the properties of fresh and/or hardened cementitious systems and is generally added during the mixing process. Both HPC and SCC are characterized by a dense particle packing, a high or medium amount of powder and low water-cement (w/c) or water-binder (w/b) ratio (0.3) to increase flow, to reduce heat of hydration and shrinkage especially at early ages. The type of powder to be employed for a given application should be carefully selected considering the advantages/disadvantages it brings with it.

High-range water reducers can either increase the strength by lowering the quantity of mixing water for a given flowing ability, or reduce both cement and water contents to achieve a given strength and flowing ability [19]. There are mainly four categories of HRWR [20, 21].They are sulfonated melamine formaldehyde condensates, sulfonated naphthalene formaldehyde condensates, modified lignosulfonates, and carboxylated acrylic ester copolymers or polycarboxylates.

2.4.1 Physical properties

High-range water reducers are generally formulated to produce high plasticity, normal- setting characteristics, and accelerated strengths in concrete. HRWRs are usually available in clear to dark brown liquid form but also obtainable in solid state as a brownish powder. They usually possess a viscosity in the range of 60 to 80 centipoises, and a solid content varying from 22 to 42% by weight [22]. Also, the relative density of HRWR is near to that of water and hence it can be easily dispersed with water.

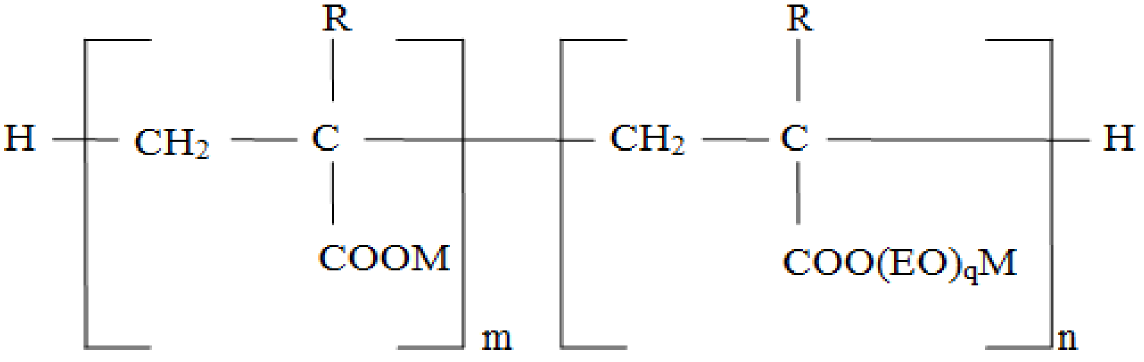
A particular type of HRWR can be used as a singular admixture or as a component in an admixture system, but it must fulfill some physical requirements and should be compatible with cementing materials for good performance in concrete. The IS: 9103, 1999 code has specified some physical requirements for HRWR [23].

2.4.2 Chemical structure

Polycarboxylate HRWRs are generally used to produce HPC. They are produced from the relevant monomers by a free radical mechanism. The molecular structure of polycarboxylate HRWRs consists of a main chain and a graft chain. The main chain contains carboxylate groups (COO-) while the graft chain comprises ethylene oxide (EO). The chemical structure of polycarboxylate HRWRs is shown in Figure 2.1.

2.4.3 Mechanisms of water reduction

High-range water reducers prevent the formation of cement-water agglomeration in concrete mixture and disperse the cement particles in aqueous phase, as can be seen from Figure 2.2 and 2.3. Thus, the water demand of concrete mixture is significantly reduced. HRWRs can exert the water-reducing action by two mechanisms, known as electrical and steric repulsions.



$$\mathrm{H}-\left[\mathrm{CH_2}-\underset{\mathrm{COOM}}{\overset{\mathrm{R}}{\mathrm{C}}}\right]_m-\left[\mathrm{CH_2}-\underset{\mathrm{COO(EO)_qM}}{\overset{\mathrm{R}}{\mathrm{C}}}\right]_n-\mathrm{H}$$

R = H, CH_3
M = Metal
EO = Ethylene oxide

Figure 2. 1 Chemical structure of Polycarboxylate based HRWR [24]

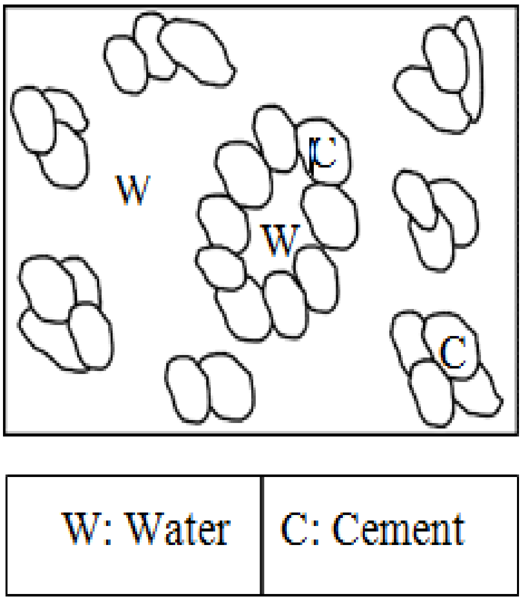


Figure 2.2: Cement-water agglomeration in absence of HRWR

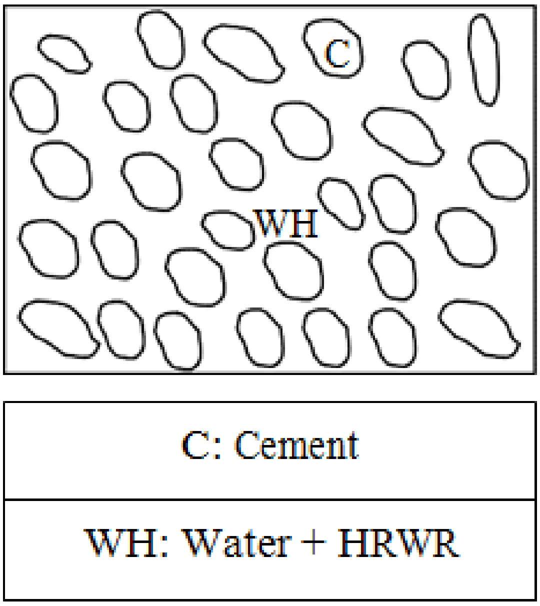


Figure 2.3: Dispersion of cement particles in presence of HRWR

2.5 Production of SRM's

2.5.1 Rice-Husk Ash (RHA)

Like many other countries, rice is the most important food grain in India after wheat. Its Basmati quality is world famous and has become one of the main export items over the years. Basmati rice has various classes but in general it is an expensive rice quality liked for its aroma, flavor and taste the world over. Rice husk is the outer covering part of the rice kernel and consists of two interlocking halves. It is removed from the rice grain because husk is not edible. Rice husk is a by-product of the process of obtaining rice grain. Bulk of the husk is disposed of by setting it on fire in fields (which creates environment related issues) although small quantities are used as a low-grade fuel in brick kilns and in low-pressure steam generation etc. In the developed world, husk is used to produce electricity through steam generation and resulting ash is used as a value added product in making HPC. Table 2.1 gives the physical properties of the rice-husk.

Table 2. 1 Physical Properties of Rice Husk [25-26]

Parameter	Nature Value
Color	Golden
Length	4.5 mm (average)
Hardness	6 Mohr's Scale
Density (Bulk)	96-160 kg/m^3
Thermal Conductivity	3.3 K Cal-cm/g m^2/° C
Angle of repose	35^0 (ungrounded)
Fuel value	2800-3700 K-cal/kg

2.5.2 Nature of Rice Husk

Rice husk is composed of both organic and inorganic matter. Organic matter consists of cellulose, lignin, hemi cellulose and some proteins and vitamins while the major component of inorganic mineral is silica. The actual composition of rice husk varies with the type of paddy, inclusion of bran and broken rice in husk, geographical factors, crop season, sample preparation and relative humidity etc. [25-26]. Moisture content of rice husk is about 9% at corresponding relative humidity of air less than

50%.Yoshida et al [27] state that silicon component is taken up from soil by roots of plant as mono-silicic acid. This soluble silica moves to outer surfaces of plant where it eventually polymerizes to form a cellulose-silica membrane. The organic matter decomposes during combustion of the rice husk and residue is ash rich in silica.

2.5.3 Composition of RHA

Rice husk has a cellular structure. On combustion, the cellulose-lignin matrix of rice husk burns away leaving behind a porous silica skeleton with extremely small domains of 3-120 nm in size [28]. This structure would yield very fine particles if ash were ground. The highly porous structure of ash gives rise to a large surface area, which is mostly internal, depending strongly on burning regime parameters like temperature, its duration and environment. James and Rao [29] have reported changes in surface area with temperature and its duration. They state that at 500^0C, the surface area reached a maximum value of $170m^2/g$. Within $500\text{-}600^0$C, the surface area decreased but actual values remained quite high ($100\text{-}150m^2/g$).

Ibrahim et al [30-31] boiled the rice husk with water, washed it and then dried. For a constant burning time of 3 hours, the surface area was found to increase from 200 to 274 m^2/g on heating husk from 500 to 600^0C. Beyond 600^0C, the surface area and total pore volume decreased with increasing temperature of thermal treatment.

Treatment with diluted HCl acid before burning the husks was reported to be very effective for obtaining ashes with a large internal surface area [28, 32]. The surface area of an ash sample produced by burning the acid treated husks at temperature 600^0C for 3 hours under inert atmosphere, followed by the combustion of residue carbon in oxygen atmosphere was found to be $260m^2/g$ [30]. Liou and Chang [32] have reported a surface area of $261m^2/g$ for an ash sample obtained by burning acid-treated husks at temperature of 900^0C for an hour. Various researchers have suggested a variety of burning regimes for producing high surface area ash.

2.5.4 Rice-Husk Combustion

Fluidized bed reactors are reported to be very suitable for the utilization of heat value of rice-husks [33]. The reactors can be used either for combustion or for gasification of rice husk. Since the bed temperature can be kept below the crystallization temperature of silica, the ash produced is amorphous and hence highly reactive [34]. A research was undertaken in Delft/Vietnam by using ash produced in a drum type incinerator (burner) developed by PCSIR (Pakistan Council of Scientific and Industrial Research, Peshawar center [35-36] which was modified to increase its capacity to 1 m^3. The drum and detachable chimney of the incinerator were made from galvanized iron sheet. The incinerator is lightweight and can be easily carried by two persons. The fire is started from bottom using a small amount of waste papers or wood. The husks burn themselves once ignited. No control is required during burning process. The highest recorded temperature was 780^0C and the carbon contents were found to be 5% for 20 experimental runs.

Haxo and Mehta [37] argued that the porosity is the primary factor controlling the surface area of RHA. Un-burnt carbon particles are very porous; hence an ash sample with greater un-burnt carbon content will have higher internal surface area. Since the pore volume mainly controls the specific surface area of RHA, collapsing the pore structure will result in a decrease of the surface area. This would happen when particle size is reduced to a value similar to the average micro-pore spacing. The mean diameter of RHA particles burnt below 800^0C is about 50-60 µm. It can be expected that when particle size of the ash approaches 5-10f.m due to milling process, a noticeable drop in specific surface area will occur.

2.5.5 Role of Un-burnt Carbon in RHA

Since un-burnt carbon has a very large surface area, the water demand is higher for the ash samples with a higher un-burnt carbon content. A carbon rich ash is considered to be a pozzolanic material of lower quality because un-burnt carbon particles increase specific area and hence the water demand and this increase in carbon content decreases silica content [36]. A high LOI (loss on ignition) value needs a higher dosage of super plasticizers for a given level of workability.

2.5.6 RHA Reactivity

Reactivity and water demand are the two main parameters of RHA. The reactivity of RHA depends on the content of amorphous silica and on its porous structure. If porous structure gets minimized by milling process in an effort to reduce particle size, the reactivity decreases. The reactivity of RHA contributes to the strength of RHA containing cement based materials by pozzolanic reactions between silica and calcium hydroxide liberated during cement hydration process. These reactions produce additional amounts of CSH that makes denser microstructure of RHA containing cement based materials. The water demand depends on the specific surface area and pore volume. Since the un-burnt carbon has very high specific surface area due to its very porous particles, the water demand is higher for ash samples with higher un-burnt carbon content [36]. Compared with ash samples free of carbon, a carbon rich ash has lower pozzolanic reactivity due to two reasons. As mentioned earlier un-burnt carbon particles in RHA increase specific surface area which increases water demand and reduces the silica content of ash.

2.5.7 Hydration Mechanism of RHA Paste

The penetration resistance coincides with the growth of Calcium Hydroxide (CH) up to 8 hours and is similar to behavior of ordinary cement paste [38]. The formation of CH at the surface of RHA may be due to adsorption by cellular structure of RHA. In such case bleeding water will be significantly reduced especially in un-plasticized systems. The adsorbed water enhances the reaction inside the inner cellular spaces and results in significant strength gain. After the formation of CH, the pulse velocity increases rapidly. After 40 hours, the pozzolanic reaction further binds SiO_2 in RHA with CH to form CSH and solid structures. This mechanism gets changed in HPC due to the interaction of SP with the constituents of paste.

2.6 Silica Fume (SF)

The Interest in the use of silica fume (SF) started with the strict enforcement of air pollution controls in many developed countries due to which Ferro-silicon industry had to stop releasing silica fume along with other flue gases into the atmosphere. SF is an industrial by-product mainly from Ferro-silicon producing industries during reduction of high purity quartz with coal or coke in an electrical arc furnace during reduction of silicon metal or Ferro-silicon alloy. The SiO_2 content of SF is highly dependent on the type of alloy product [39].The Silica Content of SF in Different Alloy Making Industries is given in table 2.2 [52]

SF comes in various forms including powder SF, slurried SF, densified SF and pelletized SF. SF generally produces filler and pozzolanic effects when added into cement based materials. The pozzolanic activity is due to the reaction between silica of

SF and the CH produced due to cement hydration

Table 2. 2 Silica Content of SF in Different Alloy Making Industries [52]

Alloy Type	SiO_2 Content of SF
50% Ferro-silicon	61-64%
75% Ferro-silicon	84-91%
98% silicon metal	87-98%

The transition zone, also sometimes known as interfacial transition zone (ITZ) is the inter-phase between aggregate and the hydrated cement paste. It is very important both from the view point of mechanical strength as well as durability. With the increase of w/c ratio, both the thickness of ITZ and the degree of orientation of CH crystals is increased due to internal bleeding. Addition of SF improves the microstructure in ITZ and also controls ASR if SF replacement level is 15% or more [39].

2.7 Comparative Hydration of SF - RHA Pastes

Although mortars and pastes using mineral admixtures have been routinely employed, cement paste systems with mineral admixtures have very rarely been investigated regarding their suitability for making high performance concrete (HPC) which has also been defined elsewhere[40] and its details are also given in the literature [2, 41]. In HPC, high powder content with low mixing water in the cementitious systems is generally the basic requirements. Such systems have high water demands which are generally reduced by using the third generation super plasticizers based on poly carboxylate ethers [19]. The comparative response of RHA and SF based cement pastes has been studied to look into the possibility of replacing silica fume (SF) by rice-husk ash (RHA) for making HPC/SCC especially in rice growing countries.

The most critical part in HPC lies in the paste [42] and the other aspects are rapid slump loss and plastic/chemical shrinkage. The particle size and surface area of these mineral admixtures are traditionally considered to be responsible for their higher water demands [43, 44]. Mixing also influences all the properties especially flow and rheology [45]. The mechanisms through which SF and RHA improve some of the properties of resulting concrete are still unclear. Some interactions have been postulated. These include densification of hydrating gel structure, filler action, pozzolanic action between silica rich SF particles and Portlandite, a by- product of cement hydration, resulting in pore size refinements with SF particles acting as nucleation sites for Portland cement hydration [46]. Traditional literature [47-48] would suggest that SF reacts readily with calcium hydroxide produced during early cement hydration. However Mitchell et al. [49] state that digestion of SF in calcium hydroxide solution for up-to 120 days showed it to persist in the form of agglomerates coated with amorphous calcium silicate hydrates. High surface area RHA is sometimes more pozzolanic than SF and its pozzolanic activity can still be further increased by treating husk with 1N HCL aqueous solution [50] so that about 50% of the lime reacts within first 24 hours. Almost similar improvements in concrete performance using RHA have been reported as those containing SF and these include improvement in workability with small RHA additions (<2-3% of cement mass), pore refinement due to filler action, resistance to acidic environment, indirect improved corrosion resistance through reduction in permeability [43], improved sulphate resistance, better freeze-thaw resistance than similar SF concrete [43] and higher compressive strengths.

Strengthening mechanisms suggested by Yu et al [52] include reduction in pore size, reduction of the effective w/c ratio of RHA concrete compared with control due to adsorption of a portion of free water in the great number of pores existing in RHA particles, improved cement hydration and more C-S-H gel formation in RHA concrete. Bui and Sugita's work [36, 51] provides more useful information on the topic.

2.8 Structural Applications

HPC is required in projects where the concrete has to resist high compressive loads. It is typically used in the erection of high-rise structures. It has been used in components such as columns (especially on lower floors where the loads will be greatest), shear walls, and foundations. High strengths are also occasionally used in bridge applications as well.

In high-rise structures, HPC has been successfully used in many U.S. cities. A high-rise structure suitable for high-strength concrete use is considered to be a structure over 30 stories. Not only has special concrete made such projects feasible due to load capacity, it has also allowed for the reduction of column and beam dimensions. Lower dead loads result, reducing the loads associated with foundation design. Also, owners benefit economically since the amount of rentable floor space, primarily on the lower floors, increases as the space occupied by the columns decreases. It is estimated that a 50-story structure with 1.2 m diameter columns using 40 MPa concrete can reduce column diameters by approximately 33% by using 80 MPa concrete.

High –strength concrete is occasionally used in the construction of highway bridges. High-strength concrete permits reinforced or pre-stressed concrete girders to span greater lengths than normal strength concrete girders. Also, the greater individual girder capacities may enable a decrease in the number of girders required. Thus, an economical advantage is created for concrete producers in that concrete is promoted for use in a particular bridge project as opposed to steel.

Chapter 3
Selection of material and their characteristic

3.1 General

This chapter deals with the selection and testing of constituent materials for the concretes used in the present research work. The physical characteristics of the constituent materials of concretes, the results of sieve analyses for coarse aggregate and sand (fine aggregates), and the specific gravity and particle size analyses of cement and rice husk ash (RHA) are presented and discussed in this chapter. In addition, this chapter discusses the usefulness of the properties of constituent materials and aggregate

3.2 Production of RHA

The rice husk required to make the RHA is brought from a rice mill situated at Gohad, district Bhind of Madhya Pradesh. RHA has been produced in the lab in a burner which is made for this purpose. Initially three samples were prepared by different methods and then they were used in concrete for the research work.

3.2.1 Preparation of burner

The burner (shown in figure 3.1 and 3.2) which is used in the production of RHA is made in the central workshop of Delhi Technological University under experts guidance. The main problem in producing active silica from rice-husks is to burn them at an appropriate temperature. For this purpose a small basket is placed concentrically inside the larger one. The reason of placing small basket concentrically inside the larger one is that the small basket allows for a more even combustion with sufficient access for air. The larger basket is about 600 mm in diameter and about 900 mm high. The inner basket is of 250 mm diameter and 750 mm high as shown in figure 3.3.

Both baskets are conveniently made from steel mesh having about 5-6 mm spacing. The longitudinal bars of the skeleton of the burner is made of 10 mm diameter and circular rings are made up of 6 mm diameter The Rice husk is burnt at about 600^0

to 800^0C to stop the silica forming inactive crystals and to obtain amorphous silica. But it is also necessary to burn them for long enough so that all the cellulose burns away and leaves a white or grey- color ash. The use of a simple basket-burner ensures that these conditions will occur (Figure.3.1).

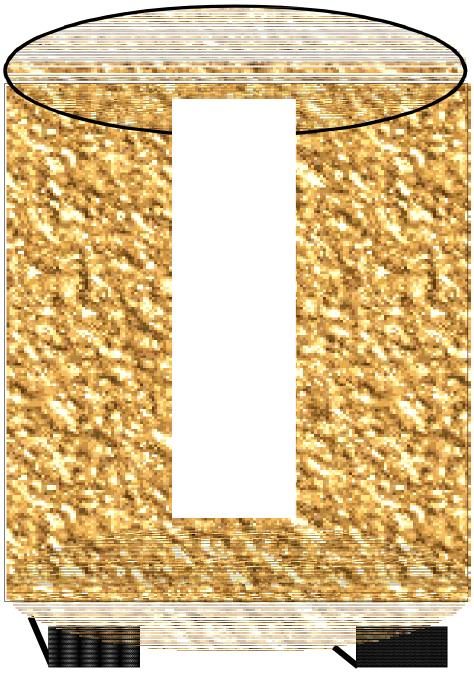


Figure 3.1 Diagram of a burner

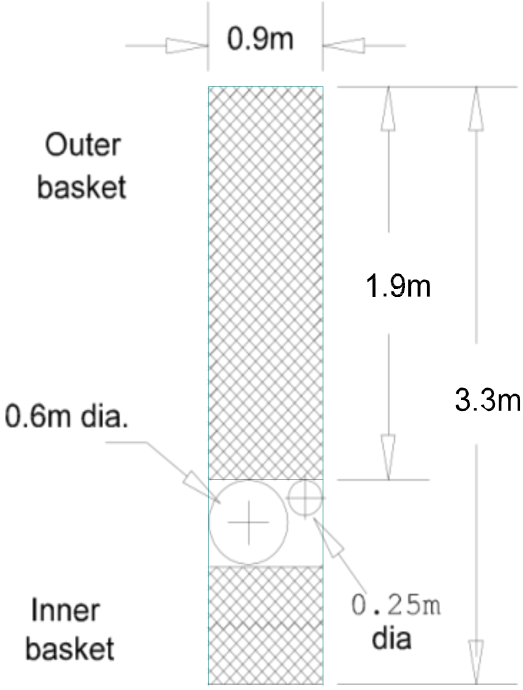


Figure 3.2 Schematic plan of cutting mesh

3.2.2 Description of burner

The basic equipment comprises two baskets – one large and one small. One alone can work but results are not good in that condition. The mesh can be cut from a roll of mesh in a planned way to minimize waste. There is no need for the mesh to be galvanized (coated with zinc) because this will burn off in the operation of the process. However, using stainless-steel mesh is worthwhile. This is because it can stand the high temperature, rain and some rough-handling without corrosion occurring. The basket should be supported on small pieces of brick or flat stone about 20 cm above the ground to let air from underneath it. Of course the ground should be level and free of plant growth for the same reason.

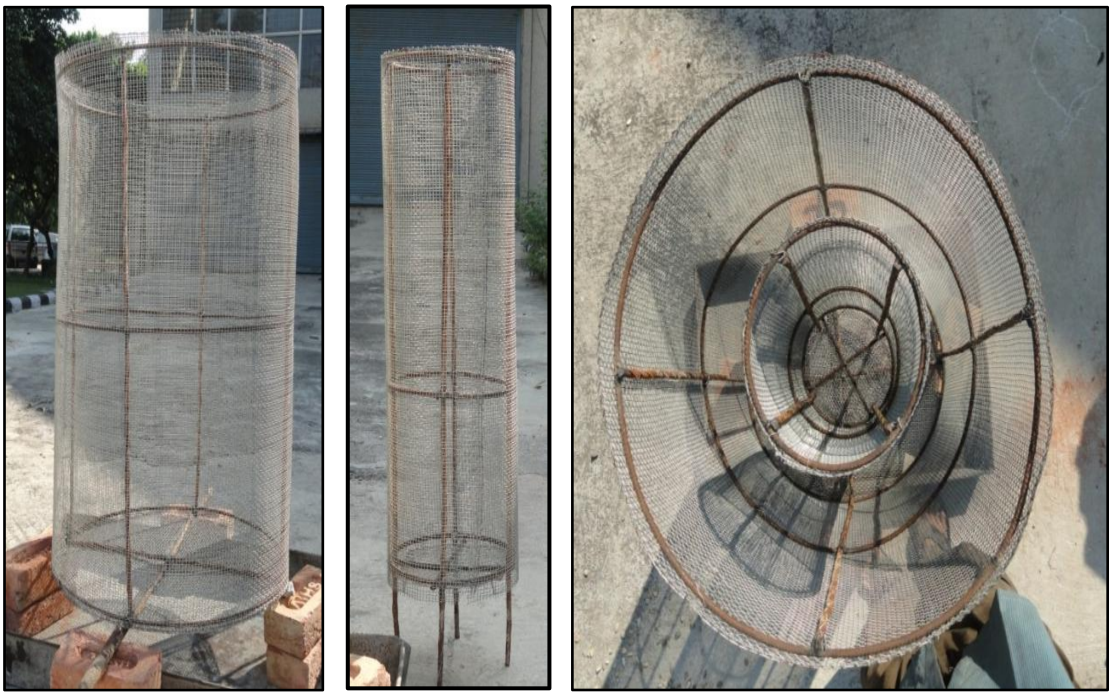


Figure 3.3 Outer basket, Inner basket and Top view of basket

Figure 3.4 Elevation and top view of Burner after being filled by rice husk

Figure 3.5 Burning the husk in the burner

3.2.3 Quantity produced

The burner is filled with the rice husk in between both the baskets (Figure 3.4). It takes about 20 kg of rice-husks to fill it completely which occupy about 0.1 m^3. Typically, one burning takes about 12 to 15 hours and produces 4 kg of Rice Husk Ash (RHA).

3.2.4 The Process

The basket should be positioned away from homes because it produces smoke. However, it can be placed under a roof provided that there is sufficient ventilation. If rain or winds are expected, the basket- burner should be under such a cover or inside a 200 liter drum as described in the Equipment Section above. Dry rice-husks are placed in a large basket until a layer of 150 mm is formed. The smaller basket can then be put in place and space between filled with husks. There should be no husks placed inside the inner basket. Ignition can be achieved by dropping a piece of burning paper or hot charcoal into the central basket. Alternatively, a piece of rag soaked in used engine oil and ignited can be dropped into the central basket as shown in figure 3.5.

3.2.5 Batches of RHA produced

Three batches of RHA (Figure 3.6) were produced by the burner for the preliminary research work

- Rice Husk burnt directly. It took about 12 hours of time. Ash obtained is comparatively black
- Extra amount of air given to burn the Rice husk. Ash obtained is grey.
- A fan is used to provide sufficient air to the burner. Time taken to burn completely is 10 hours. Ash is of white color.

Figure 3.6 Different sample of RHA Produced

3.3 Selection and testing of materials

Coarse aggregate, sand, ordinary Portland cement, amorphous RHA, silica fume, normal tap water and poly-carboxylate based high-range water reducer (HRWR) were selected to produce high performance concretes (HPC). The component materials were tested to examine their suitability and to obtain several physical properties required for the mixture proportioning process of concrete. The following sections describe the constituent materials along with the experiments conducted on them. The section also gives the references of the codes used .

3.3.1 Coarse aggregates

Locally available coarse aggregate in the form of a blend of crushed and round aggregates was used in the work. The weight percentage of round aggregate was around 50% of the total aggregates. The coarse aggregate was tested for gradation by sieve analysis, dry rodded unit weight, water absorption and specific gravity.

3.3.2 Sand

Locally available sand in the form of Badarpur sand is used as the fine aggregate (FA). The sand was found as deposits in river embankment, and obtained by forming pits there. The sand was tested for gradation be sieve analysis, dry rodded unit weight, absorption, and specific gravity.

3.3.3 Ordinary Portland cement

Normal Portland cement manufactured and marketed by Wonder cement was used as the main cementing material. It complied with the requirements of IS 12269. The cement was tested for specific gravity, setting time, and compressive strength.

3.3.4 Amorphous rice husk ash

Amorphous (non-crystalline) RHA was used as a supplementary cementing material (SCM). It was produced in very fine powder form with a whitish color. RHA was tested for specific gravity, EDX and SEM.

3.3.5 Tap water

The water used for mixing and curing was clean and free from injurious amount of oils, acids, alkalis, salts, sugar, organic materials or other substances. The normal tap water was used as the mixing water for preparing the concretes.

3.3.6 Poly-carboxylate-based high-range water reducer

A poly-carboxylate-based HRWR, commercially known as Master Glenium sky 8777, was used to produce the required flowing ability of concrete. It was available in dark brown liquid form. The specific gravity of the HRWR is 1.1.this product is manufactured and marketed by BASF chemical India Pvt. Ltd.

3.3.7 Silica fume

Micro-silica marketed by ELKEM silicon materials is used. It is an amorphous silicon dioxide (silica) consisting of sub-micron spherical primary particles and agglomerates of these. The material is highly reactive in cementitious systems. The average diameter of a micro-silica sphere is about 0.15 micron. Although some of the spheres exist as single entities, most of them form primary agglomerates. The size of these may vary between 0.1 and 1 micron. This rather wide particle size distribution contributes to high packing efficiency. (ASTM C 1240)

3.4 Characteristics of Coarse aggregate

The coarse aggregate was characterized by a number of physical properties and gradation obtained from sieve analysis before using in concrete.

3.4.1 Physical properties

The test results for the physical properties of coarse aggregate are given in table 3.1 and in table 3.2. These properties indicated that the coarse aggregate was suitable for use as coarse aggregate in producing concretes.

Table 3.1 Specific gravity of coarse aggregates

Sr. No.	Particulars	C.A
1	Basket in water (M1) gm.	550
2	Basket + aggregate in water (M2) gm.	2100
3	Dry aggregate in SSD condition (M3) gm.	2500
4	Oven dried aggregate (100-110) Celsius (M4) gm.	2486
5	Water absorption	0.56%
6	Specific Gravity, G = M4/ [(M3) - (M2 – M1)]	2.93

The specific gravity is calculated in accordance with IS: 2386-Part 3, 1963. The specific gravity of coarse aggregate was 2.93. The absorption of coarse aggregate was 0.56%. The absorption of coarse aggregates usually varies from 0.5 to 4.5% [20]. Thus, the absorption of coarse aggregate was in the lower range, which is good for concretes. If the absorption value is higher than it indicates that greater pores in aggregates are present that might affect the strength and durability of concretes.

Table 3.2 Dry rodded unit weight of aggregates

Sr. No	Particulars	Aggregate(gm.)
1	Container Weight with material	14950
2	Empty weight of container	6550
3	Volume of container (cu cm)	5016.15
4	Dry rodded density	1674.59

The dry rodded unit weight of coarse aggregate determined under compacted condition was 1674.59 kg/m^3. It generally varies from 1200 to 1750 kg/m^3 [53]. It includes the pores and voids existing in aggregates. The coarse aggregate used was air-dried. There was no free or surface moisture on the surface of aggregates. The moisture content of coarse aggregates is generally not considered in the primary mixture proportions of concrete. But the moisture content increases the quantity of mixing water that produces a higher W/B ratio and thus produces an impact on the properties of concrete. Hence, the moisture content of the aggregates should be given due allowance to adjust the mixture proportions of concrete.

3.4.2 Gradation

The gradation of coarse aggregate obtained from the sieve analysis is presented in table 3.3.

Table 3.3 Sieve analysis for coarse aggregates

Sieve size	Wt. retained (gm.)	% wt. retained	Cumulative %wt. retained	% Finer
20	141.3	2.826	2.862	97.138
16	1582.1	31.642	34.468	65.532
12.5	1532.1	30.642	65.11	34.89
10	1730.4	34.608	99.718	0.282
4.75	14.1	0.282	100	0
Pan	0	0	0	0

The nominal maximum size of the coarse aggregate was 20 mm, as observed during sieve analysis. The maximum size of the coarse aggregate influences the water content needed for a given flowing ability. An increase in maximum size decreases the required water content. An increased maximum size of coarse aggregate also reduces the cement content to make a workable paste [53]. Thus, the maximum size of coarse aggregate plays a significant role in mixture design of concrete.

The above table indicates that the coarse aggregate used was well-graded. The gradation of coarse aggregate or coarse aggregates affects the workability or flowing ability (filling ability and passing ability) of concrete. This is because it affects the required water and cement contents of concrete. The grading of coarse aggregates also influences the segregation resistance of concrete, since the packing conditions of the aggregates are affected by the gradation [20]. Thus, poorly graded coarse aggregates might have negative effects on the flowing ability and segregation resistance of HPC.

3.5 Characteristics of Sand

The sand was characterized by means of various physical properties such as specific gravity and dry rodded unit weight. In addition, the gradation of sand was also observed by conducting the sieve analysis.

3.5.1 Physical properties

The specific gravity of the sand is 2.683 as calculated by Pycnometer test conducted as per IS: 2386, part 3-1963 (Table 3.4).The absorption of sand obtained was 0.66 %. The absorption of fine aggregate generally varies in the range of 0.2 to 3.0% [20]. Hence, the absorption of sand was in the lower range, which is beneficial for concrete properties and durability.

Table 3.4 Specific gravity of fine aggregates

S. No	Particulars	F.A
1	Mass of Pycnometer (M1) gm.	681.5
2	Mass of Pycnometer + material (M2) gm.	1181.8
3	Mass of Pycnometer + material + distilled water (M3) gm.	1887.3
4	Mass of Pycnometer + distilled water (M4) gm.	1573.4
5	Mass of oven dried sample	496.7

6	Water absorption	0.66
7	Specific Gravity, G = (M2-M1)/[(M2 – M1) - (M3 – M4)]	2.683

Further the absorption of sand was near to that of coarse aggregate. It indicates that sand had somewhat equal pores than coarse aggregate.

Table 3.5 Dry rodded density of fine aggregates

Sr. No	Particulars	Sand(gm.)
1	Container Weight with material	15600
2	Empty weight of container	6550
3	Volume of container (cu cm)	5016.15
4	Dry rodded density	1804.17

The dry rodded unit weight of sand was 1804.17 kg/m^3 (Table 3.5), which is greater than that of coarse aggregate. The bulk density of sand is generally higher than that of coarse aggregate due to reduced void content [20]. A large difference between the relative densities of fine and coarse aggregates leads to increased segregation in concrete

3.5.2 Gradation

The gradation of sand obtained from the sieve analysis is shown in table 3.6 and figure 3.7.

Table 3.6 Sieve analysis for fine aggregates

Sieve size mm	Wt. retained (gm.)	% wt. retained	Cum.% Wt. retained	% Finer	minimum limit ACI	maximum limit ACI
4.75	20.8	2.08	2.08	97.92	95	100
2.36	164.5	16.45	18.53	81.47	80	100
1.18	233.4	23.34	41.87	58.13	50	85
600 µm	198.4	19.84	61.71	38.29	25	60
300 µm	173.1	17.31	79.02	20.98	10	30
150 µm	144.2	14.42	93.44	6.56	2	10
Pan	65.6	6.56	100	0		
	1000					

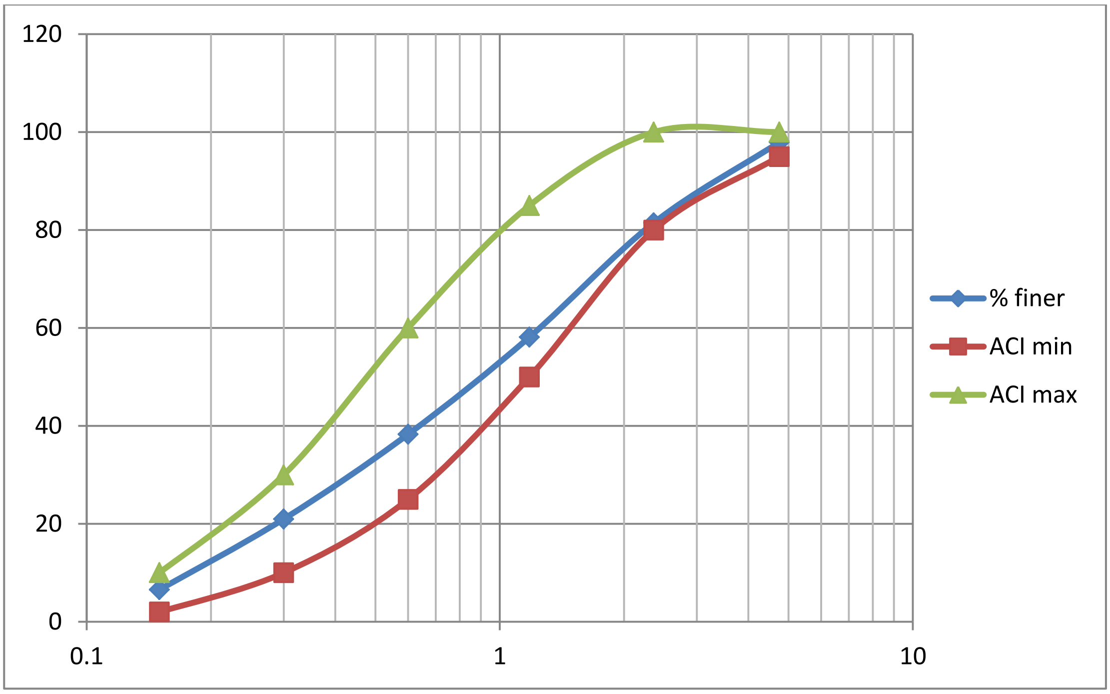


Figure 3.7 Gradation of fine aggregates as per ACI.

The nominal maximum size and fineness modulus of sand is obtained by sieve analysis. The fineness modulus of sand is 3.03. Thus, the sand was considered well-graded. Furthermore, the grading of different sizes of sand was within the limits specified by the ACI (ACI 211.4R-1993).

The fineness modulus indicates that the sand was appropriate for producing concrete mixtures. The fineness modulus of sand for use in concrete generally varies in the range of 2.4 to 3.2 (ACI 211.4R-93).

The gradation of sand influences the total surface area of the aggregates that determines the water demand as well as affects the compressive strength of concrete mixture [20]. Thus, it influences the mixture design of concrete. Moreover, the sand gradation affects the flow properties of mortar [54], and influences the physical packing of constituent materials in concrete [55]. Consequently, the sand gradation may affect the properties of HPC.

3.6 Characteristics of Ordinary Portland cement

3.6.1 Specific gravity

The specific gravity is calculated as 3.166 which are above the standard value of specific gravity i.e. 3.15. This test is performed in accordance with IS: 4031 (Part 11) – 1988.

3.6.2 Setting time

The setting time is an indicator of the soundness of cement due to storage. It is calculated by vicat apparatus as per IS: 4031 (part 5) - 1988. The initial setting time is calculated as 105 minutes and final setting time is 160 minutes which is in between the ranges of setting time as given in IS: 12269, 1987.

3.7 Characteristics of Amorphous Rice Husk Ash

The RHA was characterized by means of several physical properties and chemical composition like specific gravity, EDX and SEM

3.7.1 Specific gravity

The specific gravity is calculated to be 1.978. It proves that RHA is much lighter than the Cement. This test is performed in accordance with IS: 4031 (Part 11) – 1988.

3.7.2 Chemical composition

3.7.2.1 Energy dispersive X-Ray analysis

Energy dispersive X-Ray analysis is a widely used technique to analyze the chemical components in a material. The results of EDX are given in table.3.7 and figure 3.8. This test is performed in the Physics Department of Delhi Technological University.

The major component of RHA is silicon dioxide or silica (SiO_2). The mass content of silica is about 94% in RHA. This is the main oxide component that contributes to the pozzolanic reaction or secondary hydration in concrete including RHA. The more amount of silica is present the more will be the reactivity of RHA. There were other oxides in small quantities.

Table 3.7 Chemical components of RHA

Element Line	Net Counts	Int. Cps/nA	Weight %	Weight % Error	Atom %	Atom % Error	Formula
Mg K	13	---	0.34	+/- 0.26	0.41	+/- 0.31	Mg
Si K	3312	---	91.08	+/- 1.84	94.00	+/- 1.90	Si
Si L	0	---	---	---	---	---	
K K	65	---	3.57	+/- 0.66	2.65	+/- 0.49	K
K L	0	---	---	---	---	---	
Ca K	28	---	1.70	+/- 0.67	1.23	+/- 0.48	Ca
Ca L	0	---	---	---	---	---	
Fe K	18	---	3.31	+/- 1.65	1.72	+/- 0.86	Fe
Fe L	0	---	---	---	---	---	
Total			100.00		100.00		

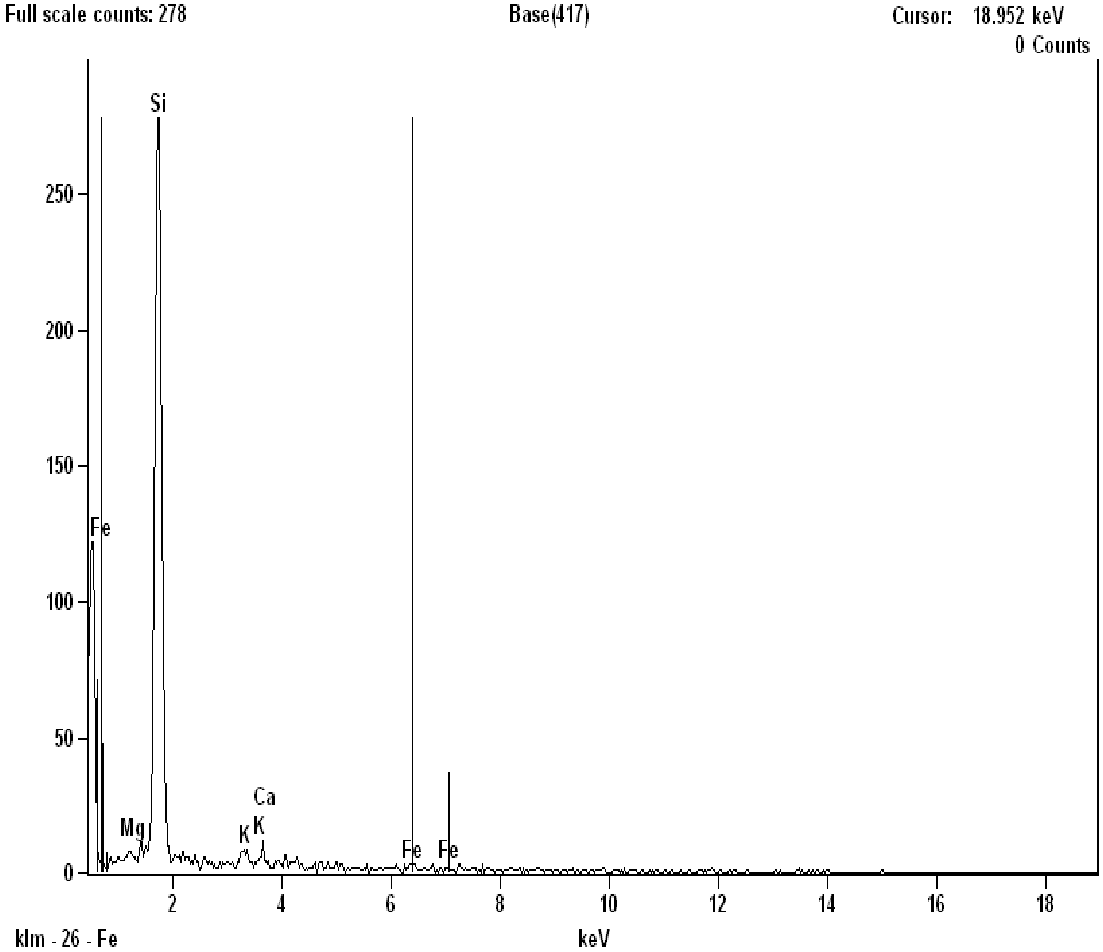


Figure 3.8 Results of EDX test for RHA

3.7.2.2 Scanning electron microscope (SEM)

Particle size of the RHA can also be seen through SEM images. This test is also performed in the Physics department of Delhi Technological University. (Figure 3.9)

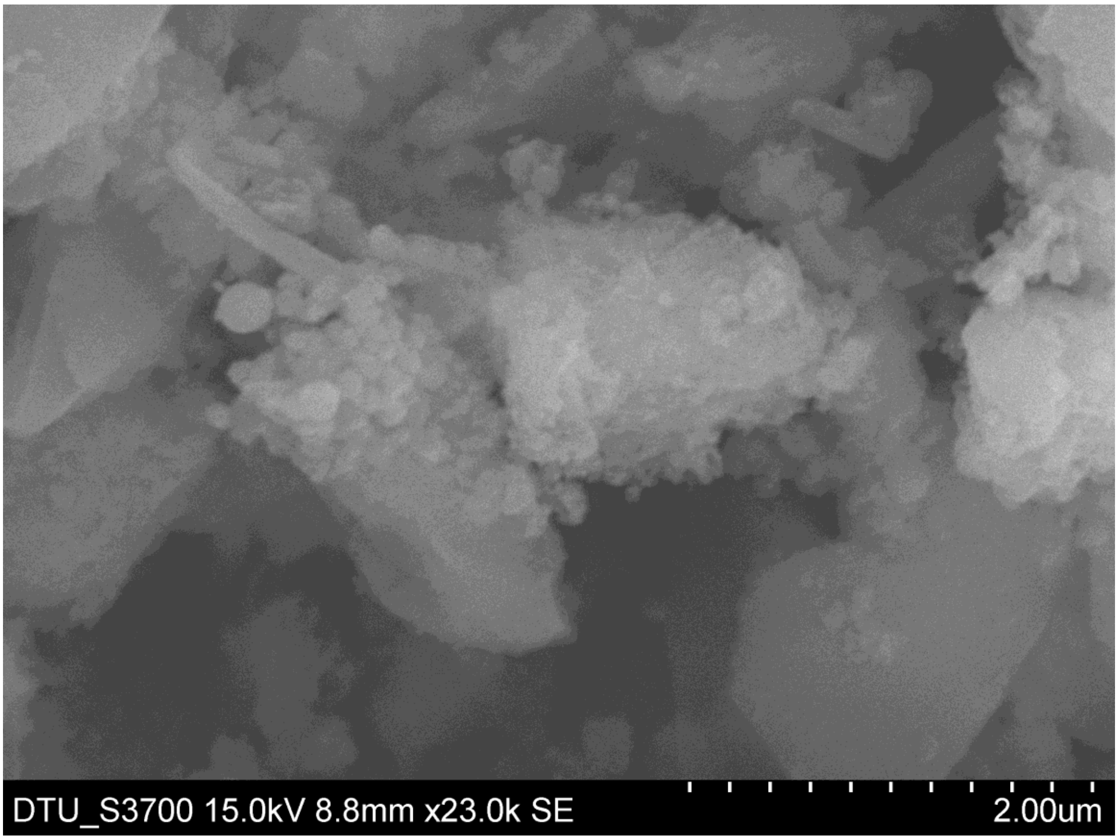


Figure 3.9 SEM of RHA

3.8 Characteristics of silica fume

3.8.1 Specific gravity

The specific gravity is calculated to be 2.32. It proves that SF is much lighter than the Cement. This test is performed in accordance with IS 4031-Part 11 – 1988.

3.8.2 Chemical analysis

3.8.2.1 Energy dispersive X-Ray analysis

Energy dispersive X-Ray analysis is a widely used technique to analyze the chemical components in a material. The results of EDAX are given in Table.3.8 and figure 3.10.This test is performed in the Physics Department of Delhi Technological University.

The major component of SF is silicon dioxide or silica (SiO2). The mass content of silica is about 90% in SF. This is the main oxide component that contributes to the pozzolanic reaction or secondary hydration in concrete including SF. The more amount of silica is present the more will be the reactivity of SF. There were other oxides in small quantities.

Table 3.8 Chemical analysis of silica fume

Element Line	Net ounts	Int. ps/nA	Weight %	Weight % Error	Atom %	Atom % Error	Formula
Mg K	91	---	2.08	+/- 0.32	2.52	+/- 0.39	Mg
Si K	3518	---	85.91	+/- 1.66	89.93	+/- 1.74	Si
Si L	0	---	---	---	---	---	
K K	86	---	4.12	+/- 0.67	3.10	+/- 0.50	K
K L	0	---	---	---	---	---	
Ca K	27	---	1.46	+/- 0.65	1.07	+/- 0.48	Ca
Ca L	0	---	---	---	---	---	
Fe K	40	---	6.43	+/- 2.09	3.38	+/- 1.10	Fe
Fe L	0	---	---	---	---	---	
Total			100.00		100.00		

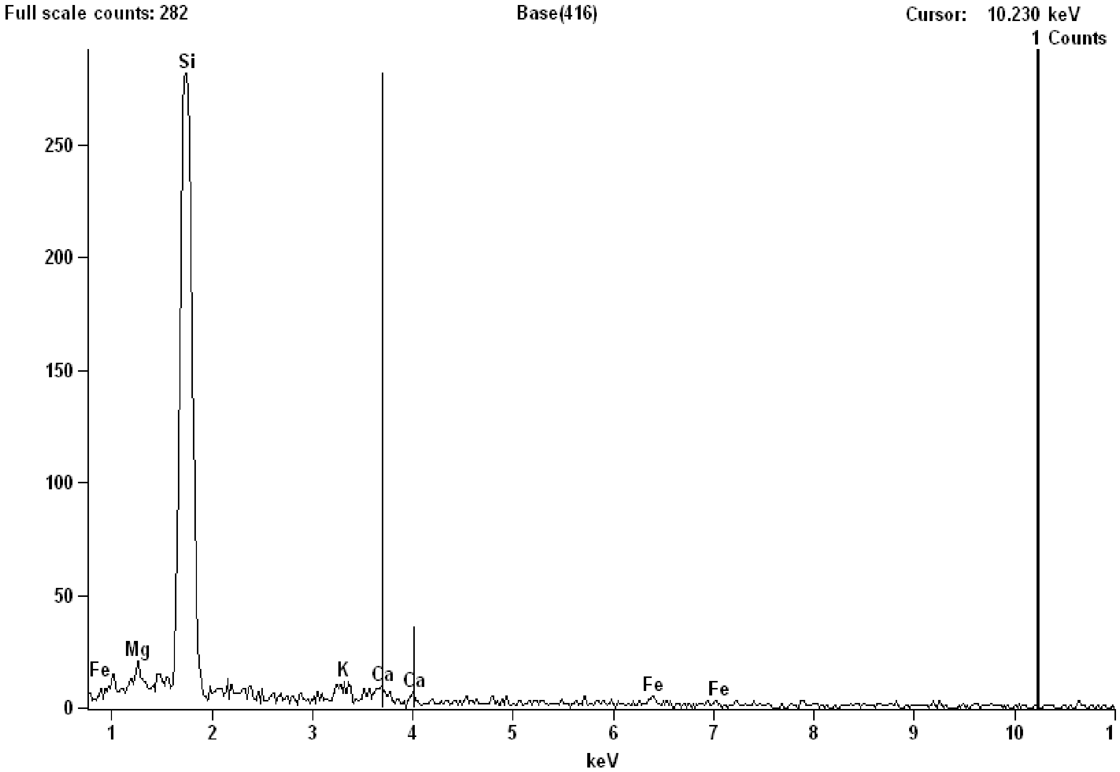


Figure 3.10 Results of EDAX test on silica fume

3.8.2.2 Scanning electron microscope (SEM)

Particle size of the RHA can also be seen through SEM images. This test is also performed in the Physics department of Delhi Technological University. (figure 3.11)

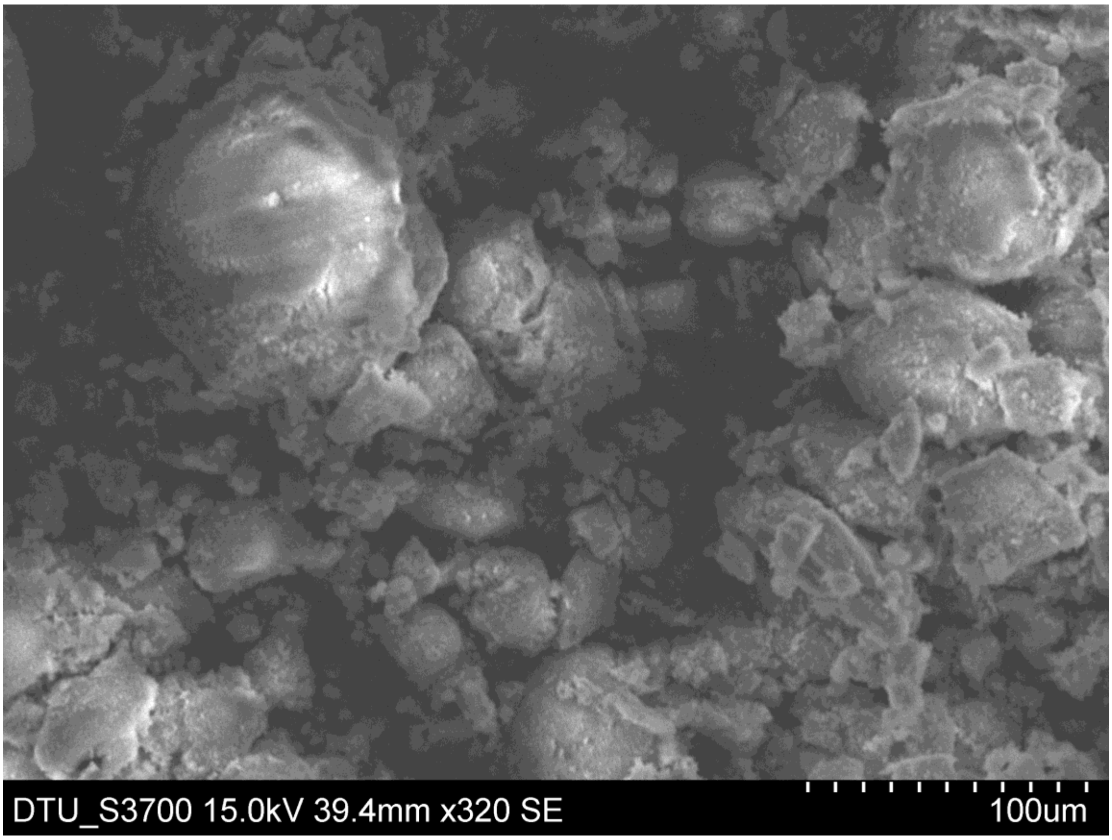


Figure 3.11 SEM for silica fume

3.9 Concrete Mix design

In this research, standard M100 grade concrete mixture without Secondary raw materials (RHA and SF) and then concrete with SRM's are casted. First of all high strength is achieved by increasing the quantity of cement and then achieved by keeping the cement at 450 kg according to the code provision of IS: 456, 2000 and replacing the remaining by RHA and SF. In this way we have replaced 15, 20, 25, 30% of cement by RHA and 5, 7.5, 10 % by SF. The quantity of various materials used for preparing plain concrete and concrete with SRM's are given in table 3.9 along with its denominations.

Table 3.9 Proportion of Concrete (all values in kg)

Denom.	Cement	SRM's	C.A.	F.A	Water	S.P
Standard	749.9	0.0	1205.7	426.2	152.7	11.2
SF 5	623.8	37.8	1205.7	481.2	152.7	11.2
SF 7.5	563.3	55.9	1205.7	509.5	152.7	11.2
SF 10	502.8	74.5	1205.7	537.3	152.7	11.2
RHA 15	566.1	110.7	1205.7	440.2	152.7	11.2
RHA 20	506.5	149	1205.7	444.8	152.7	11.2
RHA 25	446.9	186.2	1205.7	449.5	152.7	11.2
RHA 30	387.3	223.5	1205.7	454.1	152.7	11.2

A **water cement ratio** of 0.20 was maintained in all the batches.

3.10 Mixing procedure

- The aggregate and cement is put into the mechanical mixer
- The material is dry mixed for about 1 minutes
- One third of total water is mixed so as to make the material surface wet
- The super plasticizer is mixed with remaining water and then mixed with concrete.
- Mixing is done for around 5 – 6 minutes.

Chapter 4
Experimental work

4.1 Test for consistency of binder material

4.1.1 Procedure (As per IS 4031, part 4)

The standard consistency of a cement paste is defined as that consistency which will permit the Vicat plunger to penetrate to a point 5 to 7 mm from the bottom of the Vicat mold when the cement paste is tested.

Prepare a paste of weighed quantity of cement with a weighed quantity of potable or distilled water, taking care that the time of gauging is not less than 3 minutes, nor more than 5 min, and .the gauging shall be completed before any sign of setting occurs. The gauging time shall be counted from the time of adding water to the dry cement until commencing to fill the mold. Fill the Vicat mold with this paste, the mold resting upon a non-porous plate. After completely filling the mold smoothen the surface of the paste, making it level with the top of the mold. The mold may be slightly shaken to expel the air.

4.1.2 Consistency of binder material after replacing cement by RHA

The consistency of cement is found out first. It is estimated to be 28%. Now the consistency of the binder material i.e. cement after replacing with RHA is found

Table 4.1: Consistency of binder material after replacing cement by RHA

Binder material	RHA consistency
Cement	28
RHA 5	30
RHA 10	32
RHA 15	34
RHA 20	36
RHA 25	38
RHA 30	40

out. The cement is replaced by 5, 10, 15, 20, 25, and 30 % respectively by weight of RHA. The results of the experimental work are shown in table 4.1 and its graphical representation is given in figure. 4.1.

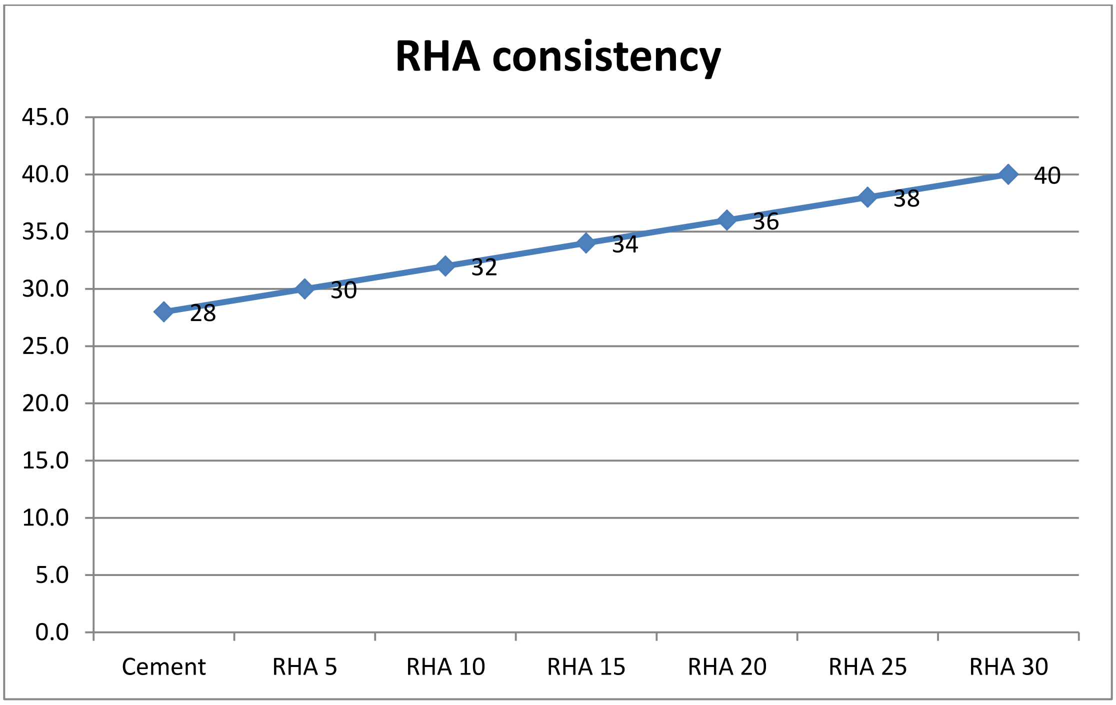


Figure 4.1: Consistency of binder material after replacing cement by RHA

4.1.3 Consistency of binder material after replacing cement by SF

The consistency of cement is found out. It is estimated to be 28%. Now the consistency of the binder material i.e. cement after replacing with SF is found out. The cement is replaced by 5, 7.5 and 10 % respectively by weight of SF. The results of the experimental work are shown in table 4.2 and its graphical representation is given in figure. 4.2.

Table 4.2: Consistency of binder material after replacing cement by SF

Binder material	SF consistency
Cement	28
SF 5	30
SF 7.5	31
SF 10	32

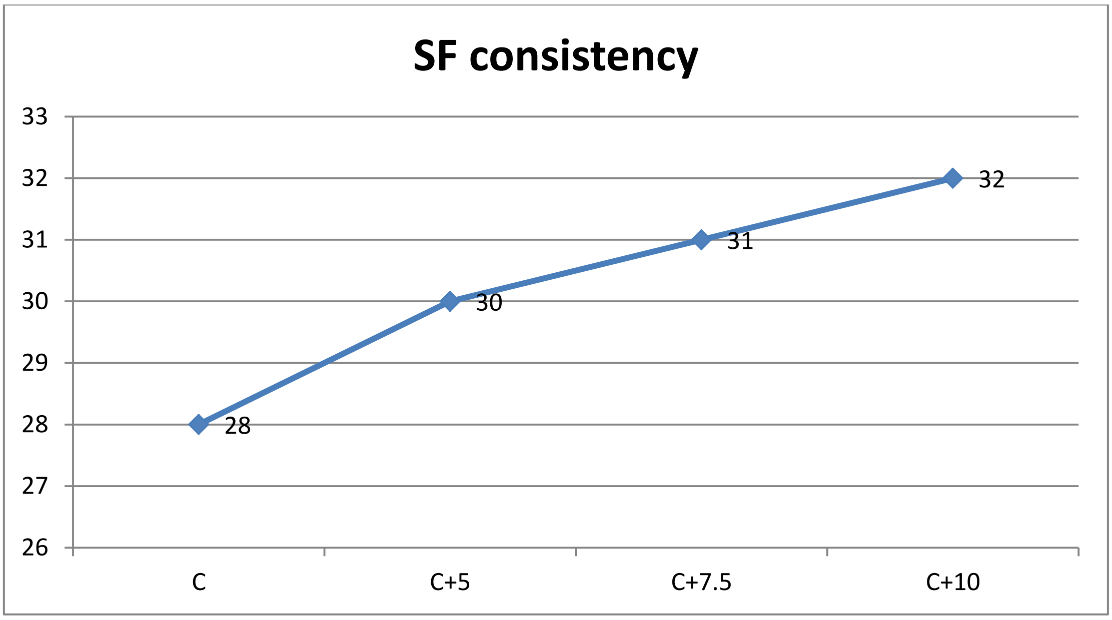


Figure 4.2: Consistency of binder material after replacing cement by SF

4.2 Test for workability of concrete - Compaction factor

4.2.1 Procedure (As per IS 1199)

The upper hopper is completely filled with concrete, which is then successively dropped into the lower hopper and then into the cylindrical mold. The excess of concrete is struck off, and the compacting factor is defined as the weight ratio of the concrete in the cylinder, to the same concrete fully compacted in the cylinder (after vibration). For the normal range of concrete the compacting factor lies between 0.8 to 0.92 (values less than 0.7 or higher than 0.98 is regarded as unsuitable because the concrete is not workable). This test is good for very dry mixes.

4.2.2. Compaction factor of concrete with RHA

The compaction factor of concrete with RHA is determined. The compaction factor test is used because the mix seems to be very dry but as the concrete is vibrated it starts flowing like liquid. Around 15 kg concrete is used to determine compaction factor. The compaction factor of all the mixes of RHA is determined. The results of the test are given in table 4.3 and in Figure 4.3.

Table 4.3: Results of compaction factor test with RHA

		Weight of cylinder before vibration		Compaction Factor
	W/C ratio	Before vibration(gm.)	After vibration(gm.)	
Standard	0.20	17250	19600	0.88

RHA 15	0.20	16650	19600	0.85
RHA 20	0.20	16450	19600	0.84
RHA 25	0.20	16050	19600	0.818
RHA 30	0.20	15870	19600	0.809

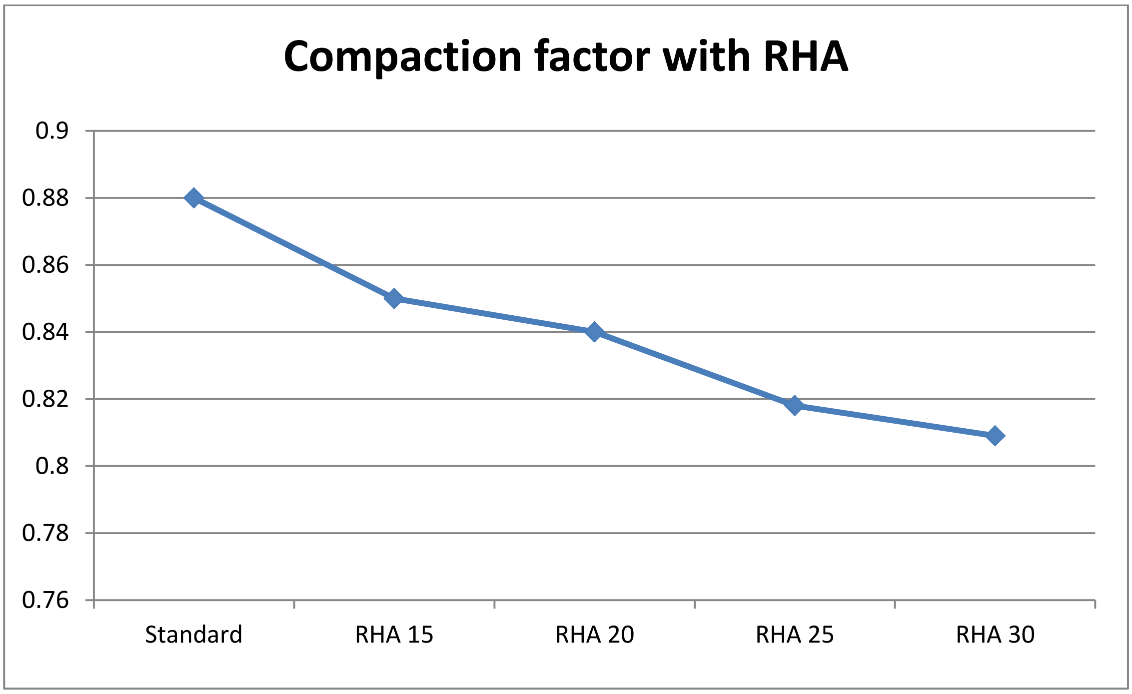


Figure 4.3: Graphical representation of compaction factor of concrete with RHA

4.2.3. Compaction factor of concrete with SF

Table 4.4: Results of compaction factor test with SF

		Weight of cylinder before vibration		Compaction Factor
	W/C ratio	Before vibration(gm.)	After vibration(gm.)	
Standard	0.20	17250	19600	0.88
SF 5	0.20	17050	19600	0.87
SF 7.5	0.20	16860	19600	0.86
SF 10	0.20	16650	19600	0.85

The compaction factor of concrete with SF is determined. The compaction factor test is used because the mix seems to be very dry but as the concrete is vibrated it starts flowing like liquid. Around 15 kg concrete is used to determine compaction factor. The compaction factor of all the mixes of SF is determined. The results of the test are given in table 4.4 and in Figure 4.4.

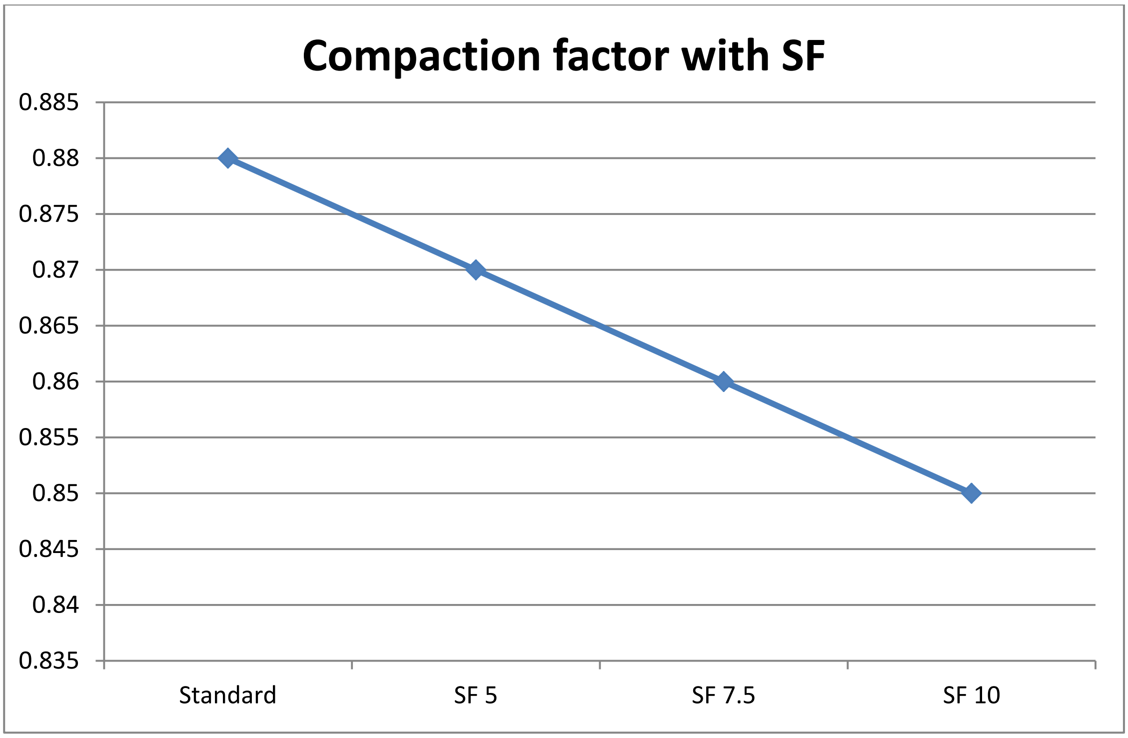


Figure 4.4: Graphical representation of compaction factor of concrete with SF

4.3 Compressive strength test on mortar cubes (AS per IS 4031, part 6)

4.3.1 Procedure:

The material for each cube shall be mixed separately and the quantity of cement, standard sand and water shall be as follows:

Cement = 200 g
Standard Sand = 600 g
Water = (P/4+3) per cent of combined mass of cement and sand, where P is the percentage of water required to produce a paste of standard consistency determined as described in IS: 4031 (Part 4)-1988*.

Place on a nonporous plate, a mixture of cement and standard sand. Mix it dry with a trowel for one minute and then with water until the mixture is of uniform color. The time of mixing shall not be less than 3 min and should not exceed 4 min

4.3.2 Results of compressive strength on mortar cubes with RHA

The mortar cubes of sizes 70.6 mm are formed. Three mortar cubes for each batch and each age of testing are made .They are then tested after 7, 28, 56 and 90 days of curing .The mortar cubes are formed by replacing 15, 20, 25 and 30 % of cement by RHA . The results of the following test are shown in table 4.5 and their graphical representation is given in figure 4.5.

Table 4.5: Results of compressive strength on mortar cubes with RHA

	Average Compressive strength of mortar with RHA (MPa)			
	7 day	28 day	56 day	90 day
Standard	38.4	56.2	58.3	61.1
RHA 15	37.1	48.3	57.3	62.3
RHA 20	35.3	49.1	56	63.4
RHA 25	33.4	52.2	59.9	67
RHA 30	31.1	45	48.6	55

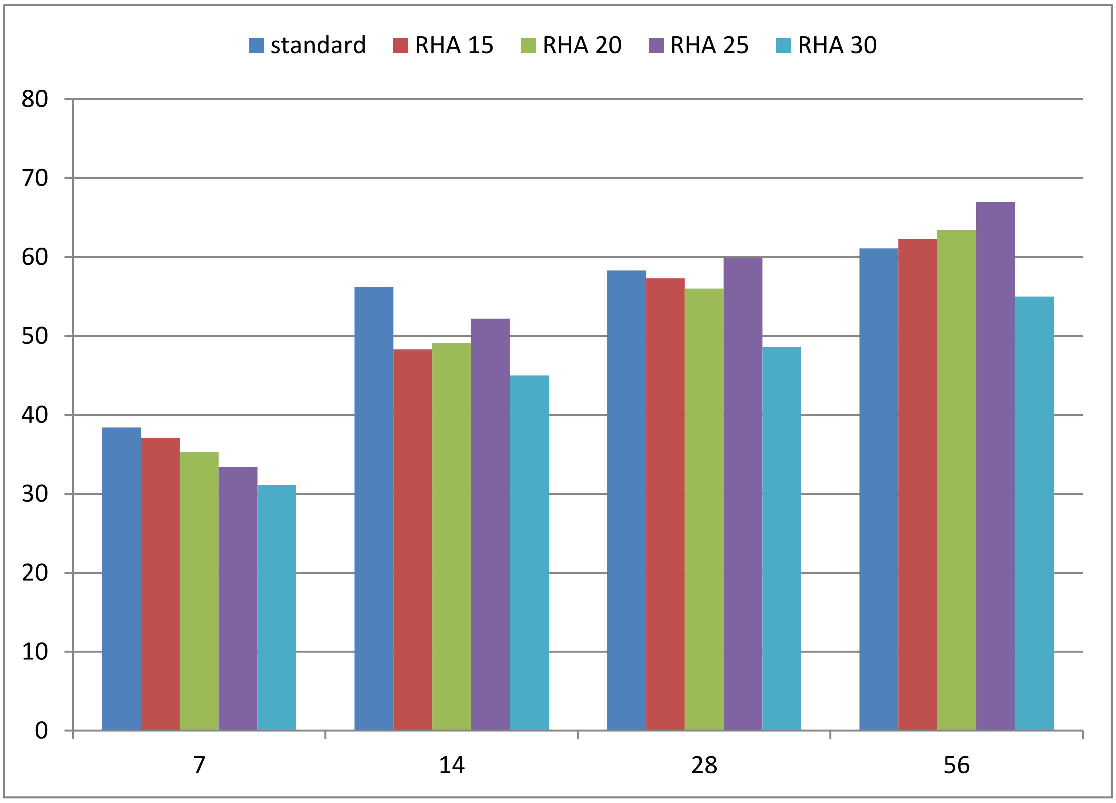


Figure 4.5: Graphical representation of compressive strength on mortar Cubes with RHA

4.3.3 Results of compressive strength on mortar cubes with SF:

The mortar cubes of sizes 70.6 mm are formed .Three mortar cubes for each batch and each age of testing are made .They are then tested after 7, 28, 56 and 90 days of curing .The mortar cubes are formed by replacing 5, 7.5 and 10 % of cement by SF. The results of the following test are shown in table 4.6 and its graphical representation is given in figure 4.6.

Table 4.6: Results of compressive strength on mortar cubes with SF

	Average Compressive strength of mortar with SF (MPa)			
	7 day	28 day	56 day	90 day
Standard	38.4	56.2	58.3	61.1
SF 5	37.2	56.1	57.2	60.3
SF 7.5	36.1	55.6	59.2	64.8
SF 10	35.4	55.2	56.1	60

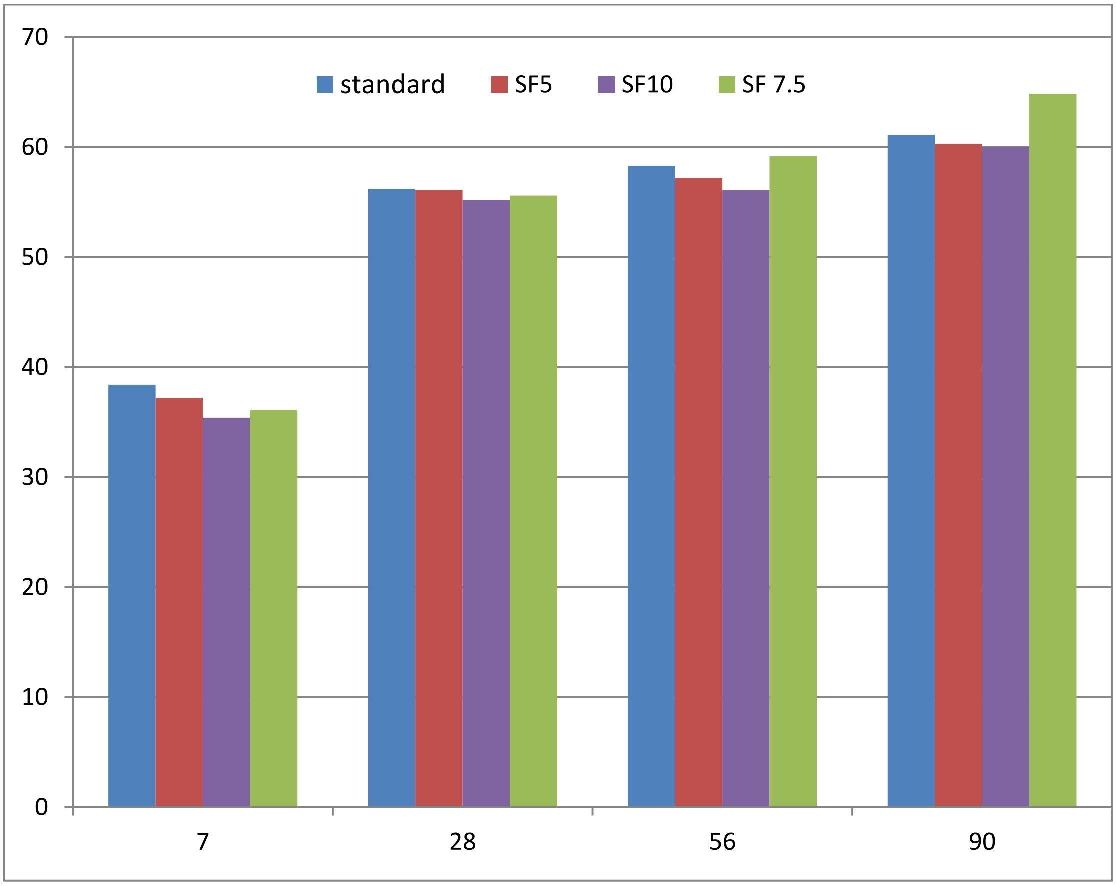


Figure 4.6: Graphical representation of compressive strength on mortar Cubes with SF

Figure 4.7: Photo of mortar cubes of 7, 28, 56, 90 days curing

4.4 Test for compression of concrete cubes (as per IS 516)

The specimen shall be placed in the machine in such a manner that the load shall be applied to opposite sides of the cubes as cast, that is, not to the top and bottom. The maximum load applied to the specimen shall then be recorded. The results of the compressive strength of cubes are given in table 4.6 and figure 4.7.

Table 4.7: Compressive strength results of cubes (all values in MPa)

Specimen	W/c	7 day	28 day	56 days	90 days
Standard	0.20	68.88	84.04	87.55	90.44
SF 5	0.20	66.22	86.66	95.33	97.26
SF 7.5	0.20	65.77	91.11	100.22	104.44
SF 10	0.20	63.55	83.11	91.42	93.27
RHA 15	0.20	64.44	84.44	92.88	93.33
RHA 20	0.20	63.55	87.11	93.33	95.22
RHA 25	0.20	64.00	93.77	101.77	103.84
RHA 30	0.20	61.33	77.77	85.55	87.29

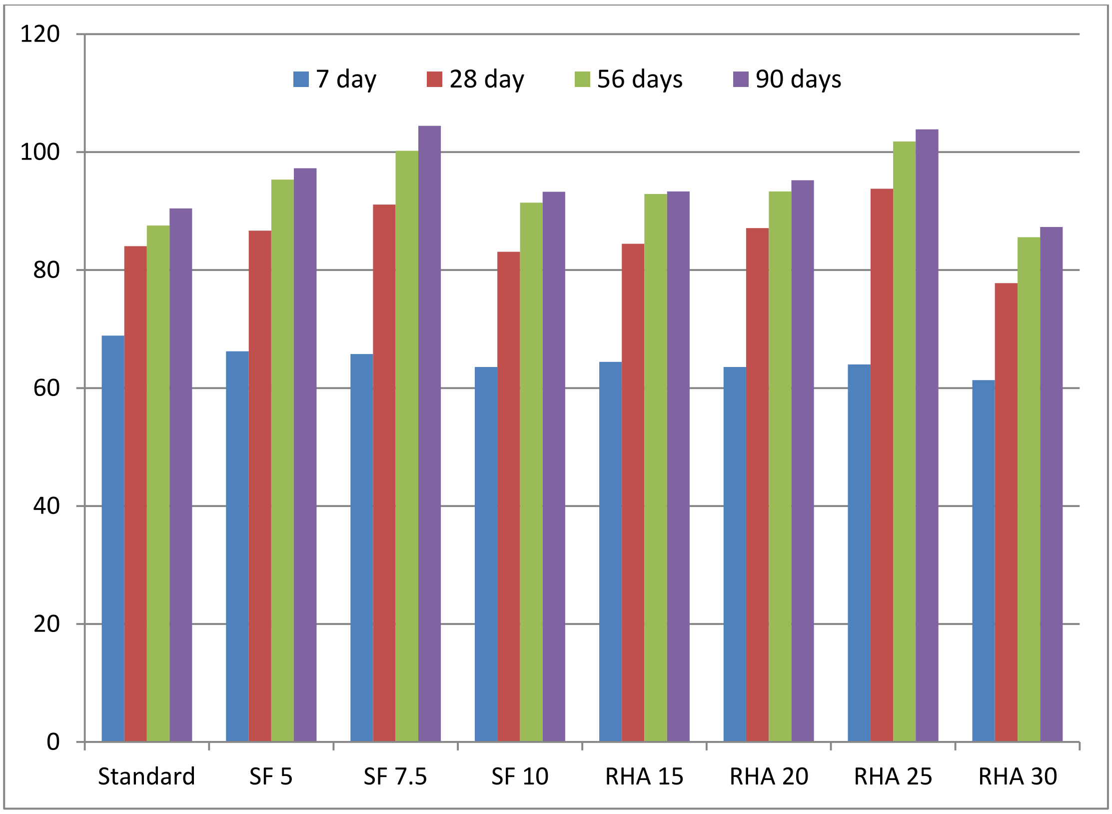


Figure 4.8: Compressive strength results for cubes

Figure 4.9: Photo of cubes for testing at 90 days curing

4.5 Test for compression of concrete cylinders (as per IS -516, 1959)

Test cylinders may be capped with a thin layer of stiff, neat Portland cement paste after the concrete has ceased settling in the molds, generally for two to four hours or more after molding. It shall be worked on the cement paste until its lower surface rests on the top of the mold. The cement for capping shall be mixed to a stiff paste for about two to four hours before it is to be used in order to avoid the tendency of the cap to shrink. The results of the test are given in table 4.8

Table 4.8: Compressive strength results of cylinders (all values in MPa)

Specimen	W/C ratio	7 day	28 day	56 days	90 days
Standard	0.20	55.48	61.14	65.11	67.94
SF 5	0.20	53.78	63.41	69.07	71.90
SF 7.5	0.20	52.65	66.80	73.60	78.13
SF 10	0.20	50.95	57.74	63.41	66.81
RHA 15	0.20	51.52	59.44	65.11	68.51
RHA 20	0.20	48.69	61.14	67.37	70.77
RHA 25	0.20	49.82	66.24	73.04	78.70
RHA 30	0.20	44.16	55.48	61.15	65.11

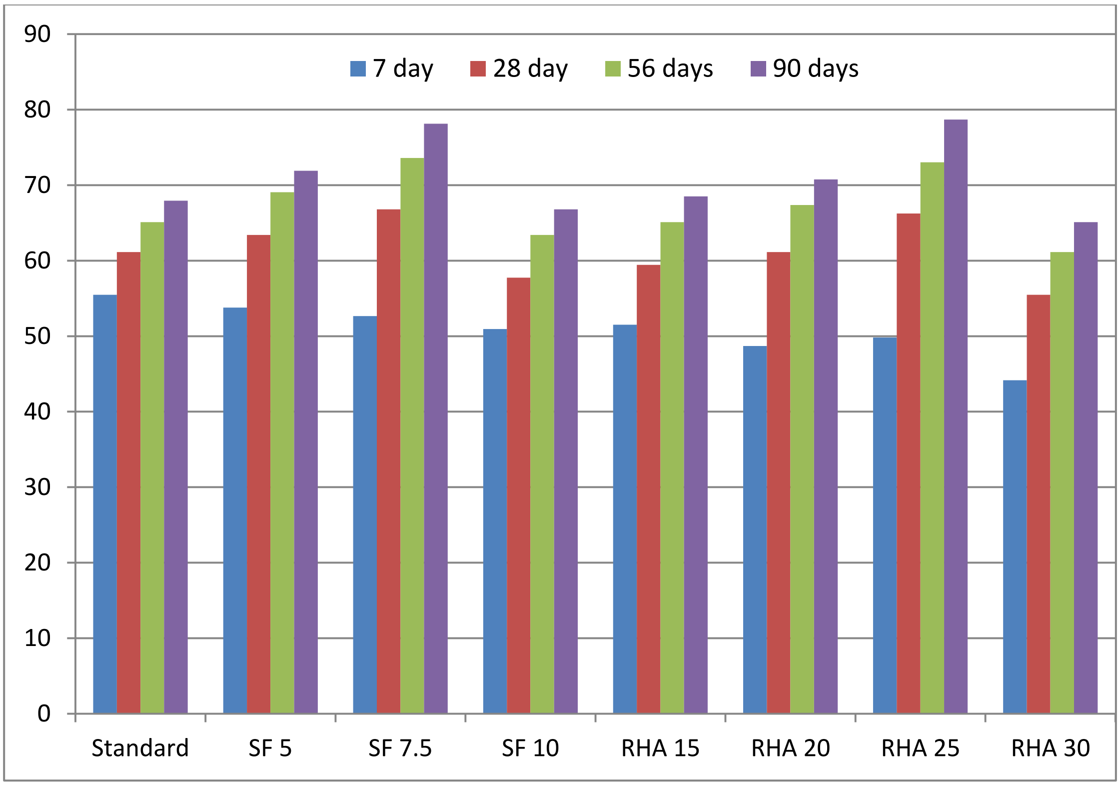


Figure 4.10: Results of compression test of cylindrical specimen

Figure 4.11: Photo of cylinders for testing at 90 days

4.6 Test for flexural strength (As per IS 516, 1959)

The mold of size 10x10x50 cm is used in this project The specimen is placed in the machine in such a manner that the load shall be applied to the uppermost surface as cast in the mold, along two lines placed 13·3 cm apart. The maximum load applied to the specimen during the test is recorded. The flexure test results are given in table 4.9 and figure 4.12.

The flexural strength of the specimen is expressed as the modulus of rupture f_b which, if ' a'· equals the distance between the line of fracture and the nearer support, measured on the center line of the tensile side of the specimen, in cm,

$$f_b = 3pa/bd^2$$

Where,

a = less than 13·3 cm but greater than 11·0 cm

b = measured width in cm of the specimen,

d = measured depth in cm of the specimen at the point of failure,

l = length in cm of the span on which the specimen was supported

p = maximum load in kg applied to the specimen

Table 4.9: Results of flexure test

Specimen	w/c ratio	7 day	28 day	56 days	90 days
Standard	0.20	9	11.34	12.06	12.6
SF 5	0.20	10.08	12.24	13.14	13.68
SF 7.5	0.20	10.44	13.5	14.22	15.12
SF 10	0.20	11.34	12.96	13.32	14.04
RHA 15	0.20	8.46	11.16	12.24	12.96
RHA 20	0.20	9.9	11.7	12.06	12.42
RHA 25	0.20	11.7	13.86	14.58	15.3
RHA 30	0.20	10.8	11.7	12.6	12.96

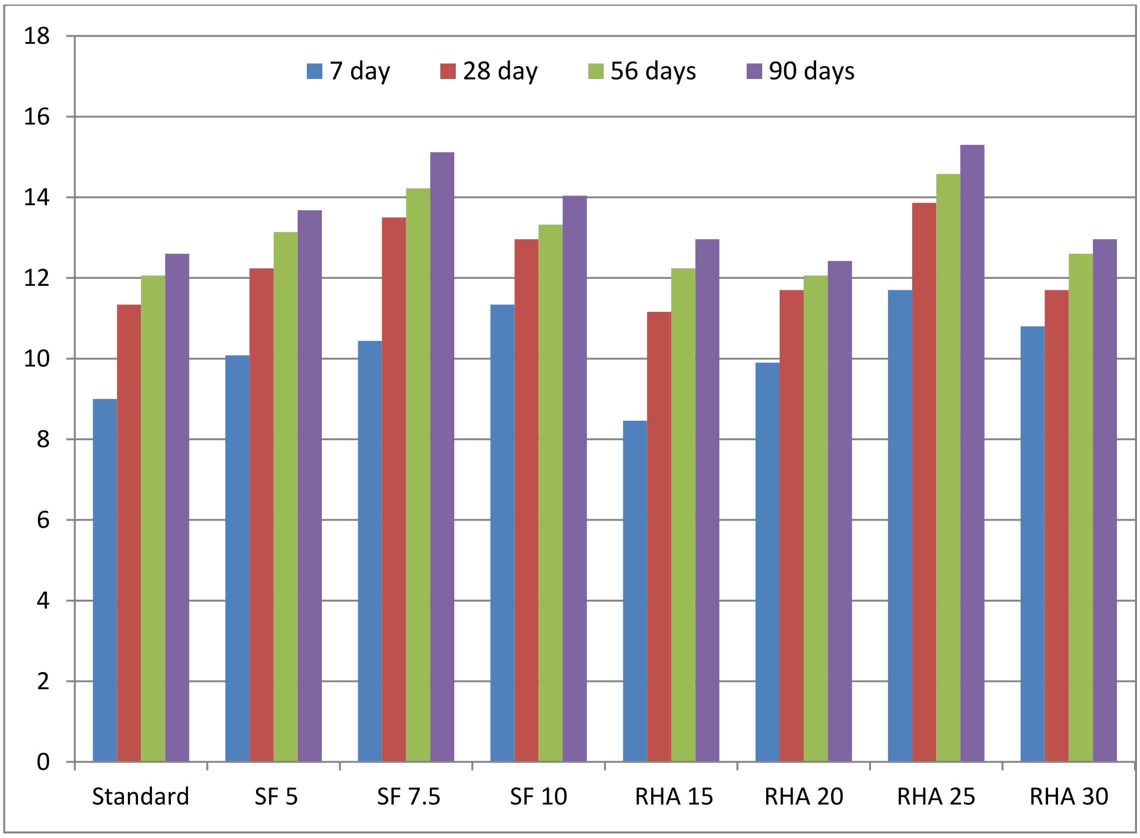


Figure 4.12: Results of flexural test

Figure 4.13: Photo of flexure specimen

4.7 Test for impact (As per ACI- 544)

Impact resistance has been characterized by a measure of the number of blows in a “repeated impact” test to achieve a prescribed level of distress.

Results from such tests are useful for ascertaining the relative merits of the different mixtures as well as for providing answers to specific practical problems. However, they depend on the specimen geometry, test system compliance, loading configuration, loading rate, and the prescribed failure criterion The simplest of the conventional tests is the “repeated impact,” drop- weight test described in the next subsection.

More recently, instrumented impact tests have been developed that provide reliable and continuous time histories of the various parameters of interest during the impact-load, deflection, and strain These provide basic material properties at the various strain rates for the calculation of flexural/tensile strength, energy absorption capacity, stiffness, and load-deformation characteristics. These types of tests are described in the instrumented impact test subsection.

More information on the merits and drawbacks of all the types of impact tests with particular emphasis on their usefulness for measuring the impact resistance of FRC is also available

4.7.1 Drop-weight test

The simplest of the impact tests is the “repeated impact,” drop-weight test. This test yields the number of blows necessary to cause prescribed levels of distress in the test specimen. This number serves as a qualitative estimate of the energy absorbed by the specimen at the levels of distress specified.

Referring to Figure 4.14, the equipment for the drop-weight impact test consists of:

- A standard manually operated 4.54 kg compaction hammer with a 457 mm drop.
- 63.5 mm diameter hardened steel ball,
- A flat base plate with positioning bracket similar to that shown in Figure 4.14.

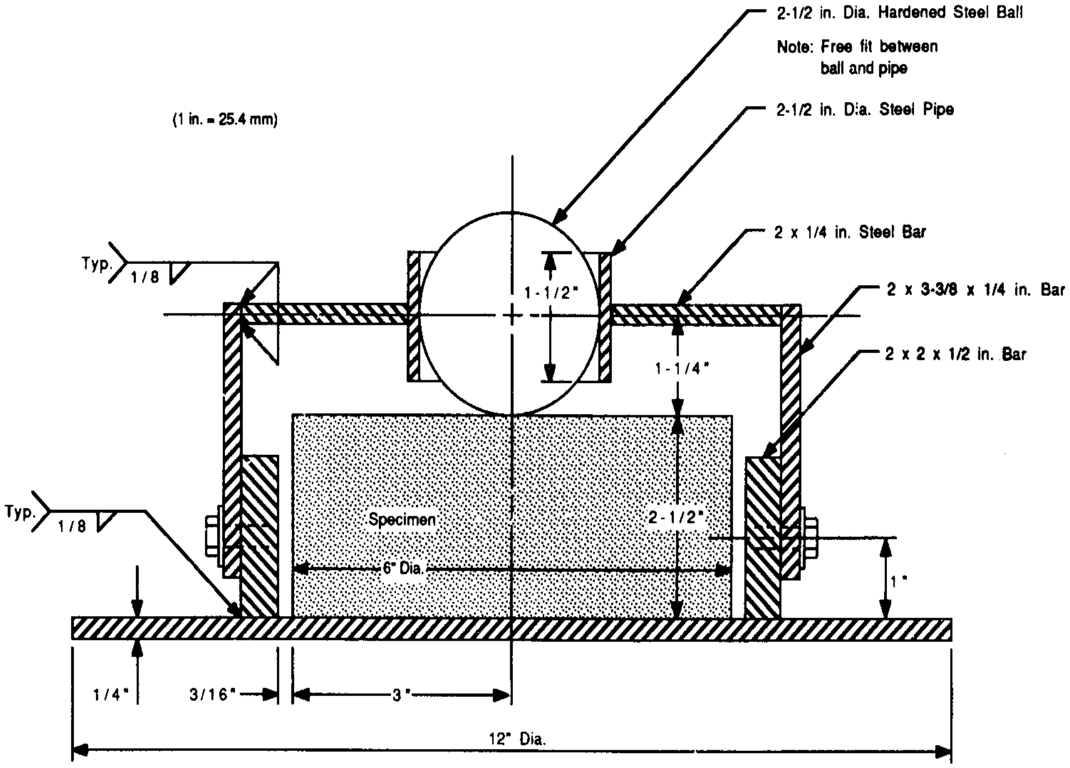


Figure 4.14: Schematic diagram of drop weight impact test

In addition to this equipment, a mold to cast 152 mm diameter by 63.5 mm thick concrete specimens is needed. These specimens are made only in one layer.

Specimens are tested at 7 and 28 days.

The drop hammer is placed with its base upon the steel ball and held there with just enough down pressure to keep it from bouncing off the ball during the test. The base plate should be bolted to a rigid base, such as a concrete floor or cast concrete block. Ultimate failure is defined as the opening of cracks in the specimen sufficiently so that the pieces of concrete are touching three of the four positioning lugs on the baseplate.

Table 4.10: Results of impact test

	7 day Results		**28 day Results**	
Specimen	**No. of blows**	**Energy absorbed (KNm)**	**No. of blows**	**Energy absorbed(KNm)**
Standard	447	9.09	572	11.64
SF 5	431	8.77	887	18.05
SF 7.5	908	18.48	1430	29.10
SF 10	560	11.398	780	15.87
RHA 15	357	7.26	691	14.06
RHA 20	440	8.95	880	17.91
RHA 25	780	15.87	1709	34.78
RHA 30	461	9.38	870	17.70

Figure 4.15: Some photos of impact tested specimens

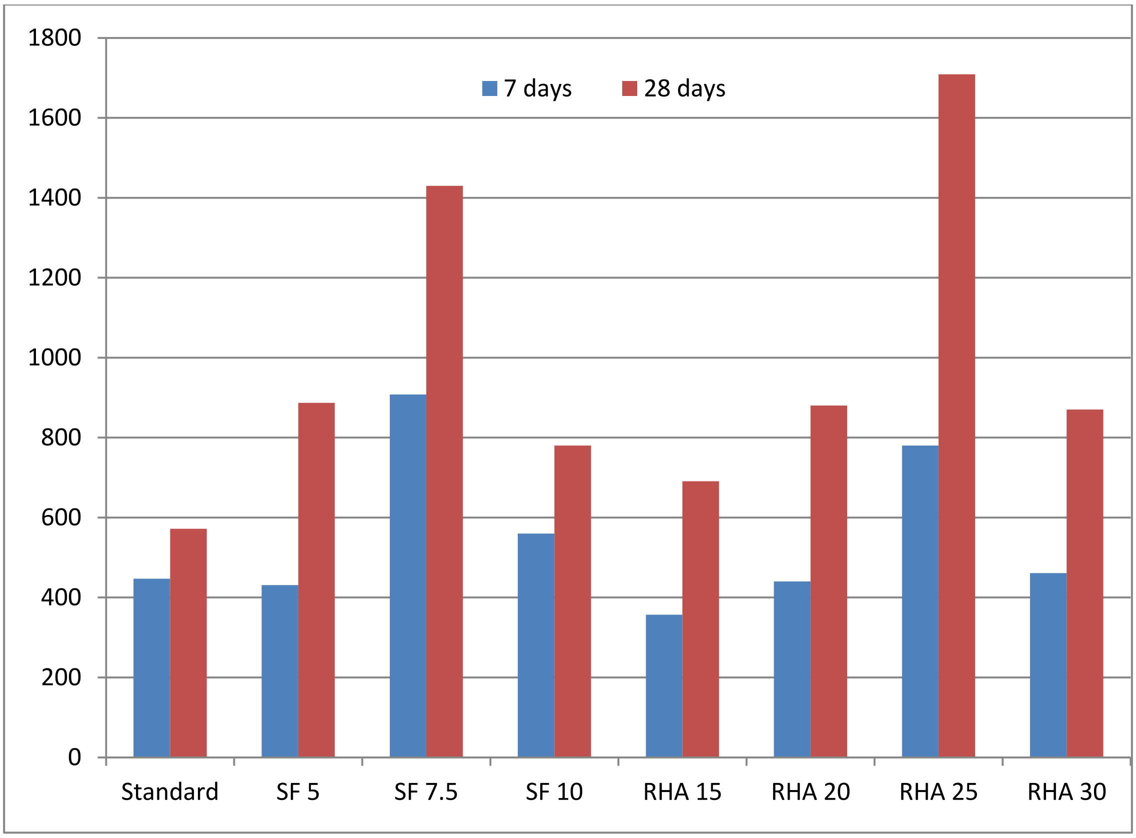


Figure 4.16: Results of the impact tests

Figure 4.17: Specimens of impact test at 7 days testing

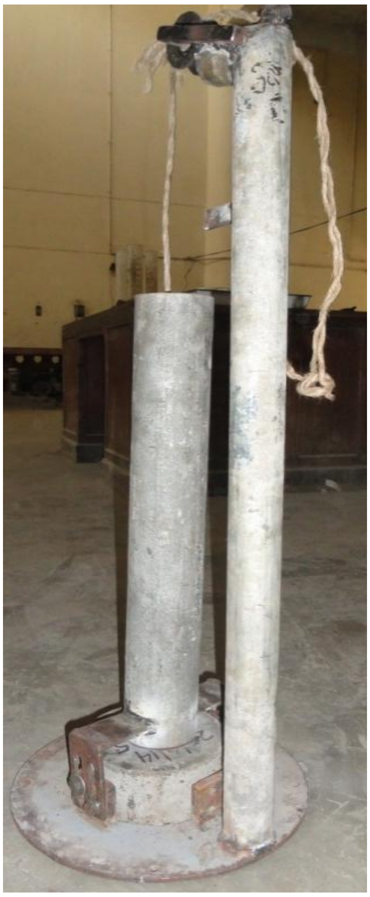


Figure 4.18: Impact test apparatus **Figure 4.19: Photo of failed specimen**

4.8 Cost analysis of the project:

The cost analysis of the project is done according to Delhi schedule of rates 2013.

Table 4.11: Cost of material as per DSR 2013

Material	**Unit**	**Cost /unit**	**Cost /kg**
Cement	Bag(50 kg)	300	6 Rs
RHA	Kg	4	4 Rs
SF	Bag (25 kg)	1000	40
Sand	Cubic m	1120	0.72 paise
Aggregate	Cubic m	106.64	0.688 paise
Super plasticizer	liter	270	270 Rs

Table 4.12: Cost analysis of Concrete (all values in kg)

Denom.	Cement	SRM's	C.A.	F.A	Water	S.P	Total Cost
Standard	749.9	0.0	1205.7	426.2	152.7	11.2	
	4499.4	0.0	829.52	306.86	0	3024	8659.78
SF 5	623.8	37.8	1205.7	481.2	152.7	11.2	
	3742.8	1512	829.52	346.46	0	3024	9454.78
SF 7.5	563.3	55.9	1205.7	509.5	152.7	11.2	
	3379.8	2236	829.52	366.84	0	3024	9836.162
SF 10	502.8	74.5	1205.7	537.3	152.7	11.2	
	3016.8	2980	829.52	386.85	0	3024	10237.18
RHA 15	566.1	110.7	1205.7	440.2	152.7	11.2	
	3396.6	442.8	829.52	316.94	0	3024	8009.86
RHA 20	506.5	149	1205.7	444.8	152.7	11.2	
	3039	596	829.52	320.25	0	3024	7808.77
RHA 25	446.9	186.2	1205.7	449.5	152.7	11.2	
	2681.4	744.8	829.52	323.64	0	3024	7603.36
RHA 30	387.3	223.5	1205.7	454.1	152.7	11.2	
	2323.8	894	829.52	326.95	0	3024	7398.27

Chapter 5
Discussion

5.1. Discussion on Consistency

The results of consistency are given in table 4.1 and figure 4.1. The standard consistency of cement is found to be 28%. When partial replacement of RHA is made at levels 5, 10, 15, 20, 25, 30 % respectively, the consistency of paste increases i.e. the amount of water required to maintain consistent paste increases, as can be seen from the figure 4.1 .The consistency of paste varies from 30 to 40%. The increment is due to the fact that RHA particles have adsorptive character and high fineness which increases their specific surface area.

The results of consistency are given in table 4.2 and figure 4.2. The standard consistency of cement is found to be 28%. When partial replacement of SF is made at levels 5, 7.5 and 10 % respectively the consistency of paste increases i.e. the amount of water required to maintain a consistent paste increases, as can be seen from the figure 4.2 .The consistency of paste varies from 30 to 32 %. The increment is due the increases in its specific surface area.

The consistency with RHA increases more in comparison to SF. This also shows that the fineness and specific surface area of RHA is more than that of SF.

5.2. Discussion on Compaction factor

The results of the compaction factor with RHA are given in table 4.3 and in Figure 4.3. The compaction factor of standard concrete is 0.88. After addition of RHA this compaction factor decreases and varies from 0.85 to 0.80. The decrease in compaction factor is due to the increase in demand of water due to higher surface area of RHA for similar cement content.

The results of the compaction factor with SF are given in table 4.3 and in Figure 4.4. The compaction factor of standard concrete is 0.88. After addition of SF this compaction factor decreases and varies from 0.87 to 0.85. The decrease in compaction factor is due to the increase in demand of water due to higher surface area of SF for similar cement content.

The compaction factor is decreasing with both the SRM's but decrement is more in the case of RHA. Therefore it is not much workable in comparison to SF. But if we consider the cost with reference to strength and workability, then the RHA is more efficient.

5.3. Discussion on Compressive strength of mortar

The results of the compressive strength test for mortar cubes test are shown in table 4.4 and in figure 4.5. The mortar cubes are formed by replacing 15, 20, 25 and 30 % of cement by RHA. At 7 days the, the mortar cubes with RHA replacement shows lesser strength in comparison to standard plain mortar. It shows that the RHA does not gain much early strength in comparison to cement. At 28 days, the mortar cubes with 25% of RHA shows comparable strength with plain mortar. At 56 days the strength of cubes having of 25 % replacement of RHA exceeds the strength of plain mortar. As the age of mortar cubes is increasing the strength is also increasing for all the replacement .At 90 days mortar cubes with 25% replacement of RHA shows the maximum strength at 90 days i.e. of 67 MPa against 61.1 MPa of plane concrete at the same age. As the age of mortar cubes is increasing the strength is also increasing for all the replacement

The results of the compressive strength on mortar with and without SF are shown in table 4.5 and its graphical representation is given in figure 4.6. .The mortar cubes are formed by replacing 5, 7.5 and 10 % of cement by SF. At 7 days the, the mortar cubes with SF replacement shows lesser strength in comparison to standard plain mortar but not as much less as with RHA. It shows that the SF does not gain much early strength in comparison to cement but gains more strength in comparison to RHA. At 28 days, the mortar cubes with 5 and 7.5% of SF shows comparable strength with plain mortar. At 56 days the strength of cubes having of 7.5 % replacement of SF exceeds the strength of plain mortar i.e. reaches 59.2MPa as against the 58.3 of plain mortar. As the age of mortar cubes is increasing the strength is also increasing for all the replacement. At 90 days mortar cubes with 7.5%

replacement of SF shows the maximum strength at 90 days i.e. of 64.8 MPa against 61.1 MPa of plain concrete at the same age.

5.4. Discussion on Compressive strength of concrete

The detailed results for compressive strength are given in Tables 4.6. The partial replacement of Portland cement with RHA at levels 15,20,25,30 resulted in higher compressive strength of concrete at ages 28, 56 and 90 days. At 7 days, the strength of concrete having RHA as replacement has lesser strength in comparison to plain concrete. At 28 days, the strength of concrete with 25 % replacement shows the highest strength i.e. 93.77 MPa against 84.04 MPa of plain concrete. At 90 days also the maximum strength is shown by RHA 25 i.e. 103.84 MPa against 90.44 MPa of plain concrete. The addition of RHA has been found to increase the compressive strength due to the pozzolanic effect. However, the largest strength development happened between 7 and 28 days, as can be seen from Figures 4.8.

The details of compressive strength are given in table 4.6. The partial replacement of Portland cement with SF at levels 5, 7.5 and 10% resulted in greater compressive strength of concrete at ages 28, 56 and 90 days. At 7 days the strength of concrete cubes having SF as replacement shows lesser strength in comparison to standard Specimen. At 28 days SF 7.5 shows the highest strength of 91.11 MPa against 84.04 MPa of plain concrete. The strength of other specimens is also comparable to the standard specimen. At 56 days also, the strength of SF 7.5 is highest i.e. 100.22 MPa against 87.55 MPa of plain concrete. At 90 days the SF 7.5 shows highest strength of 104.44 MPa against 90.44 MPa of plain concrete. However, the largest strength development happened between 3 and 28 days, as can be seen from Figures 4.8.

5.5. Effect of rice husk ash

The RHA significantly increased the compressive strength of concretes at the ages of 28, 56 and 90 days, as evident from Tables 4.6 and Figure 4.8. The improvement of compressive strength is mostly due to the micro-filling ability and pozzolanic activity of RHA. With a smaller particle size, the RHA can fill the micro-voids within the cement particles. Also, the RHA readily reacts with water and calcium hydroxide, a by- product of cement hydration and produces additional calcium silicate hydrate or CSH. The additional CSH increases the compressive strength of concrete since it is a major strength-contributing compound. Also, the additional CSH reduces the porosity of concrete by filling the capillary pores, and thus improves the microstructure of concrete in bulk paste matrix and transition zone leading to increased compressive strength.

5.6. Discussion on Flexure strength

The results of the flexure test are given in table 4.8 and figure 4.12. The flexure strength of the standard specimen increases with the number of curing days. The flexure strength is 9 MPa at 7 days and increases to 12.6 at 90 days. At 7 days, the specimen with partial replacement of RHA shows comparable and increased strength in comparison to standard specimens.at 28 days, the specimen with 25% replacement of RHA shows highest strength of 13.86 MPa against 11.34 of standard specimen. At 56 days again, the specimen with 25% replacement of RHA shows the highest strength of 14.58 MPa against 12.06 of standard specimen. These results are concurrent at 90 days also. RHA 25 shows the highest strength of 15.3MPa.

The specimens with partial replacement of SF at 7 days shows increased strength in comparison to standard specimens. SF 10 shows the highest strength of 11.34 MPa against 9MPa of standard specimen. At 28 days, the partial replacement of cement by SF with 7.5% shows the highest strength of 13.5 MPa against 11.34 of standard specimen. At 56 days, SF 7.5 shows the highest strength of 14.22 MPa against 12.06 MPa of standard specimen. At 90 days also the specimen with 7.5% replacement of SF shows the highest strength of 15.12 MPa against 12.6 MPa of standard specimen.

5.7. Discussion on Impact strength

The results of the impact test are given in table 4.9 and figure 4.16. The number of blows increases as the curing period increases for all the type of concretes. At 7 days, SF 7.5 shows the highest number of blows i.e. 908 as against 447 of plain concrete specimen. At 28 days, SF 7.5 again shows the highest number of blows i.e. 1430 as against 572 of plain concrete.

For the specimens containing RHA as the replacement, the highest value at 7 days is given by RHA 25. The number of blows taken by RHA 25 specimen is 780 for 7 days and 1709 for 28 days. As the number of blows increases, the amount of energy absorbed also increases. The RHA 25 shows the highest energy absorbed due to its dense structure due to the fineness of RHA.

5.8. Discussion on cost effectiveness:

The cost of M100 concrete which has been made in this project is about 8659 Rupees. When the partial replacement of SF is made, the cost of concrete increases, due to the high cost of SF. The cost of 7.5 % replacement of SF is 9836 Rupees which is about 13.5 % more than that of standard concrete.

When the partial replacement of RHA is made the cost of concrete reduces due to the less cost of RHA. The cost of 25% replacement of RHA is 7603 rupees which is about 12.19 % less than the standard concrete. The cost to strength ratio for standard concrete is 95.74, for SF 7.5 is 94.17 and for RHA 25 is 73.21.there is about 23 % reduction in cost to strength ratio as compared with standard specimen.

Figure 5.1: Photo showing compressive test of cubes and cylinder specimens

Figure 5.2: Photo showing flexural test of beam specimen

Chapter 6
Conclusions and future scope of work

6.1 Conclusions

1. The properties of the hardened HPCs were improved at later ages such as 28, 56 and 90 days due to greater hydration of cement and enhanced pozzolanic activity of RHA and SF.

2. The properties of the hardened HPC were improved with higher RHA content due to the micro-filling and pozzolanic effects of rice husk ash. The maximum strength is achieved at 25 % replacement of cement with RHA and 7.5% replacement with SF.

3. The flexure strength of concrete with RHA at 25% cement replacement shows better results in comparison to concrete with SF. The highest values are obtained with RHA at 25% cement replacement and at 7.5 % cement replacement with SF.

4. The impact resistance of concrete also increases with the addition of RHA and SF. The maximum value is given by 25% cement replacement with RHA and 7.5 % cement replacement with SF. They showed that before failure the 25% cement replacement with RHA and 7.5 % cement replacement with SF has absorbed the highest energy.

5. The consistency of cement paste decreases after addition of RHA and also after addition of SF. This is due to change in charge level surface of RHA and SF particles.

6. The mortar compressive strength also shows good results. These results are in synchronization with the results obtained for compressive strength of concrete.

7. The cost of concrete made with 25 % replacement of RHA is minimum. The cost to strength ratio of 25% cement replacement with RHA is also minimum. The cost of concrete with partial replacement of SF increases in comparison to plain concrete.

8. Finally it is concluded that 25 % replacement of cement with RHA can be used as optimum level and shows enhanced strengths at later ages in comparison to SF.

6.2 Future scope of work

1. Modeling of hydration and microstructure development of cement paste containing RHA. Modeling for compressive, flexure and impact strength will be done.

2. Durability of HPC incorporating RHA will by studied, such as chloride penetration, carbonation, alkali silica reactions and behavior under explosions or earthquakes may be carried out.

3. Combination of RHA and other mineral admixtures in producing HPC in terms of sustainable development may be studied.

References

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