EFFECT OF ADDITION OF STONE DUST AS FINE AGGREGATE ON PROPERTIES OF CONCRETE CONTAINING RICE HUSK ASH AS CEMENT REPLACEMENT

Thesis report submitted

in partial fulfilment of the requirement for

award of degree of

MASTER OF ENGINEERING

in

STRUCTURAL ENGINEERING

Submitted by

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DECLARATION

I, Navdeep Singh Oberoi, hereby declare that this thesis report entitled **"EFFECT OF ADDITION OF STONE DUST AS FINE AGGREGATE ON PROPERTIES OF CONCTERE CONTAINING RICE HUSK ASH AS CEMENT REPLACEMENT"** submitted in the partial fulfilment of the requirements for the award of degree of Master of Engineering in Structural Engineering, in the Civil Engineering Department, Thapar University, Patiala, is work done by me.

This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

Date: 30-08-2015

Place: PATIALA

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CERTIFICATE

This is to certify that the work which is presented in this thesis report entitled **"EFFECT OF ADDITION OF STONE DUST AS FINE AGGREGATE ON PROPERTIES OF CONCTERE CONTAINING RICE HUSK ASH AS CEMENT REPLACEMENT"** submitted by **Mr. Navdeep Singh Oberoi, Roll No. 821022002 (P.T.)** in partial fulfilment of the requirements for the award of degree of **Master of Engineering** in **Structural Engineering in Civil Engineering Department** at **Thapar University, Patiala,** is an authentic record of student's own work carried out under my supervision and guidance. The matter embodied in this report has not been submitted anywhere for the award of any degree.

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ABSTRACT

River sand is most commonly used fine aggregate in the production of concrete poses the problem of acute shortage in many areas. The continuous use of river sand has started posing serious problems with respect to its availability, cost and environmental impact. In such a situation the Quarry rock dust or stone dust can be an economic alternative to the river sand.

This thesis aims to find the possibility of the structural usage of stone dust as a fine aggregate as an alternative or mixed in different proportion with natural aggregates. Rice husk ash is used as additional cementing material. A comprehensive literature review is carried out for better understanding of mechanical properties of concrete containing stone dust as fine aggregate and rice husk ash as a cement replacement.

The mixes of M30 grade concrete was prepared with normal sand, stone dust and combination of normal sand and stone (50%-50%) as a fine aggregate. Additional cementing material i.e. rice husk ash was used as a cement replacement with 0%, 10%, 20% and 30% substitution by weight of cement. Tests were conducted on cubes to study the strength of concrete made of Quarry Rock Dust and the results were compared with the Natural Sand Concrete. Primarily, fresh properties, mechanical properties (compressive strength), durability properties (water sorptivity), along with microstructure analysis with XRD and SEM is discussed in the present study.

The tests results revealed that Physical and chemical properties of quarry rock dust satisfies the requirements of Indian Standard code provision for fine aggregate and hence, can be used as possible replacement of fine aggregate. The slump values within the desired range of 50-75 mm were observed for all the mixes. The Slump value increases with increase in percentage replacement of sand with quarry dust for the same w/c ratio and decreases with the addition of rice husk ash as a cement replacement. The compressive strength of concrete made with stone dust increases up to 73% as compare to concrete made with normal sand.

Sorptivity of the concrete decreses with addition of stone dust and rice husk ash. Microstructer analysis revealed that there is also no qualitative change in phases present in concrete on replacement of natural sand with stone dust and cement with rice husk ash. The mix made with stone dust has dense CSH gel formation as compare to concrete made with natural sand.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Research concerning the use of by-products to augment the properties of concrete has been going on for many years. In the recent decades, the efforts have been made to use industry by-products such as fly ash, silica fume, ground granulated blast furnace slag, glass cullet, etc., in concrete manufacturing and civil applications. The potential applications of industry by-products in concrete are as partial aggregate replacement or as partial cement replacement, depending on their chemical composition and grain size. The use of these materials in concrete comes from the environmental constraints in the safe disposal of these products. The last decades marked a period of growth and prosperity in construction industry which involves the use of natural resources. This growth is jeopardized by the lack of natural resources that are available. . On the other hand there has been rapid increase in the industrial waste production. Most of the waste do not find any effective use and cause a waste disposal crisis, thereby contributing to health and environmental problems. Recycling of industrial waste as aggregate is thus a logical option to manage this problem. It has been observed that some of these wastes have high potential and can be utilized as substitute of raw materials in construction industry.

Big attention is being focused on the environment and safeguarding of natural resources and recycling of wastes materials. Many industries are producing a significant number of products which incorporate scrap (residues) such as- reclaimed aggregate, reclaimed asphalt pavement, foundry sand, glass cullet, polyethylene terephthalate, high density polyethylene (HDPE), un plasticized polyvinyl chloride (UPVC) plasticized polyvinyl chloride (PPVC), low density polyethylene (LDPE), polypropylene(PP), polystyrene (PS) expanded polystyrene (UPS).

In the early 19th century, concrete was novel and not very well understood. Presently, most structures use what is known as reinforcement. Steel bars with ribs or notches are added to the concrete to give it strength in tension. Concrete is a very fickle material. After all, this quality was one of the major reasons why it did not gain acceptance for so long.

If there were criterion for a solution for the issues held by concrete, it would meet the following: Low tech, widely available, and be an improvement. A solution would need to be low tech because application needs to not require expensive tools. Barriers, such as these, cause implementation to be limited to the well funded or just slow. Wide availability ensures that people will have access to the material and that it will be cheap. Cost is one of the major contributors to the problem of limited access to concrete aggregate and a cheaper solution would help communities anyway. Concrete's greatest strength of being able to handle high compressive loads also doubles as its greatest weakness in ductility. Not every project would benefit from increase ductility but areas with high seismic loads would view this as a considerable improvement.

The basic ingredients of the concrete are cement, fine and coarse aggregates and water. Aggregate is a broad category of coarse material used in construction, including sand, gravel, crushed stone, slag, recycled concrete and geosynthetic aggregates. Aggregates are the most mined materials in the world. Fine and coarse aggregates are naturally occurring resources, which results that these resources are depleting at a very high rate. Engineers and environmentalists are making efforts to use the waste produced from the demolition of various structures as a substitute of natural aggregates. Researchers has suggested the possibility of appropriately treating and reusing concrete as aggregate in new concrete, especially in lower level applications.

1.2 WHY REPLACEMENT OF AGGREGATE NEEDED?

The aggregate typically account for 70-80% of the concrete volume and play a substantial role in different concrete properties such as workability, strength, dimensional stability and durability. Conventional concrete consists of sand as fine aggregate and gravel, limestone or granite in various sizes and shapes as coarse aggregate. There is growing interest in using waste materials as alternative aggregate materials and significant research is made on the use of many different materials as aggregate substitute as coal ash, blast furnace slag, fibre glass waste materials, waste plastics, rubber waste and others. The consumption of waste materials can be increased manifold if these are used as aggregate into concrete. This type of use of a waste material can solve problems of lack of aggregate in various construction sites and reduce environmental problems related to aggregate mining and waste disposal. The use of waste aggregates can also reduce the cost of concrete production. As aggregates can significantly control the properties of concrete, the properties of the aggregates have a great importance. Therefore a thorough evaluation is necessary before using any waste material as aggregate in concrete. Significant work has been done on the use of several types of waste materials as an aggregate in concrete.

1.3 WHAT IS STONE DUST?

Stone Dust or Quarry Rock Dust can be defined as residue, tailing or other non-valuable material obtained after the extraction and processing of rocks to form fine particles, less than 4.75mm. Quarry dust is made while blasting, crushing, and screening of coarse aggregate. Quarry dust has rough, sharp and angular particles, and as such causes a gain in strength due to better interlocking (R. Ilangovana1 et al 2008).

Fig. 1.1 Stone Dust

1.4 USE OF STONE DUST IN CONCRETE:

The use of quarry dust in concrete is desirable because of its benefits such as useful disposal of by-products, reduction of river sand consumption as well as increasing the strength parameters and increasing the workability of concrete. On the other hand, the advantages of utilization of by-products or aggregates obtained as waste materials are pronounced in the aspects of reduction in environmental load and waste management cost, reduction of production cost as well as improving the quality of concrete. Stone dust can be used either as replacement of cement or of fine aggregate in concrete. The use of stone dust concrete makes concrete financially more attractive and reduces the CO_2 footprint of the produced concrete products. The following study deals with deals with stone dust as fine aggregate replacement of concrete.

1.5 GRADATION OF STONE DUST:

Sieve analysis (or gradation test) is a practice or procedure used to assess the particle size distribution for sand. Gradation affects many properties of a fine aggregate. With careful selection of the gradation, it is possible to achieve high bulk density, and low permeability. Sieve analysis of fine aggregates determined as per IS: 383 (1970) given in Table 1.1

Table 1.1 Sieve analysis of Natural sand and stone dust (S. P. S. Rajput 2014)

Sieve Designation	Percentage Passing		Grading Limits for Zone II Sand (IS 383)
	Natural Sand	Crushed stone dust	
4.75 mm (No.4)	100	100	90-100
2.36 mm (No. 8)	99.3	94.5	75-100
1.18 mm (No.16)	97.1	69.2	55-90
600 micron (No.30)	89	49.8	35-59
300 micron (No.50)	2.7	21.4	08 - 30
150 micron (No.100)	1	6.1	0-10

1.6 COMPARISON OF PHYSICAL PROPERTIES OF STONE DUST WITH NATURAL SAND

The physical properties of stone dust are mentioned in table 1.2.

Table 1.2 Physical properties of stone dust and natural sand (R. Ilangovana1 et al 2008).

Property	Quarry rock dust	Natural sand	Test method
Specific gravity	2.54-2.60	2.60	[5] IS 2386 (Part III) 1963
Bulk relative density (kg/m^3)	1720-1810	1460	IS 2386 (Part III) 1963
Absorption (%)	1.20-1.50	Nil	IS 2386 (Part III) 1963
Moisture content (%)	Nil	1.50	IS 2386 (Part III) 1963
Fine particles less than 0.075mm (%)	12-15	06	[5] IS 2386 (Part I) 1963
Sieve analysis	Zone II	Zone II	[4]IS 383 - 1970

1.7 COMPARISON OF CHEMICAL PROPERTIES OF STONE DUST WITH NATURAL SAND

The Chemical properties of stone dust are given in table 1.3.

Table 1.3 Chemical properties of stone dust and natural sand (R. Ilangovana1 et al 2008).

Constituent	Quarry rock dust (%)	Natural sand (%)	Test method
SiO_2	62.48	80.78	[10]IS: 4032-1968
Al_2O_3	18.72	10.52	
Fe_2O_3	06.54	01.75	
CaO	04.83	03.21	
MgO	02.56	00.77	
Na_2O	Nil	01.37	
K_2O	03.18	01.23	
TiO_2	01.21	Nil	
Loss of ignition	00.48	00.37	

1.8 PRODUCTION OF STONE DUST OR QUARRY DUST

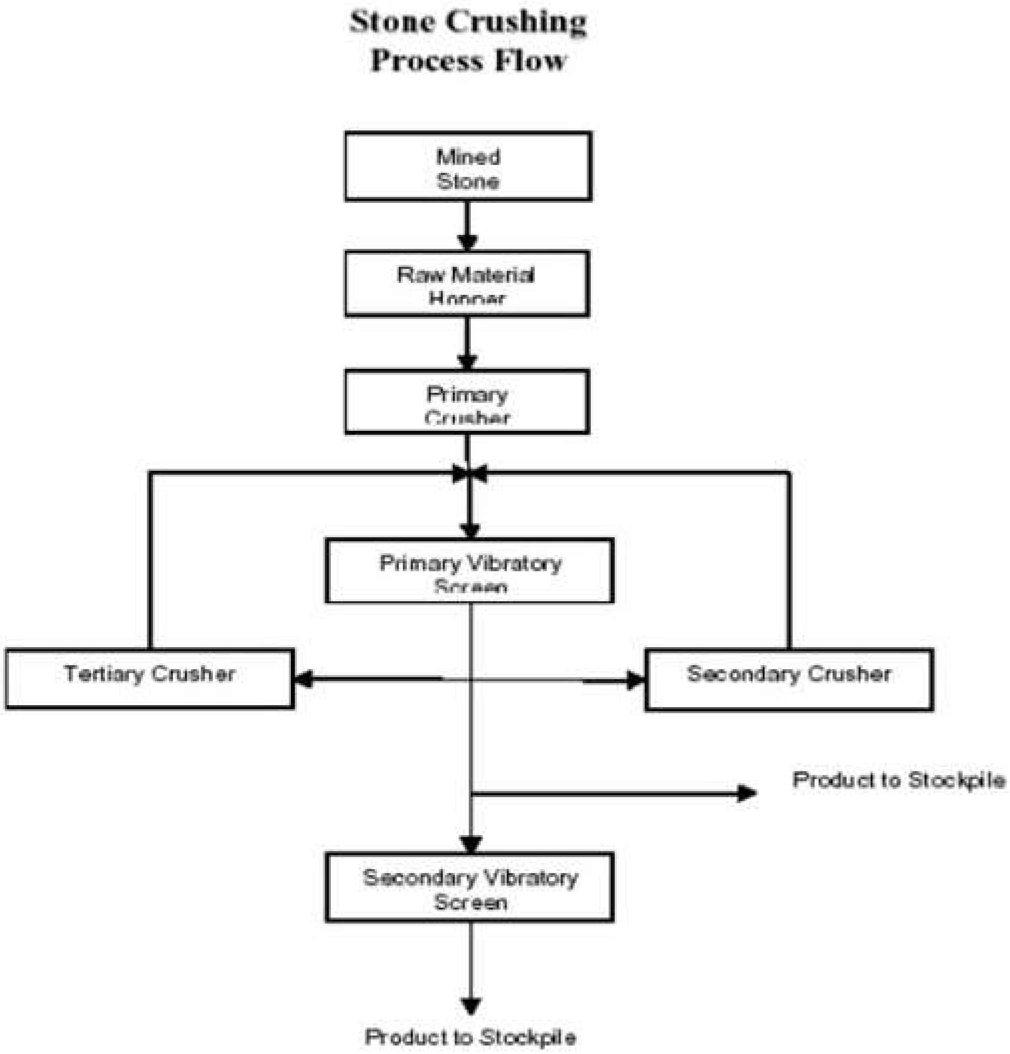


Fig 1.2: Production process of stone dust

1.9 PROSPECTS IN INDIA

In general, the demand of natural sand is quite high in developing countries to satisfy the rapid infrastructural growth. In this situation, developing country like India is facing shortage of good quality natural sand. Particularly in India, natural sand deposits are being depleted and causing serious threat to environment as well as the society. Increasing extraction of natural sand from river beds causing many problems, loosing water retaining sand strata, deepening of the river courses and causing bank slides, loss of vegetation on the bank of rivers, exposing the intake well of water supply schemes, disturbs the aquatic life as well as affecting agriculture due to lowering the underground water table etc are few examples. In past decade variable cost of natural sand used as fine aggregate in concrete increased the cost of construction. In this situation research began for inexpensive and easily available alternative material to natural sand.

In India the extractive activity of decorative sedimentary carbonate rocks, commercially indicated as Marbles and “Granites”, is one of the most thriving industry. Marble sludge powder is an industrial waste containing heavy metals in its constitutes. Stone slurry generated during processing corresponds to around 40% of the dimension stone industry final product. This is relevant because dimension stone industry presents an annual output of 68 million tons of processed product. Thus Crushed stone dust, as a fine aggregate, is an attractive alternative of river sand for cement Concrete. It is purpose made fine aggregate produced by crushing and screening or further processing i.e. washing, grading, classifying of quarried rock, cobbles, boulders or gravels from which natural fine aggregate had been removed.

1.10 USE OF ADDITIONAL MATERIALS

From the viewpoint of sustainability and durability, immense number of studies on the partial replacement of Portland cement with various mineral admixtures such as fly ash, blast furnace slag, silica fume, nano-silica and lime powder were used. In most of the countries, different cementitious materials such as Fly-Ash,Ground Granulated Blast furnace Slag (GGBS), Silica Fume and Rice Husk Ash (RHA) is used to achieve high performance, good quality and low cost concrete mixtures. Satisfactory properties compressive strength, bond strength, split tensile strength of Concrete mixes have been reported, depending on the replacement of cement and natural aggregates and type of mineral admixtures used.

1.11 RICE HUSK ASH (RHA):

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. 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 it by making commercial use of this RHA.

1.12 WHAT IS RICE HUSK ASH?

Rice milling generates a by-product known as husk. This surrounds the paddy grain. During the milling of paddy about 78 % of weight is received as rice, broken rice and bran. The rest 22 % of the weight of paddy is received as husk. This husk is used as fuel in the rice mills to generate steam for the parboiling process. This husk contains about 75 % organic volatile matter which burns up and the balance 25 % of the weight of this husk is converted into ash during the firing process, which is known as **rice husk ash (RHA)** (Fig 1.3)**.** Rice husk was burnt approximately 48 hours under uncontrolled combustion process. The burning temperature was within the range of 600 to 850 degrees. The ash obtained was ground in a ball mill for 30 minutes and its color was seen as grey. This RHA in turn contains around 85%-90% amorphous silica. So for every 1000 kg of paddy milled, about 220kg (22%) of husk is produced, and when this husk is burnt in the boilers, about 55kg (25%) of RHA is generated.

Fig. 1.3 Rice husk ash

Rice husk ash (RHA) can be used as a highly reactive pozzolanic material to improve the:

- microstructure of the interfacial transition zone (ITZ) between the cement paste and the aggregate in high-performance concrete. The utilization of rice husk ash as a pozzolanic material in cement and concrete provides several advantages, such as improved compressive strength and durability properties, reduced materials cost due to cement savings, environmental benefits related to the disposal of waste materials and reduced carbon dioxide emissions.
- The cements containing Rice Husk Ash possess excellent resistance to dilute organic and mineral acids.
- It is also highly absorbent, and is used to absorb oil on hard surfaces and potentially to filter arsenic from water.

1.13 APPLICATIONS OF RICE HUSK ASH

- **Cement and concrete-** It is an active pozzolan which when combined with lime in the presence of water results in a stable and more amorphous hydrate (calcium silicate). This is stronger, less permeable and more resistant to chemical attack (Owens, 1999).
- **Steel industry-** Rice husk ash is used by the steal industry in the production of high quality flat steel used for automotive body panels (Sugita, 1993).
- **Oil absorbent-** Husks burnt slowly over a period of six months have been found to be effective as oil absorbent and are marketed in California under the trade name 'Greas weep'.
- **Soil ameliorant-** RHA help break up clay soils and improve soil structure. Its porous nature also assists with water distribution in the soil. .RHA was found to increase the pH of the soil, and so was recommended for use with plants which require alkaline soil, or in situations where acid irrigation water is present.
- **Silicon chips-** The Indian Space Research Organization has successfully developed technology for producing high purity precipitated silica from RHA and this has a potential use in the computer industry. Consortiums of American and Brazilian scientists have also developed ways to extract and purify silicon with the aim of using it in semiconductor manufacture.

- **Refractory bricks-** Refractory bricks are used in furnaces which are exposed to extreme temperatures, such as in blast furnaces used for producing molten iron and in the production of cement clinker.

- **Light weight insulating material -** There is anecdotal evidence of RHA being used in the manufacture of lightweight insulating boards in developing countries. Research at the University of Arkansas has also focused the manufacture of insulation from RHA. The material produced is very low density and so lightweight it floats.

The main field of application is as pozzolanic material for high performance concrete. Physical and chemical properties of Rice Husk Ash are shown in Table .1.4 and 1.5 respectively.

Table: 1.4. Physical properties of Rice Husk

Sr.no.	Particulars	Properties
1	Color	Gray
2	Shape Texture	Irregular
3	Mineralogy	Non Crystalline
4	Particle Size	< 45 Micron
5	Odour	Odourless
6	Specific Gravity	2.3
7	Appearance	Very Fine

Table .1.5 Chemical properties of Rice Husk Ash

Sr.no.	Particulars	Properties
1	Silicon dioxide	86.94%
2	Aluminium Oxide	0.2%
3	Ion Oxide	0.1%
4	Calcium Oxide	0.3-2.2
5	Magnesium Oxide	0.2-0.6%
6	Sodium Oxide	0.1-08%
7	Potassium Oxide	2.15-2.30%
8	Loss of Ignition	3.15-4.4%

1.14 OBJECTIVE OF PRESENT STUDY

The review of literature reported in Chapter 2 indicates that scanty work has been carried out to investigate the bond strength properties of recycled aggregates with varying replacement ratios. Therefore, the main objective of the present study is to investigate and comparison of characteristic strength of concrete containing Normal sand and Quarry dust as Fine aggregates with RHA as replacement of cement in different proportions.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

This chapter gives a comprehensive review of the work carried out by various researchers in the field of using stone dust/ Quarry dust and Rice Husk Ash in concrete as full or partial replacement of aggregates and cement.

2.2. EFFECT OF STONE DUST ON FRESH PROPERTIES OF CONCRETE

Some of the required fresh properties of fresh concrete are workability characteristics of concrete, which include slump, loss of slump and bleeding. All these aspects are discussed in the following section.

2.2.1 Density

Hebhoub et al [2011] demonstrated the possibility of using marble wastes as a substitute rather than natural aggregates in concrete production. The experimental investigation was carried out on three series of concrete mixtures: sand substitution mixture, gravel substitution mixture and a mixture of both aggregates (sand and gravel). The concrete formulations were produced with a constant water/cement ratio. The results obtained show that the mechanical properties of concrete specimens produced using the marble wastes were found to conform to the concrete production standards and the substitution of natural aggregates by waste marble aggregates up to 75% of any formulation is beneficial for the concrete resistance. The main characteristics of the aggregates are resumed in Table 2.1.

The experimental program was applied to concrete mixes according to the percentage of substitution of natural aggregates with recycled aggregates (marble waste) and is summarized as follows:

–The natural sand (NS) is substituted by the recycled sand (RS) at 25%, 50%, 75% and 100%. The concrete formulation is noted (S).

– Natural aggregates mixtures are noted (NA).

Table 2.1 Physical and chemical characteristics of marble (Hebhoub et al 2011)

Physico-mechanical properties	White Fil-Fila marble
True density (g/cm^3)	2.736
Bulk density (kg/cm^3)	2.684
Porosity (%)	1.96
Absorption (by weight) (%)	0.39
Saturation (%)	0.87
Compressive strength (dry state) (MPa)	94.3
Compressive strength (after cooling and reheating) (MPa)	94.8
Wear resistance (mm)	1.82
Impact resistance (cm)	40
Chemical characteristics	
$CaCO_3$	99.05
MgO	1.03
CaO	54.86
Fe_2O_3	0.04
Al_2O_3	0.08
SiO_2	0.15
P.C	44.26

The density of the concrete mixtures (Fig. 2.1) does not change much over the change of the mixture or the substitution rate. Therefore, the variation of density values is relatively low and generally acceptable. The density of concrete is a function of the initial materials densities, mix proportions, initial and final water content and hydration degree. It can be expected that the recycled aggregates (marble waste) may have an influence on the density of concrete. The density values of different mixtures vary due to the different percentage of substitution content.

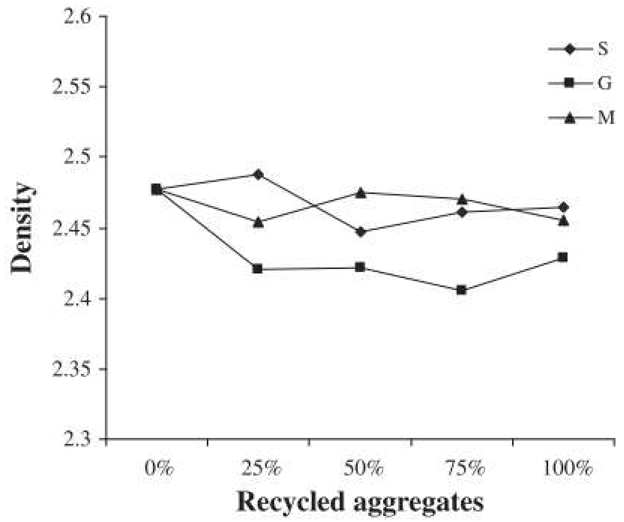


Fig. 2.1 Concrete density versus recycled aggregates (marble waste) substitution rate (Hebhoub et al 2011)

Gritsada et al [2013] concluded that the unit weight of the SCC increased with increasing Alumina Waste (AW) replacement and decreased with increasing cement content. The higher unit weight of AW-containing mixtures was due to the greater density of the AW particles and a filler effect caused by the finer particle size.

2.2.2 Air Content

Hebhoub et al [2011] illustrated the variation of air content according to the substitution rate of the recycled aggregates (marble waste) of the three mixtures [Fig. 2.2]. The air content values are acceptable and the maximum value is obtained for the mixture (S) at 100% of recycled aggregates. It is known that the air content is dependent on mix design proportions and is usually determined to ensure the presence of air entrainment for freeze–thaw durability.

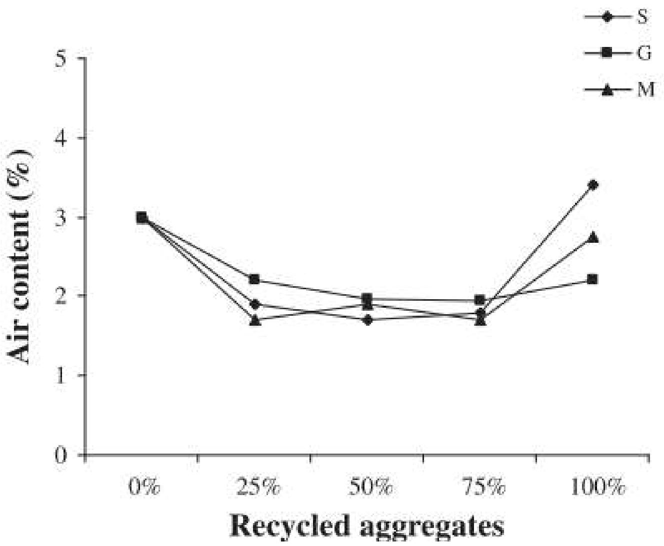


Fig. 2.2 Air content of concrete with recycled aggregates (marble waste) substitution rate (Hebhoub et al 2011)

2.2.3 Workability

The slump test is a convenient mean of measuring the workability of the concrete mix. It is therefore useful in controlling the quality of the concrete produced. The slump flow is reported as the mean diameter achieved by the concrete mass after lifting the inverted slump mold. The slump flow time is the amount of time required for the mixture to reach a diameter of 500 mm.

Hebhoub et al [2011] presented the curves (Fig. 2.3) which explain how levels of workability were achieved by these concrete formulations. They provide knowledge on the effects of the properties and proportions of mixture aggregates. They indicate that concrete workability decreases with the increase of the substitution rate. The workability has decreased for all mixtures with marble waste aggregates. However, some of the factors that may affect the workability of these concretes are grading and shape of fine aggregates, proportion of fine to coarse aggregates and characteristics of the materials. The main critical parameter in the workability is that natural aggregates absorb more water than waste marble aggregates. Therefore, the correct quantity of water required for the mixes needs correction and depends on the mix proportions.

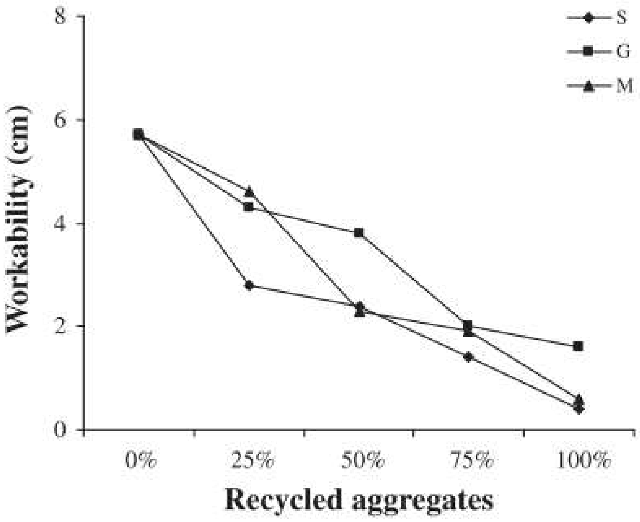


Fig. 2.3 Workability of concrete according to recycled aggregates (marble waste) substitution rate (Hebhoub et al 2011)

Gritsada et al [2013] studied the feasibility of using alumina waste (AW) as a partial replacement for the fine aggregate in self-compacting concrete (SCC). The fine aggregate was replaced with up to 100% AW by weight. All of the mixtures exhibited satisfactory average slump flows of 700 ± 25 mm diameter (Fig. 2.4), which is an indication of good workability. The slump flow time increased with increasing AW content to 75%, then decreased in mixtures containing 100% AW. The flow time increased due to the increase in the quantity of water absorbed by the AW, which increased the viscosity of the paste and reduced the workability. The decrease in flow time in the 100% AW mixture was due to the absence of an interlocking effect in the AW particles, which also resulted in an unstable mortar mixture.

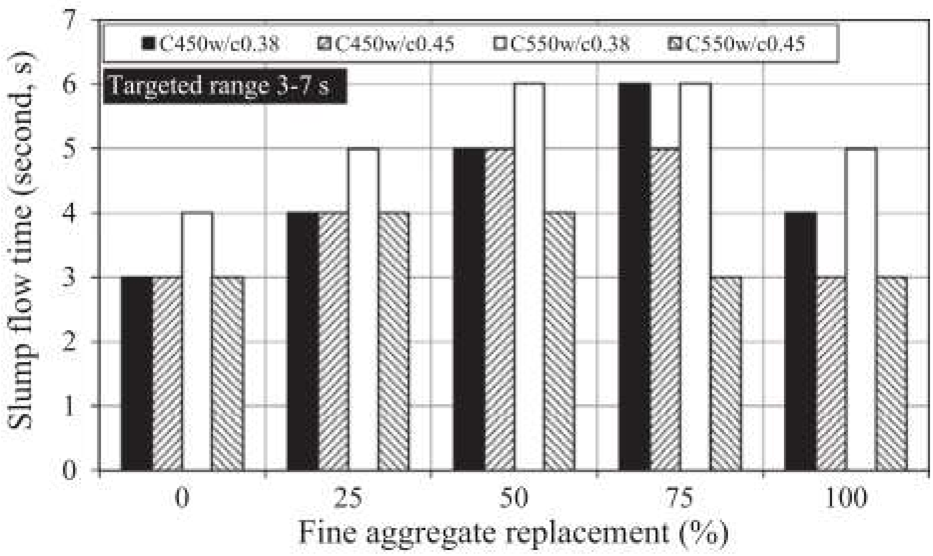


Fig 2.4 Slump flow times for SCC mixture (Gritsada et al 2013)

Almeida et al [2007] describes the behaviour of high-performance white cement concrete, incorporating stone dust, in terms of its fresh and hardened concrete properties. The stone dust chosen for these experiments was white to light coloured (originated from limestone and marble). It was expected that this dust was compatible with, or might even enhance, the characteristics of regular white cement concrete. Eight concrete mixtures with stone dust (CMSD) were produced, replacing 0% (reference mixture), 5%, 10%, 15%, 20%, 34%, 67% and 100% of fine aggregate (sand), in terms of volume. All concrete mixtures were set with a slump of 230±10 mm and a spread of 550±10 mm, obtained by adjusting the water/cement ratio. As a result of the stone dust introduction, the very fine material content increased and the water need (for constant workability) decreased, thus lowering the water/cement and water/microfines ratios. The results indicated that dust particles had size, form and texture that benefited fresh concrete workability. For these ratios of dust incorporation, higher workability prevailed over the higher specific surface area of the dust particles, comparing with the substituted sand particles. From 0 to 10% of dust incorporation, there was lower water demand, superior behaviour of fresh concrete, better grading, efficient packing, and better aesthetic of finished concrete elements [Fig. 2.5]

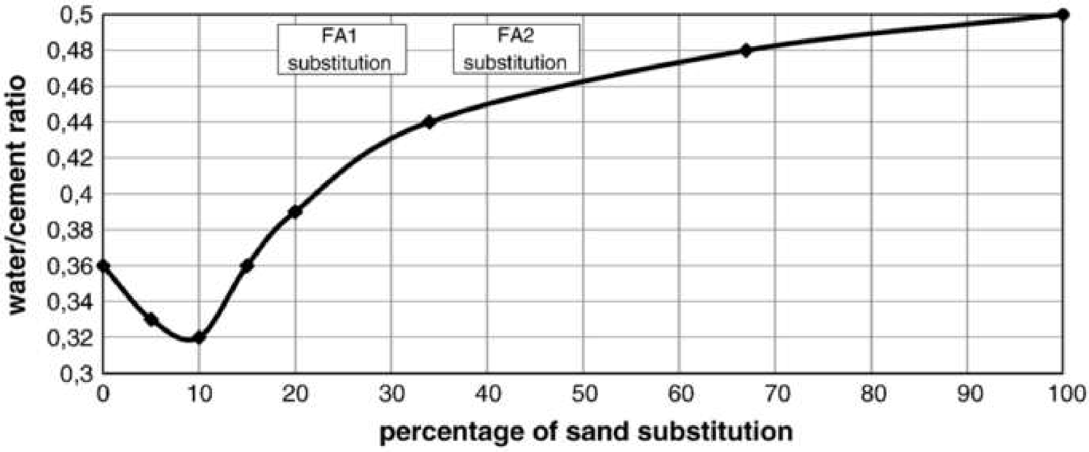


Fig. 2.5 Water/cement ratio variation according to the sand substitution percentage (Almeida et al 2007)

Comparing with the 0–10% range, there was a behaviourv reversal. Variation was characterized by increasing water demand, thus higher water/cement ratio (for constant workability). Water/microfines ratio also increased, due to a higher specific surface area. Possibly, there was also deficient grading due to the introduction of stone dust in detriment of sand (as shown in Fig. 2.6).

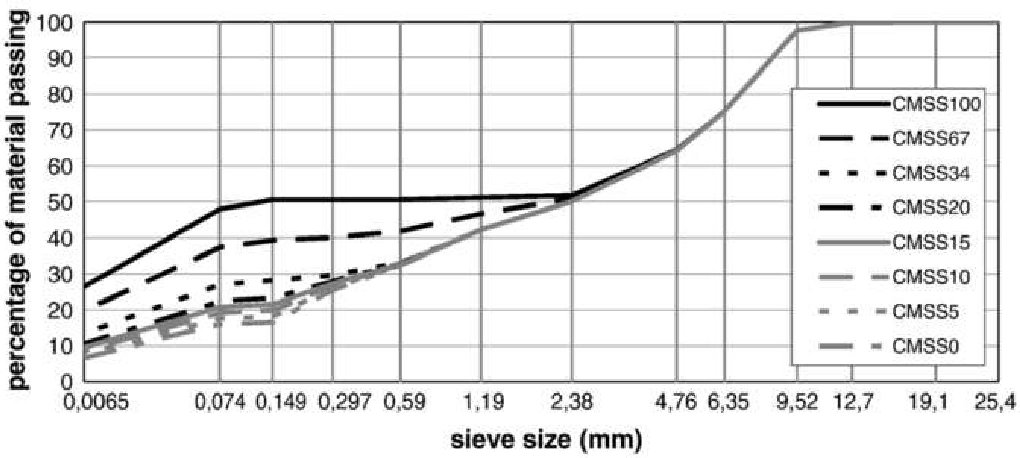


Fig. 2.6 Grading variation due to substitution of fine aggregate for stone dust (Almeida et al 2007)

Even though water demand increased, the sensitivity to very high levels of sand substitution was reduced. The water/microfines ratio regained the expected tendency (decreasing). Generally, stone dust (regardless of the incorporated amount) incorporation induced more paste, thus improving fresh concrete behaviour in terms of viscosity and showing good potential to be used in self compacting concrete mixtures.

2.2.4 Flowing Ability

The V-funnel test determines the time required for a concrete mixture to flow through a funnel and provides a means of evaluating the viscosity and segregation resistance of concrete mixtures.

Gritsada et al [2013] studied the feasibility of using alumina waste (AW) as a partial replacement for the fine aggregate in self-compacting concrete (SCC). Alumina is a common by-product of industrial grit blasting operations. The mixtures were designed to produce a controlled slump flow diameter. The fine aggregate was replaced with up to 100% AW by weight.

Table 2.2 SCC Mixture proportions (Gritsada et al 2013)

Mix no.	AW (% mass)	w/c	Materials (kg/m^3)				
			Cement	Fine aggregate		Water	Coarse aggregate
				Sand	AW		
1	0	0.38	450	922	0	171	804
2	25	0.38	450	692	230	171	804
3	50	0.38	450	461	461	171	804
4	75	0.38	450	230	692	171	804
5	100	0.38	450	0	922	171	804
6	0	0.45	450	922	0	202	804
7	25	0.45	450	692	230	202	804
8	50	0.45	450	461	461	202	804
9	75	0.45	450	230	692	202	804
10	100	0.45	450	0	922	202	804
11	0	0.38	550	813	0	209	708
12	25	0.38	550	610	203	209	708
13	50	0.38	550	407	406	209	708
14	75	0.38	550	203	610	209	708
15	100	0.38	550	0	813	209	708
16	0	0.45	550	813	0	248	708
17	25	0.45	550	610	203	248	708
18	50	0.45	550	407	406	248	708
19	75	0.45	550	203	610	248	708
20	100	0.45	550	0	813	248	708

The compositions of the SCC mixtures are listed in Table 2.2. Mixtures were prepared containing various fine aggregate replacement amounts. The cement content was held constant at 450 or 550 kg/m 3. The water content was adjusted to achieve a w/c ratio of 0.38 or 0.45. Mass measurements were preferred to volume measurements due to the significant difference in specific gravity between AW and sand. AW was used to replace natural sand in amounts of 0%, 25%, 50%, 75, or 100% by weight.

The flow time increased in proportion to the water requirement and level of aggregate replacement. In mixtures 2, 3, 8, 13, 14, and 19 (Fig. 2.7), the V-funnel values were within the acceptable range, as the AW particles absorbed sufficient water to produce a highly viscous mix and reduce bleeding effects. Flow times could not be measured for the 100% mixture, and it appears that mixtures containing 50–75% AW represent the ideal composition in terms of V-funnel measurements.

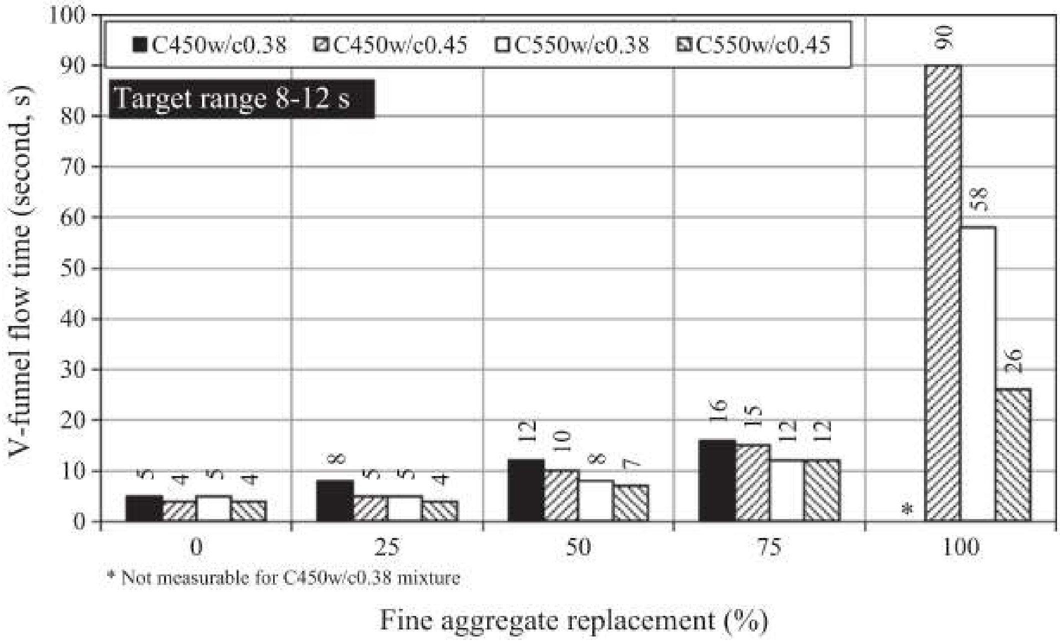


Fig. 2.7 V-funnel flow times for SCC mixtures (Gritsada et al 2013)

2.2.5 Passing Ability

The J-ring and slump flow tests provide a means of determining the passing ability of SCC, or the ability of the concrete to flow under its own weight to completely fill all voids. The differences in the slump flow and J-ring flow diameters were used to assign a blocking assessment according to the criteria defined in ASTM C1621, in which 0–25 mm is defined as no visible blocking, 25–50 mm is defined as minimal to noticeable blocking, and greater than 50 mm is defined as noticeable to extreme blocking

Gritsada Sua-iam et al [2013] concluded that the samples containing greater amounts of cement exhibited minimal or no apparent blocking, while extreme blocking was observed in samples with low cement content. In J-ring tests, mixtures containing AW achieved adequate passing ability and maintained sufficient resistance to segregation around congested reinforcement areas due to the combined influence of increased cement content, decreased water-cement ratio, and increased viscosity.

2.3 MECHANICAL PROPERTIES

2.3.1 Compressive Strength

Hebhoub et al [2011] showed that compressive and tensile strength are the most important investigated properties of the concrete. The specimens were tested at 2, 14, 28 and 90 days of curing in order to assess the strength development according to sand substitution at different percentages. The recycled aggregates (marble waste) affected the compressive strength (Fig. 2.8) at a certain rate of substitution. The (S) formulation showed a significant strength gain, the compressive strength with the substitution rate of 25%, 50% and 75% are fairly greater than values obtained with natural aggregates. The curves clearly show that the concrete with 100% substitution rate provided poor results in strength.

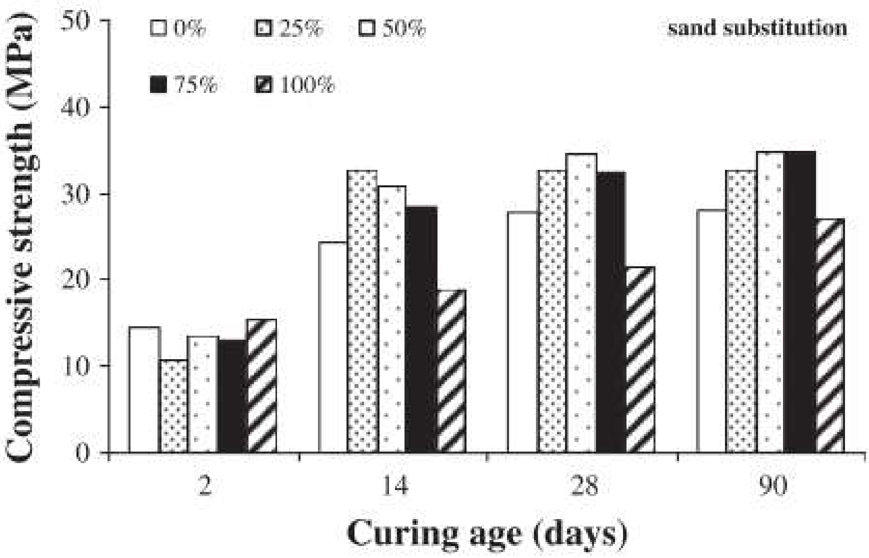


Fig. 2.8 The compressive strength versus the curing age, formulation (S) (Hebhoub et al 2011)

Fig 2.9 to 2.11 shows the formulation (S) of sand substitution provided low compressive strength. That being said, the substitution of natural aggregates with waste marble aggregates at a certain percentage of any formulation appears beneficial for the resistance except for the 100% substitution rate which reduces the resistance.

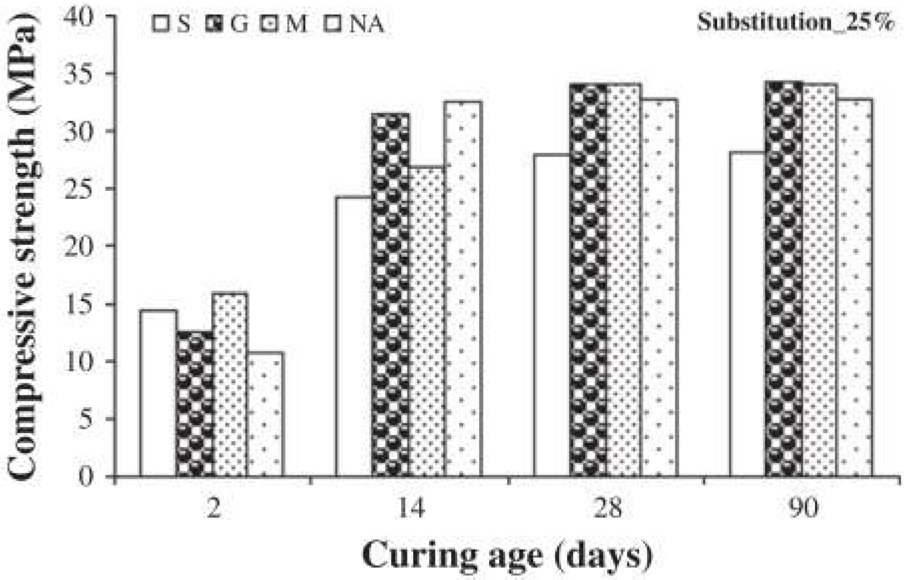


Fig. 2.9 The compressive strength versus the curing age, 25% of substitution (Hebhoub et al 2011)

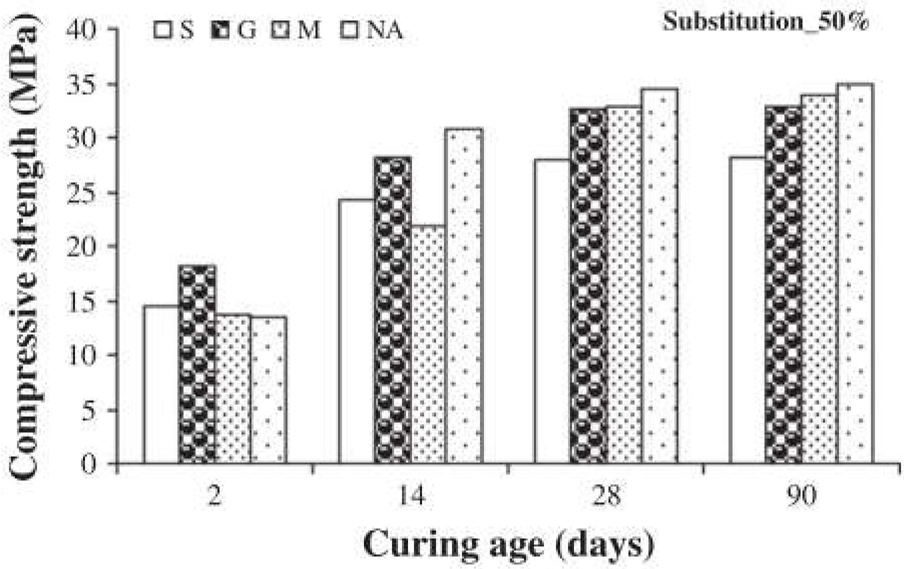


Fig. 2.10 The compressive strength versus the curing age, 50% of substitution (Hebhoub et al 2011)

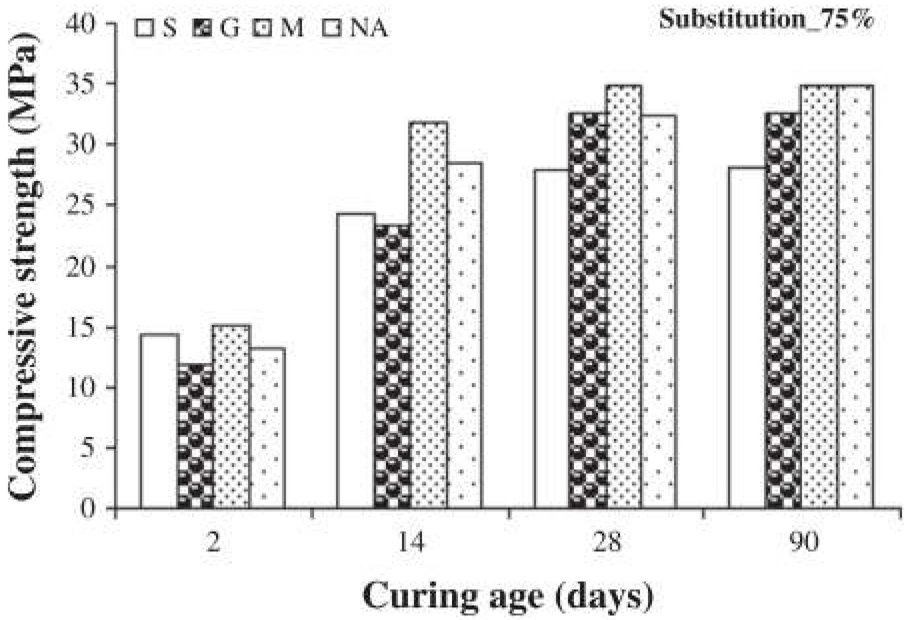


Fig. 2.11 The compressive strength versus the curing age, 75% of substitution (Hebhoub et al 2011)

Gritsada et al [2013] concluded that compressive strength continued to increase over the 91-day curing period. The 28-day compressive strength ranged from 22.9 to 59.9 MPa, while the 91-day compressive strength ranged from 28.6 to 66.6 MPa. The greatest compressive strength at 28 and 91 days was achieved in the high-cement, low w/c ratio mixture containing 75% AW. Conversely, the lowest compressive strength at all ages occurred in samples containing 0% AW. The increase in strength was ascribed to the filling ability and pozzolanic activity of AW]. The added alumina may be amorphous or glassy and reacts with calcium hydroxide produced from the hydration of calcium aluminates. The rate of the pozzolanic reaction is proportional to the amount of surface area available for reaction. The mechanical interlocking capacity between the fine aggregate particles and the matrix phase, which improves the mechanical performance of the transition zone, is related to the compressive strength. Both of these properties improve the microstructure in the bulk paste matrix and transition zone. The compressive strength of concrete increases with curing time. Moreover, the binding mechanisms of radionuclides to cement eventually enter calcium–silicate–hydrate (C–S–H)]. On the other hand, mixtures containing 100% AW possessed lower compressive strengths due to the lack of interlocking between the AW particles indicated by longer V-funnel flow times. In addition, residual impurities on the AW surface interfered with the bond between the cement paste and the alumina waste .

Almeida et al [2007] shown that by replacing 5% of the initial sand content with stone dust (CMSD5), 10.3% higher compressive strength after 7 days and 7.1% higher compressive strength after 28 days were detected (Fig. 2.12). Eight concrete mixtures with stone dust (CMSD) were prepared, replacing 0% (reference mixture), 5%, 10%, 15%, 20%, 34%, 67% and 100% of fine aggregate (sand), in terms of volume. The increase in compressive strength can be related to the higher concentration of hydrated cement compounds within the available space for them to occupy. Furthermore, by acting as micro filler, the stone dust promoted an accelerated formation of hydrated compounds, thus resulted a significant improvement of compressive strength at earlier ages (7days).

Regarding higher contents of stone dust (substitution of more than 20% of sand), the decrease of compressive strength values was significant. The incorporation of such amounts of very fine material did not permit the microfiller effect to prevail, which, in addition to a rather inappropriate grading, caused lower results. When substituting all the sand for stone dust (CMSD100), test results showed 50.3 MPa at 28 days and 30.1 MPa at 7 days. Whereas these results were acceptable by comparison with conventional concrete, the relative reduction amounted 40.9% for 28 days and 50.1% for 7 days. Therefore, it is possible to conclude that full substitution of fine aggregate for stone dust is not reliable when compressive strength is a critical aspect to take in consideration.

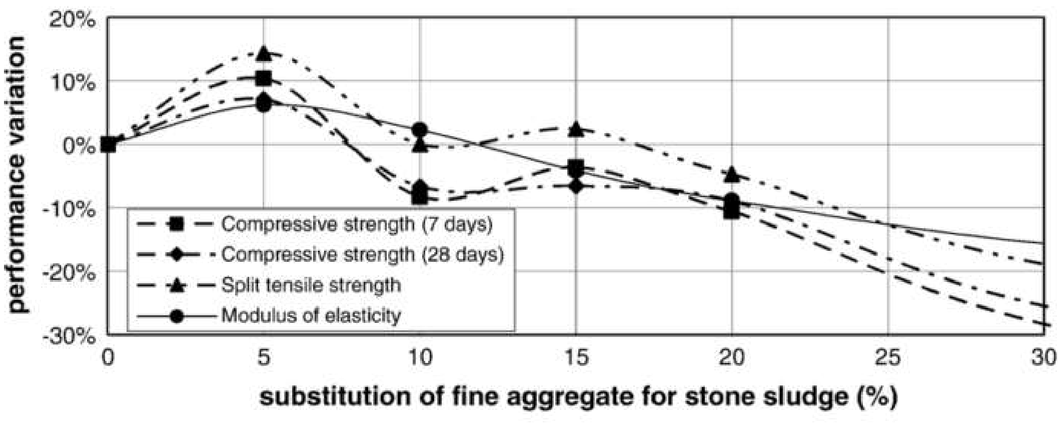


Fig. 2.12. Variation of mechanical properties for low contents of stone dust (Almeida et al 2007)

Omar et al [2012] investigated the influence partial replacement of sand with limestone waste (LSW), with marble powder (M.P) as an additive on the concrete properties. The replacement proportion of sand with limestone waste, 25%, 50%, and

75% were practiced in the concrete mixes. Besides, proportions of 5%, 10% and 15% marble powder were practiced in the concrete mixes. Compressive strength test results of normal concrete with LSW with different replacement percentages are presented in Table 2.3 for 0.0, 25, 50, and 75%, respectively. Using LSW with levels 25% and 50% increased compressive strength of normal concrete about (6%, 13%, 8%) 25 , (10%, 12%, 11%) 50 at 7, 28 and 90 days respectively, as compared with the normal concrete N_{350}(represents cement content 350 Kg/m^3).

Table 2.3 Results of the compressive strength specimens (Omar et al 2012)

Mix symbol	% (LSW)	% (M.P)	Compressive strength (MPa)		
			7 days	28 days	90 days
N^{*}_{-350}	0.0	0.0	26.2	33.5	36.7
$N_{25\text{-}350}$	25		27.9	38.1	39.7
$N_{50\text{-}350}$	50		29.3	37.7	40.9
$N_{75\text{-}350}$	75		28.1	31.8	35.2
$M_{1\text{-}350}$	0.0	5	29.3	35.2	38.4
$M_{2\text{-}350}$		10	31.7	39	42.3
$M_{3\text{-}350}$		15	33.7	40.6	44.5
$M_{4\text{-}350}$	25	5	31.1	38.5	41.6
$M_{5\text{-}350}$		10	36.2	42.2	44.8
$M_{6\text{-}350}$		15	38.8	44.1	46.5
$M_{7\text{-}350}$	50	5	31.2	38.3	41.9
$M_{8\text{-}350}$		10	34.9	41.7	44.3
$M_{9\text{-}350}$		15	36.5	43.6	46.4
$M_{10\text{-}350}$	75	5	28.5	35.5	37.2
$M_{11\text{-}350}$		10	30.1	38.6	41.6
$M_{12\text{-}350}$		15	31.2	40.7	43.4

Using LSW with level 75% increased compressive strength of normal concrete about 6% at 7 days as compared with the normal concrete N_{350}. On the other hand, there is reduction about 5% and 4% at 28 and 90 days respectively, when replacement level of 75%, as compared with the normal concrete N_{350}. The loss of the compressive strength at a replacement level 75% can be related to its physical and chemical effects for limestone powder. Moreover, the percentage of free calcium hydroxide during the reaction of cement is increase, when powder content in LSW increases.

2.3.2 Tensile Strength

Hebhoub et al [2011] showed the recycled aggregates (marble waste) affected the compressive tensile strengths (Fig. 2.13) at a certain rate of substitution. The (S) formulation showed a significant strength gain, the compressive and tensile strength with the substitution rate of 25%, 50% and 75% are fairly greater than values obtained with natural aggregates. The curves clearly show that the concrete with 100% substitution rate provided poor results in strength. We noticed a good correlation between compressive and tensile strength behaviour for the three formulations. Furthermore, the tensile strength rises after 28 days of curing; this increase is not visible for the compressive strength bars.

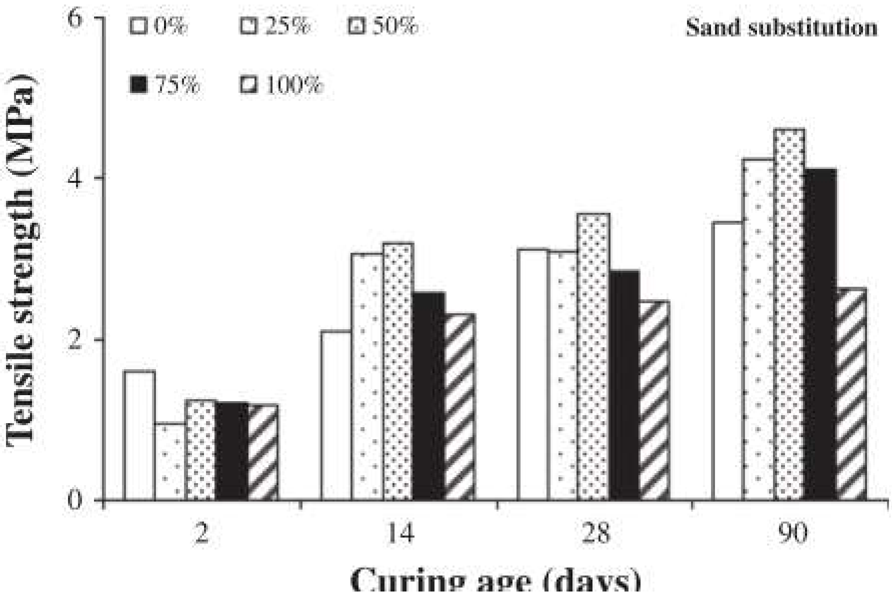


Fig. 2.13 The tensile strength versus the curing age, formulation (S) (Hebhoub et al 2011)

Nuno Almeida et al [2007] studies that when the substitution level of sand surpassed 20%, the tensile splitting strength was significantly reduced. Nevertheless, test results show that tensile splitting strength is less sensitive to high contents of very fine particles than compressive strength. CMSD100 presented a result of 3 MPa, correspondent to a quite acceptable reduction of 28.6% relatively to CMSD0.

Omar et al [2012] concluded that using 50% Lime stone waste (LSW) with 15% Marble Powder (M.P) increased the splitting tensile strength about 17% as compared with normal concrete mix N_{350}. On the other hand using 50% LSW with 15% M.P increased the splitting tensile strength about 8% as compared with normal concrete mix N_{450}. Uniform dispersion and disorganized in shape of LSW is vital to the development of cement strength which effectively take advantage of the bond strength properties of LSW. As shown from Tables 2.4, the ratio of the indirect tensile strength to the compressive strength (f sp /f cu) of the mix containing 50% from LSW as replacement from sand weight, and 15% M.P as an addition by weight from cement, was generally similar to that of the corresponding normal concrete mix at the same cement content.

Table 2.4 Tensile Strength of the concrete specimens (Omar et al 2012)

Mix symbol	% (LSW)	% (M.P)	350 Kg/m^3	
			$f_{sp,28}$ day MPa	f_{sp}/f_{cu}
N^*_{-350}	0	0	3.7	11
M_{3-350}	0	15	4.1	10.1
M_{9-350}	50	15	4.5	10.3

2.3.3 Modulus of Elasticity

Almeida et al [2007] showed that 5% replacement of sand with stone dust had the better behaviour in terms of modulus of elasticity (6.2% higher than the normal) and that all mixtures containing less than 20% of stone dust obtained acceptable results. Mix with 100% replacement of sand with stone dust (CMSD100) slight behaviour improvement of 2.2%. In the extreme case of dust incorporation (CMSD100), the average of test results for the modulus of elasticity was 26.7 GPa (34.1% less than the reference concrete mixture CMSD0). It is known that cement paste modulus of elasticity is generally half the modulus of elasticity of aggregates. Therefore, when introducing stone dust (very fine particles, with slight inferior size than cement particles), the paste could be considered as increased, thus promoting a negative effect on the modulus of elasticity of the hardened concrete's. This fact, in addition to the higher water/cement ratio, could explain the lower modulus of elasticity attained for more than 15% substitution (inclusively).

2.4 DURABILTY PROPERTIES

2.4.1 Water Permeability

Omar et al [2012] studied that the addition of Lime stone waste (LSW) to the concrete improves the impermeability of concrete because it blocks the passages connecting capillary pores and the water channels. This blockage is affected by the amount of dust content in the LSW, and the more water passages were blocked, the more reduction in the permeability of concrete specimens is observed. Omar M. Omar etal found that the coefficient of permeability, K, decreases as the dust content increases. The coefficient of permeability was 6.8 $x10^{-10}$ cm/sec for normal concrete mix N_{350} , and $4.62x10^{-10}$ cm/sec for mix content 15% Marble powder (M.P). As the same time the coefficient of permeability was 4.87 x 10^{-10} cm/sec for mix content 50% LSW, with 15% M.P.

2.4.2 Chloride Permeability

Vijayalakshmi et al [2013] investigated the suitability of granite powder (GP) waste as a substitute material for fine natural aggregate in concrete production. Concrete mixtures were prepared by 0%, 5%, 10%, 15%, 20% and 25% of fine/natural aggregate substituted by GP waste. He showed that the chloride permeability of the concrete is directly proportional to the substitution rate and the penetration rate was increased when increasing the GP waste substitution rate. However the penetration values of the mixtures CGP 5%, CGP 10% and CGP 15% were almost equivalent to the penetration value of the CM. Mixtures CGP 20% and CGP 25% were showed highest permeability value and the total charge passed is above 1500 Coulombs. The increases in the chloride penetrationis attributed to poor compaction resulting high porous microstructure and a discontinuous pore system, increase the permeability of chloride ions. On the whole, the inclusion of GP waste had a profound effect on the depth of chloride penetration of the concrete.

2.4.3 Sulphate Resistance

Vijayalakshmi et al [2013] examined that the concrete containing GP waste showed significant loss in the compressive strength when compared to the control mixtures in addition the action of sulphate increased when increasing the substitution rate of Granite powder. The increase in sulphate action was due to the presence of kerosene, diesel and wax traces in GP waste which has been used during the process of sawing and polishing. During the process of sawing and polishing, the formation of enormous heat in the blade, transformed the sulphur content present in the kerosene and diesel into sulphur trioxide**.** The presence of those sulphur ions in the GP waste increase the sulphate strength of the NaSO 4 and MgSO 4 solution, and enhance the ettringite formation causing the deterioration of concrete.

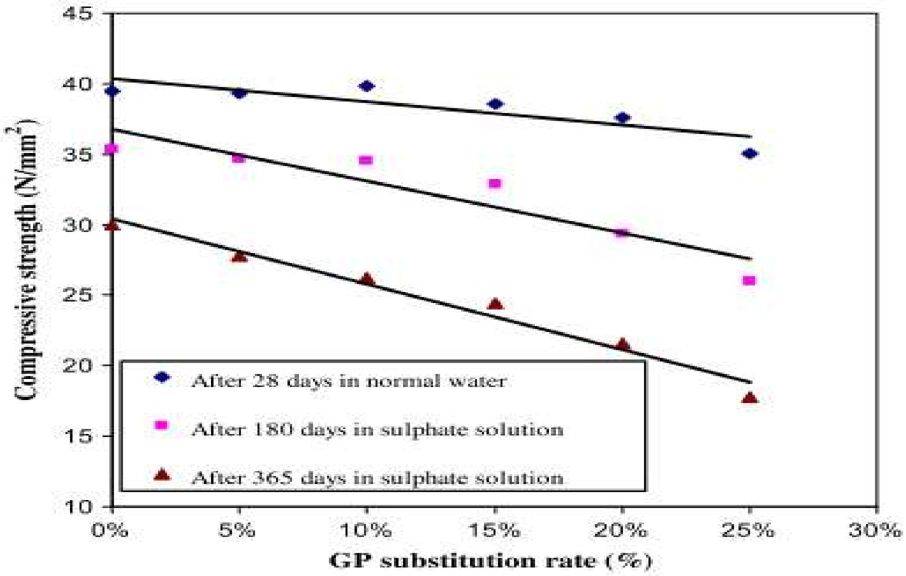


Fig. 2.14 Relationship between GP substitution rate and loss of compressive strength of concrete in $NaSO_4$ and $MgSO_4$ solution (Vijayalakshmi et al 2013)

The concrete cubes were immersed in solution containing $NaSO_4$ and $MgSO_4$ for the duration of 180 days and 365 days and the loss in compressive strength of concrete in NaSO4 and $MgSO_4$ solution is shown in Fig. 2.14.

2.4.4 Carbonation Depth

Carbonation depth of all mixtures was measured at the age of 180 days and 365 days, and they were represented by the corresponding carbonation coefficient (C) value.

$$C = \frac{X}{T^{0.5}}$$

Where C is the tested carbonation depth (mm), X and T is the carbonation depth in mm and period of exposure in months respectively.

Vijayalakshmi et al [2013] examined that the carbonation depth values of mixtures CGP 5%, CGP 10% and CGP 15% were relatively close to the control mixture (CM) and the effect of Granite powder (GP) waste on carbonation depth was significant when increasing the fine aggregate substitution rate beyond 15%. The observation of Fig. 2.15 showed that the carbonation depth value of the concrete increases with the increase in GP waste substitution however the increase in depth was not proportional.

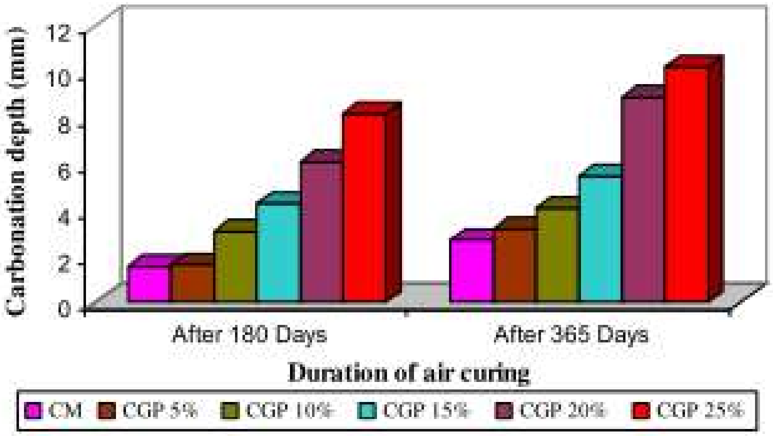


Fig. 2.15 Carbonation depth of all mixtures – comparison (Vijayalakshmi et al 2013)

Up to 15% substitution rate, for every increase in 5%, the average increase in carbonation depth value was 1.2 mm; however the increase was not proportional beyond the substitution rate of 15%. This is a result of the fact that low workability of the concrete resulting poor compactness. The carbonation depth value of mixtures CGP 20% and CGP 25% were 8.9 mm and 10.2 mm at the age of 365 days, which was closer to the cover of reinforcing steel bars and it may be cause corrosion.

2.5 EFFECT OF RICE HUSK ASH ON FRESH PROPERTIES OF CONCRETE

2.5.1 Workability

Memon et al. (2008) studied the fresh concrete properties. Nine different mixes were prepared. These were subdivided into three groups: Control concrete, 5% RHA and 10% RHA. Dosage of super plasticizer was varied from 3.5% to 4.5% with an increment of 0.5%.

Slump Flow Test- Slump flow for all the mixes except 10R3.5 (10% RHA and 3.5% super plasticizer) were within the EFNARC range of SCC. Flow increased with increase in quantity of super plasticizer. Proportionally, there was decrease in the flow with increase in the quantity of RHA. The experimental readings achieved in slump flow test were from 595 to 795 mm.

Safiuddin et al. (2012) studied the fresh concrete properties of self –consolidating concrete (SCC) incorporating rice husk ash (RHA). Air entrained SCC mixtures were produced based on w/b ratios of 0.30-0.40. RHA was used substituting 0-30% of cement by weight.

The slump varied in the range of 265-280 mm (Table 2.5). The slump only increased by 5mm although the deformability of concrete was significantly improved in the presence of 30% RHA. It was then suggested that the slump is not a suitable criterion to assess the filling ability of SCC.

Table 2.5: Slump of different SCC mixture (Safiuddin et al., 2012)

Concrete Type	**Slump (mm)**
C30RHA0	275
C30RHA15	280
C30RHA20	275
C35RHA0	270
C35RHA5	270
C35RHA10	270
C35RHA15	280
C35RHA20	275
C35RHA25	275
C35RHA30	275
C40RHA0	265
C40RHA15	270
C40RHA20	265

The slump flow of SCC mixtures varied from 665 mm to 770 mm *(Table 2.6).* The range of slump flow indicates an excellent filling ability of SCC. The slump flow was significantly increased by 60 mm in the presence of 30% RHA.

Table 2.6: Slump flow for various SCC mixture (Safiuddin et al., 2012)

Concrete Type	Slump (mm)
C30RHA0	710
C30RHA15	735
C30RHA20	770
C35RHA0	690
C35RHA5	700
C35RHA10	710
C35RHA15	720
C35RHA20	710
C35RHA25	740
C35RHA30	750
C40RHA0	665
C40RHA15	680
C40RHA20	675

2.5.2 Passing Abilibty

L Box Test – **Memon et al. (2008)** studied that **w**hile testing the concrete for passing ability, majority of the mixes passed through the bars very easily and without blockage. Ratio of L BOX increased with the increase in the quantity of super plasticizer. Proportionally, the ratio decreased with the increased quantity of RHA. Experimental readings achieved in L box test were from 0 to 1.

Safiuddin et al. (2012) studied that the passing ability of SCC mixtures were obtained with respect to J-ring slump, slump cone- J ring flow spread, orimet- J ring flow spread. The J-ring slump varied in the range of 255-270 mm for various SCC mixtures. The Slump cone J-ring flow spread (slump flow in the presence of J-ring) varied in the wide range of 650-740 mm . Reduction is observed in case of J-ring slump flow spread. The reduction in slump flow in presence of J-ring should not be greater than 50 mm to maintain a good passing ability (Ozawa *et al*., 2001).

Juma et al. (2009) verified by using the slump flow and L-box tests, that self - compacting concrete (SCC) achieved consistency and self compact ability under its own weight, without any external vibration or compaction. Also, because of the special admixtures used, SCC has achieved a density between 2400 and 2500 kg/m3.

Sua-iam et al. (2013) prepared several mixtures were prepared containing various fine aggregate replacement amounts. RHA were used to replace the river sand at levels of 0%, 10%, 20%, 40%, 60%, 80% or 100% by volume. All of the mixtures exhibited satisfactory average slump flows of 70 ± 2.5 cm diameter which is an indication of good workability. The slump flow time increased with increasing RHA content. The slump flow time increased varied in the range of 6-15 sec, 8- 20 sec and 6-16 sec for SCC mixtures containing RHA.

2.5.3 Flowing Ability

V-Funnel Test- **Memon *et al.* (2008)** studied that most of the results of V funnel test remained more towards minimum range or even lesser. This shows more filling ability but less viscous mix. With the increase in quantity of RHA, viscosity of mix started increasing

Sua-iam *et al.* (2013) found that Acceptable flow times were obtained for mixtures RHA10 and RHA20. The RHA particles absorbed water, resulting in a highly viscous mix and reducing bleeding. There was either no blocking or minimal apparent blocking in samples containing RHA. A small degree of blocking was evident in the control and in mixtures containing 10%, 20%, or 40% RHA. Extreme blocking was observed in samples containing more than 60% RHA.

2.6 HARDENED CONCRETE PROPERTIES WITH RICE HUSK ASH

2.6.1 Compressive Strength

Ahmadi et al. (2007) studied the compressive strength of SSC mix containing RHA in comparison to normal mix. Six series of self compacting concrete with ordinary concrete were mixed. Two different replacement percentages of cement by RHA, 10%, and 20% with mix have no RHA and two different w/b material ratios (0.40 and 0.35), were used for both of self compacting and ordinary concrete specimens. The mixture proportions according to w/b ratio adopted and are reported in Table 2.7 and 2.8.

Table 2.7: Mix Design of various SCC mixes (Ahmadi et al., 2007)

Mix	Gravel	Sand	Water	Cement	RHA	W/B
SCC(0%RHA)	770	970	184	460	0	0.4
SCC(10%RHA)	770	970	184	414	46	0.4
SCC(20%RHA)	770	970	184	368	92	0.4
OC(0%RHA)	1043	700	184	460	0	0.4
OC(10%RHA)	1043	700	184	414	46	0.4
OC(20%RHA)	1043	700	184	368	92	0.4

Table 2.8: Specimen's Dimensions (Ahmadi *et al.,* 2007)

Type Of Test	Dimensions		
	Length (cm)	Width (cm)	Height (cm)
Compressive Strength	10	10	10

For compressive strength the specimens were test at different ages from 7 to 180 days. The results are shown in Figure 2.16 and Figure 2.17. According to results SCC mixes show higher compressive strength than normal concrete. This difference is around 31% to 41% of normal concrete compressive strength. However mixes containing rice husk ash indicate lower compressive strength until 60 days rather than samples with no replacement, but by increasing the rate of pozzolanic reactions of rice husk ash in the matrix, strength of composite mixes goes up.

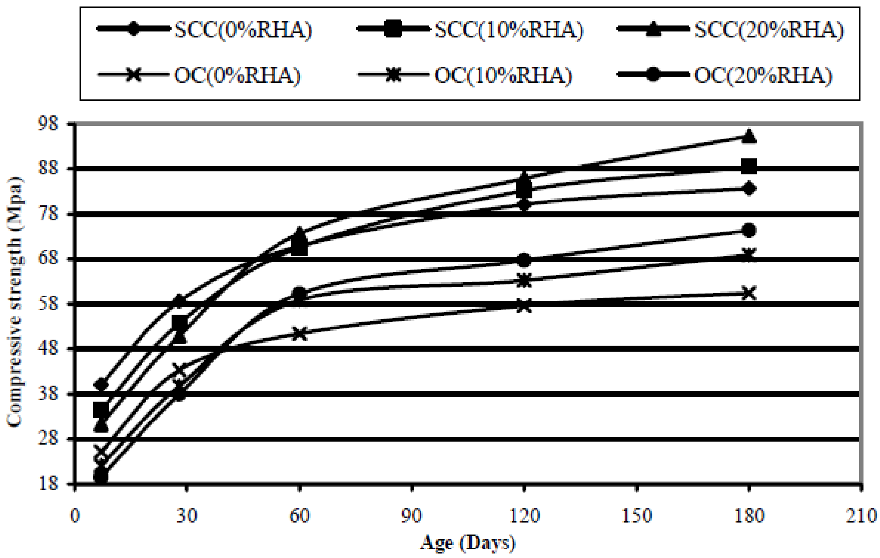


Figure 2.16: Compressive strength with w/b ratio 0.40 (Ahmadi et al., 2007)

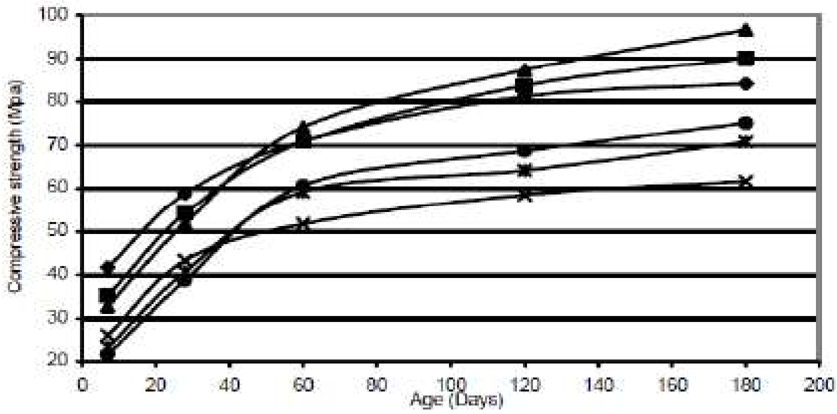


Figure 2.17: Compressive strength with w/b ratio 0.35 (Ahmadi et al., 2007)

The mixes containing 20% rice husk ash have the highest compressive strength than the others. In addition water to binder ratio has more impact on normal concrete rather than self-compact concrete. Moreover, by increasing the amount of replacement, water to binder ratio rises up.

Nor atan et al. (2011) investigates the compressive strength of self compacting concrete incorporating raw rice husk ash, individually and in combination with other types of mineral additives, as partial cement replacement.

Table 2.9: Mixture Proportions for the Control Mix, Binary Mix, Ternary Mixes and Quaternary Mixes (Nor atan et al., 2011)

Mix	Label	OPC	LP	FA	SF (kg/m^3)	RRHA	S	G
NM	CM	475	-	-	-	-	1047	712
BM	C/RHA	403.75	-	-	-	71.25	1027	698
TM1	C1/LP/RRHA	332.5	71.25	-	-	71.25	1023	695
TM2	C1/FA/RRHA	332.5	-	71.25	-	71.25	1007	686
TM3	C1/SF/RRHA	332.5	-	-	71.25	71.25	1012	688
QM1	C2/LP/FA/RRHA	261.25	71.25	71.25	-	71.25	1004	681
QM2	C2/LP/SF/RRHA	261.25	71.25	-	71.25	71.25	1006	683
QM3	C2/FA/SF/RRHA	261.25	-	71.25	71.25	71.25	994	676

Tests carried out after 90 days reveal that the control mix (CM) obtained compressive strength values of 44.7 MPa , while the binary mix BM obtained 42.5 MPa . This shows that replacing 15% of OPC with RRHA produces slightly lower compressive strength as compared to the control mix. Similar results are also shown when 30% of OPC was replaced with LP/RRHA and FA/RRHA blends. However, 30%

replacement with SF/RRHA blend produced substantially lowers compressive. Two quaternary mixes QM2 and QM3 are shown to produce comparable results with the control mix. But, quaternary mix QM1 is shown to exhibit substantially lower strength as compared with the control mix.

Saifuddin et al. (2010) studied the compressive strength of self consolidating high performance concrete (SCHPC). The concrete mixes were designed based on w/b ratios of 0.30, 0.35, 0.40, and 0.50, using RHA substituting 0% to 30% of cement by weight. A total air content of 6% was adopted for air entrained SCHPC's and 2 % for non air entrained SCHPC'S. Mixes were named as per C (w/b ratio), R (replacement percentage), A (air entrained).

Highest level of later age compressive strength was achieved for C35R30A6. Conversely, the lowest level of compressive strength al all ages was obtained for C50R0A6. The compressive strength of the concrete with and without RHA increased with a lower w/b ratio. The increase is directly proportional to the reduction in concrete porosity. In this study total porosity of concrete decreased with lower w/b ratio. With decreased porosity, microstructure of concrete is improved both in bulk paste matrix and interfacial transition zone.

The RHA increased the compressive strength of concrete at age of 7, 28 and 56 days. It is basically due to micro filling ability and pozzolanic activity of RHA.

The increased air content decreased the compressive strength of concrete. The reduction in compressive strength was about 4 MPa per 1% increase in air content. This is due to entrained air voids that increase the total void content. The increased void content decreased the load carrying capacity of concrete, producing low compressive strength.

Memon et al. (2010) aimed at evaluating the usage of rice husk ash as viscosity modifying agent in SCC. To calculate compressive strength nine different mixes were prepared. Three controlled mix and six mixes with different proportions of RHA. Three w/b ratios are considered i.e. 0.4, 0.38 and 0.36. Three percentages by weight of binder, super plasticizer is considered i.e. 3.5, 4 and 4.5.

Table 2.10: Compressive Strength at 7 and 28 days (Memon et al., 2010)

Mix Name	Compressive Strength	
	7 days (MPa)	28 days (MPa)
CC3.5	10.5	28.4
CC4	6.8	18.3
CC4.5	1.2	8.6
5R3.5	25.2	38
5R4	21.4	37.8
5R4.5	11.9	22.2
10R3.5	22.5	36.2
10R4	36.8	41.4
10R4.5	38.3	48.5

Among the three control mixes, CC3.5 developed highest compressive strength of 10.5 and 28.4 MPa at 7 and 28 days. For control concrete and mixes with 5% RHA, the compressive strength decreased with increase in the dosage of super plasticizer. More the dosage of super plasticizer, lesser would be the strength. In the mixes with 10% RHA, the strength increased with increase in dosage due to improved workability and sufficient self compactibility. For equal dosage of super plasticizer, rice husk ash mixes showed higher compressive strength as compared to control mixes. This increase is basically due to reduced w/b ratio, dense particle packing, pore size refinement and grain size refinement.

Juma *et al.* (2009) studied that the RHA significantly increased the compressive strength of concretes at the ages of 3, 7, 14 and 28 days. The improvement of compressive strength is mostly due to the micro filling ability and pozzolanic activity of RHA and SCBA. With a smaller particle size, the RHA blended with SCBA 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. The compressive strength increases gradually with the SCC incorporated with RHA and SCBA than the one without pozzolona materials incorporated with it.

Shatat (2013) studied the effect of pozzolana on the strength of the pozzolanic cement pastes depends on number of factors such as the content, type and surface area of pozzolana and the individual characteristics of the OPC. The results of compressive strength of the blended cement pastes made from OPC-MK blends with/without rice husk ash at various curing times up to 180 days are shown in *Figure 2.3*. The compressive strength of the all pastes increases with curing time. As the hydration proceeds, more hydration products and more cementing materials are formed leading to an increase in compressive strength of cement pastes. This is mainly due to the fact that the hydration products possess a large specific volume than the unhydrated cement. Therefore, the accumulation and compaction of these hydrated products give higher strength. The compressive strength values of the hardened pastes made from OPC-MK blends including rice husk ash, increase continuously with increasing age of hydration it is clear that the best mixes are those with 5% and 10% rice husk ash (mixes R1 and R2). Thus, 5–10% addition of rice husk ash to PC-MK blends may be considered as the optimum limit. The increase in compressive strength in the presence of 5–10% rice husk ash may be both due to the pozzolanic reaction between calcium hydroxide and silica and the hydration of silica itself will be responsible for the increased compressive strength (Yu *et al*., 1999). Up to 10% replacement of rice husk ash, the compressive strength decrease. This may be due to the fact that the quantity of RHA present in the mix is higher than the amount required to combine with the liberated lime during the hydration process thus leading to excess silica leaching out causing a deficiency in strength as it replaces part of the cementitious material but does not contribute to strength.

Table 2.11: Mix composition in wt. % of blended cements (Shatat 2013)

Symbol	OPC	MK	Rice Husk Ash
B	100	0	0
R0	75	25	0
R1	75	20	5
R2	75	15	10
R3	75	10	15
R4	75	05	20

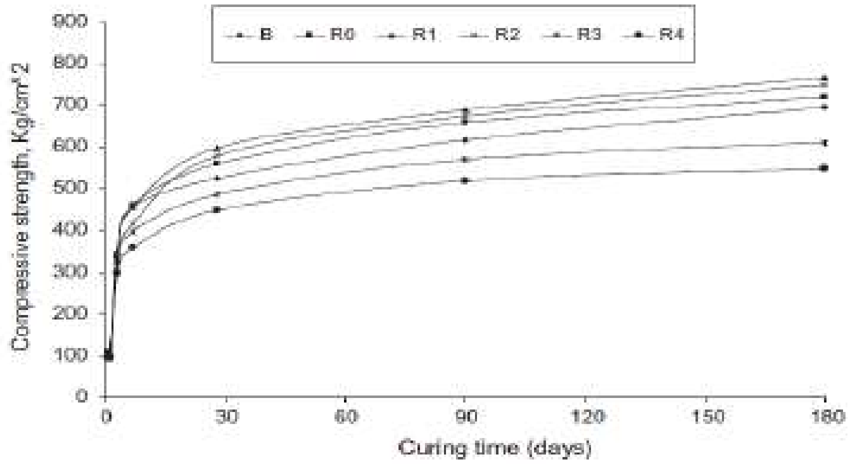


Figure 2.18: Compressive strength (kg/cm2) of hardened specimens made from OPC and MK with/without rice husk ash as function of curing time (days) (Shatat 2013)

2.6.2 Flexural Strength

Ahmadi *et al.* (2007) studied the flexural strength of SSC mix containing RHA in comparison to normal mix. Six series of self compacting concrete with six series of ordinary concrete were mixed. Two different replacement percentages of cement by RHA, 10%, and 20% with mix have no RHA and two different w/b material ratios (0.40 and 0.35), were used for both of self compacting and ordinary concrete specimens. The mixture proportions according to w/b ratio adopted and are reported in Tables 2.12 and 2.13.

Table 2.12: Mix Design for various SCC mixes (Ahmadi et al., 2007)

Mix	Gravel	Sand	Water	Cement	RHA	w/b
SCC(0%RHA)	770	970	184	460	0	0.4
SCC(10%RHA)	770	970	184	414	46	0.4
SCC(20%RHA)	770	970	184	368	92	0.4
OC(0%RHA)	1043	700	184	460	0	0.4
OC(10%RHA)	1043	700	184	414	46	0.4
OC(20%RHA)	1043	700	184	368	92	0.4

Table 2.13: Mix Design for various SCC mixes (Ahmadi et al., 2007)

Mix	Gravel	Sand	Water	Cement	RHA	w/b
SCC(0%RHA)	770	970	184	460	0	0.35
SCC(10%RHA)	770	970	184	414	46	0.35
SCC(20%RHA)	770	970	184	368	92	0.35
OC(0%RHA)	1043	700	184	460	0	0.35
OC(10%RHA)	1043	700	184	414	46	0.35
OC(20%RHA)	1043	700	184	368	92	0.35

All of concrete specimens were made and covered with plastic sheet and burlap for the first 24 h to prevent moisture loss. After 24 h, the specimens were de moulded and placed in the water with 22 ± 2 ^{o}C for all times of test. Specimen's dimensions are shown in Table 2.14.

Table 2.14: Specimen's Dimensions (Ahmadi et al., 2007)

Type of Test	Dimensions		
	Length (cm)	Width (cm)	Height (cm)
Flexural Strength	45	10	10

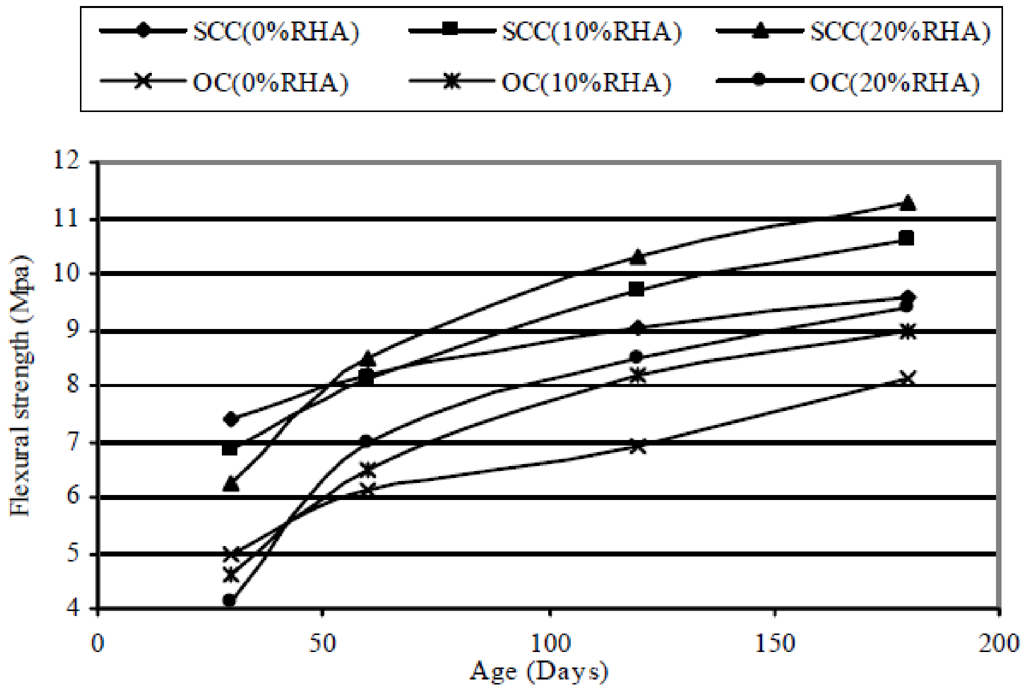


Figure 2.19: Flexural strength with w/b ratio 0.40 (Ahmadi et al., 2007)

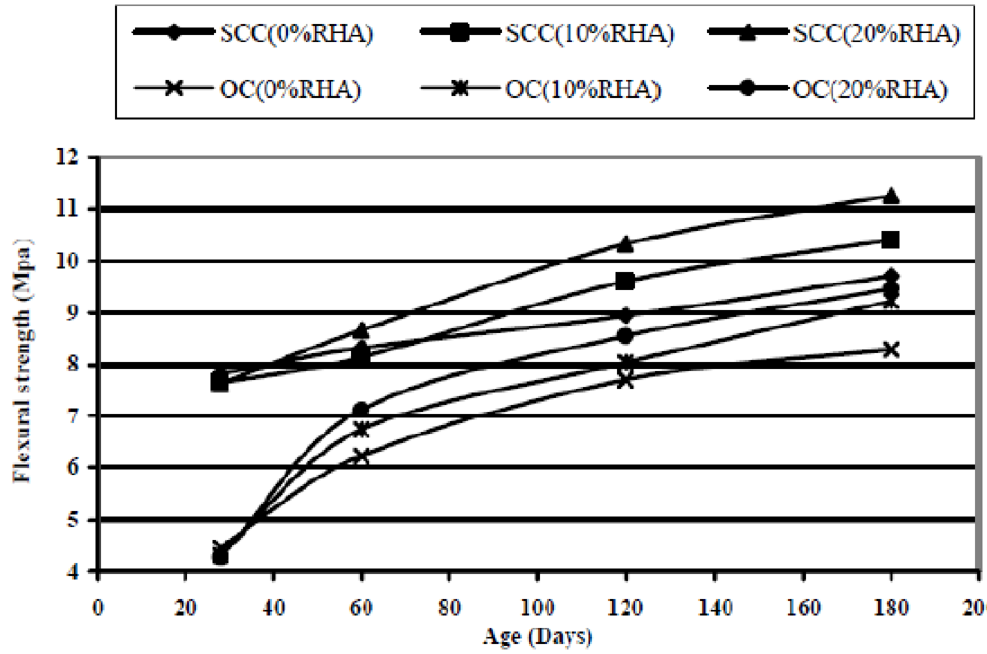


Figure 2.20: Flexural strength with w/b ratio 0.35 (Ahmadi et al., 2007)

For the study of flexural strength specimens were tested at 28, 60, 120 and 180 days age, and test results have been shown in Figure 2.19 and 2.20

According to results, SCC mixes show the strength about 12% to 20% more than normal concrete. Also the mixes containing 20% rice husk ash have the highest flexural strength in all cases.

Nor atan *et al.* (2011) investigates the flexural strength of self compacting concrete incorporating raw rice husk ash, individually and in combination with other types of mineral additives, as partial cement replacement. The additives paired with raw rice husk ash were fine limestone powder, pulverized fuel ash and silica fumes shown in Figure 2.21.

Figure 2.21: Mineral Additives used to replace Cement (OPC), Fine Limestone Powder (LP), Pulverized-Fuel Ash (FA), Silica Fume (SF) and Raw Rice Husk Ash (RRHA) (Nor atan et al., 2011)

Table 2.15: The Hardened Properties of the Control Mix (NM), Binary Mix (BM), Ternary Mixes (TM) and Quaternary Mixes (QM) (Nor atan et al., 2011)

Mix	Label	Age (Days)	Flexural Strength
NM	CM	7 14 28 60 90	4.5 4.7 5.7 5.8 5.7
BM	C/RRHA	7 14 28 60 90	3.2 3.5 4.0 6.1 6.5
TM1	C1/LP/RRHA	7 14 28 60 90	3.4 3.8 4.1 5.3 6.2
TM2	C1/FA/RRHA	7 14 28 60 90	2.7 3.8 3.7 6.0 5.8
TM3	C1/SF/RRHA	7 14 28 60 90	2.2 5.8 3.5 4.0 4.1
QM1	C2/LP/FA/RRHA	7 14 28 60 90	1.9 2.9 3.3 3.7 4.1
QM2	C2/LP/SF/RRHA	7 14 28 60 90	3.4 4.5 5.0 5.7 6.2
QM3	C2/FA/SF/RRHA	7 14 28 60 90	3.2 3.8 4.1 5.2 5.2

Seven SCC mixes were prepared comprising of one binary mix BM (C/RRHA), three ternary mixes TM1 (C1/LP/RRHA), TM2 (C1/FA/RRHA) and TM3 (C1/SF/RRHA) and three quaternary mixes QM1 (C2/LP/FA/RRHA), QM2 (C2/LP/SF/RRHA) and QM3 (C2/FA/SF/RRHA). One control mix (NM) was also designed using the same proportioning as the SCC mixes. Flexure strength test was carried out after 7, 14, 28, 60 and 90 days of water curing. The results are shown in Table 2.15.

2.6.3 Split Tensile Strength

Rahman *et al.* (2013) studied the splitting tensile strength of SCC that contained RHA as cement replacement. The percentage of RHA content in the Mix1, Mix2, Mix3 and Mix4 are 0, 20, 30 and 40 respectively. The results in *Table 2.16* shows that splitting tensile strength decreased with increase in percentage of RHA. 20% rice husk ash replacement is acceptable, as its strength is similar to the strength of controlled mix.

Table 2.16: Splitting tensile strength (Rahman et al., 2013)

Splitting Tensile Strength (MPa)			RHA Based SCC	
DAYS	**MIX 1**	**MIX 2**	**MIX 3**	**MIX 4**
28	5.1	5.1	4.3	2.8

Khadiry et al. (2014) aimed at producing and comparing SCC incorporating rice husk ash (RHA) and shell lime powder (SL), both locally available mineral admixtures as an additional cementing material. Split tensile strength (cylinder size: length 300 mm and diameter 150 mm), the test included for both SCC mixes for a period of 7, 14, and 28 days of curing.

Table 2.17: Splitting tensile strength for both the SCC mixes. (Khadiry *et al.*, 2014)

Strength (MPa)	Ages (in days)	SL Based SCC	RHA Based SCC
Splitting Tensile Strength	7	1.944	1.568
	14	1.89	1.797
	28	2.51	2.53

It is clear from the Table 2.17 and Figure 2.*22* that 28 days strength for RHA mix is higher as compared to SL. Split tensile strength of SL when compared to RHA gave a higher strength by 23.98% for 7 days of curing. For 14 days of curing, the strength of SL was 5.2% higher than that of RHA. For 28 days of curing, the strength of RHA was 0.8% higher than that of SL.

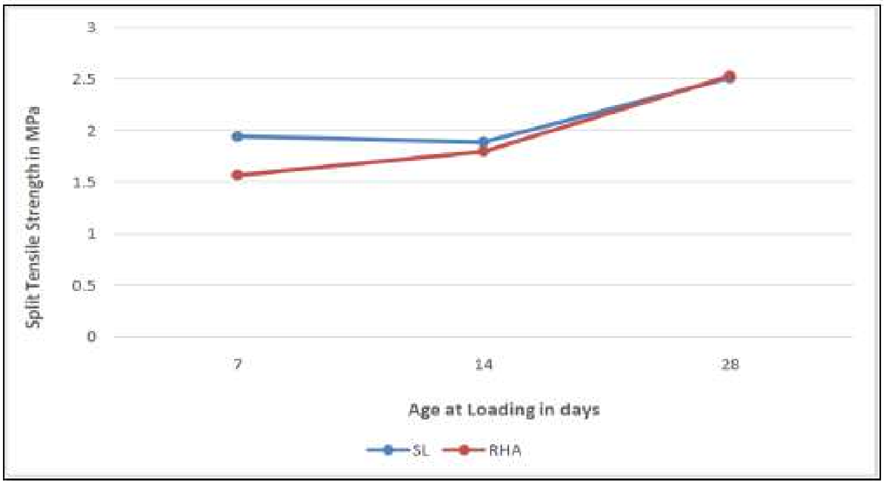


Figure 2.22: Splitting Tensile strength at various ages (Khadiry *et al.*, 2014)

Since RHA contains silica contents and SL contains calcite contents, the silica contents react better with cement compared to that of calcite contents, as cement contains lime, which in turn consist of calcite contents. Thus, this probably explains the higher strength in RHA when compared to SL.

2.6.4 Modulus of Elasticity

Ahmadi *et al.* (2007) deliberate the flexural strength of SSC mix containing RHA in comparison to normal mix. Six series of self compacting concrete with six series of ordinary concrete were mixed. Two different replacement percentages of cement by RHA, 10% and 20% with mix have no RHA and two different water/cement ratios (0.40 and 0.35), were used for both of self compacting and ordinary concrete specimens. The mixture proportions according to w/b ratio adopted and are reported in Tables 2.18 and 2.19.

Table 2.18: Mix design for various SCC mixes (Ahmadi et al., 2007)

Mix	Gravel	Sand	Water	Cement	RHA	W/B
SCC(0%RHA)	770	970	184	460	0	0.4
SCC(10%RHA)	770	970	184	414	46	0.4
SCC(20%RHA)	770	970	184	368	92	0.4
OC(0%RHA)	1043	700	184	460	0	0.4
OC(10%RHA)	1043	700	184	414	46	0.4
OC(20%RHA)	1043	700	184	368	92	0.4

Table 2.19: Mix Design for various SCC mixes (Ahmadi et al., 2007)

Mix	Gravel	Sand	Water	Cement	RHA	W/B
SCC(0%RHA)	770	970	184	460	0	0.35
SCC(10%RHA)	770	970	184	414	46	0.35
SCC(20%RHA)	770	970	184	368	92	0.35
OC(0%RHA)	1043	700	184	460	0	0.35
OC(10%RHA)	1043	700	184	414	46	0.35
OC(20%RHA)	1043	700	184	368	92	0.35

All of concrete specimens were made and covered with plastic sheet and burlap for the first 24 hours to prevent moisture loss. After 24 h, the specimens were de moulded and placed in the water with 22 ± 2 °C for all times of test. Specimen's dimensions are shown in *Table 2.20*

Table 2.20: Specimen's Dimensions (Ahmadi et al., 2007)

Type Of Test	Dimensions		
MOI	Length (Cm)	Width (Cm)	Height (Cm)
	10	10	10

For the study of flexural strength specimens were tested at 28, 60, 120 and 180 days, and test results have been shown in Figure 2.23.

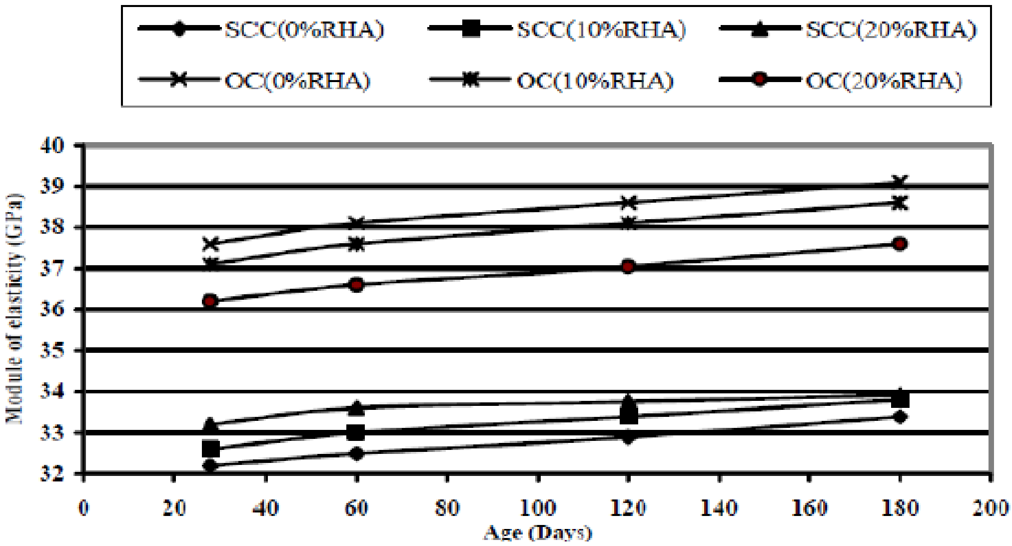


Figure 2.23: Modulus of Elasticity of various SCC mixes (Ahmadi et al., 2007)

According to results, by aging and hardening of concrete mixes, the module of elasticity like compressive and flexural strength increases. Normal concrete mixes show bigger module of elasticity around 9% to 17% more than of SCC ones. Also by increasing the amount of rice husk ash in the matrix, module of elasticity of all mixes reduced.

2.6.5 Rapid Chloride Permeability

Ramasamy (2011) reported that most of the chloride ion permeability values fall in the range of very low (100-1000 coulombs) category. From the test results, it is found that as the cement replacement by rice husk ash level increases, the charge passed decreases. The incorporation of the RHA in concrete results in a finer pore structure in the hydrated cement paste especially at the aggregate and paste interface. As shown in Figure 2.24 rapid chloride permeability decreased with the increase in age. The values obtained by mixes with the addition of SP have obtained higher values as compared to the mixes without SP. As per ASTM C1202, RHA reduced the rapid chloride penetrability of concrete from a low to very low rating from higher to lower replacement levels. The same trend was reported by Nehdi *et al.* (2003) in RHA replaced concrete. Zhang *et al.* (1996) reported that RHA concrete (10% replacement of cement) had excellent resistance to chloride ion penetration and the charge passed in coulombs was below 1000 both at 28 and 91 days.

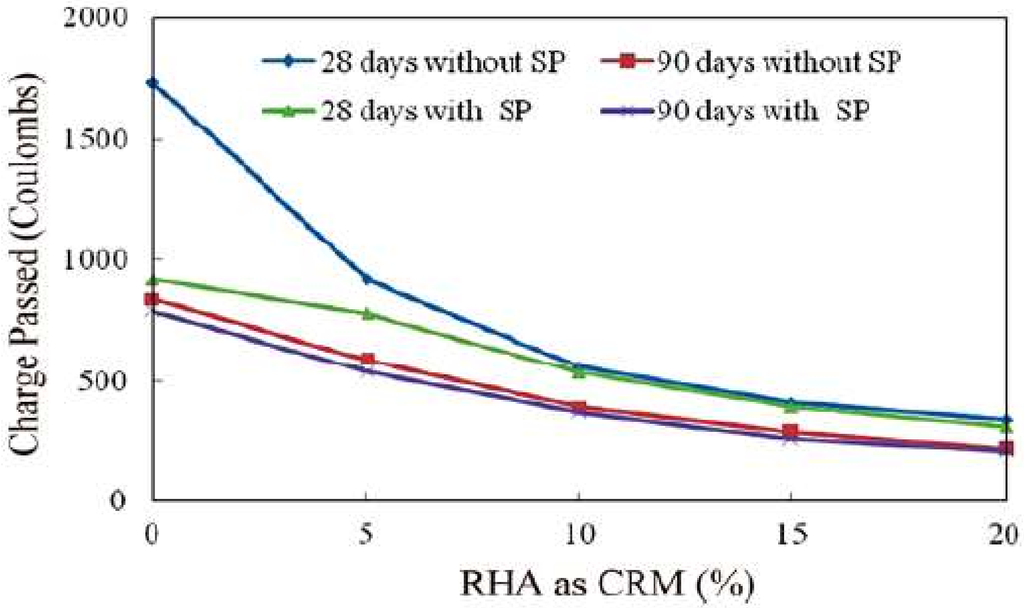


Figure 2.24: Rapid Chloride Ion Permeability in M30 Grade Concrete with and without RHA and SP (Ramasamy, 2011)

Zhang and Malhotra (1996) reported that RHA concrete (10% replacement of cement) had excellent resistance to chloride ion penetration and the charge passed in coulombs was below 1000 both at 28 and 91 days.

2.6.6 Porosity

Ramasamy (2011) calculated porosity test values of control concrete and different percentage of rice husk ashes in concrete after 60 days are shown in Table 2.21. From the results it is observed that the porosity value decreases as the percentage of replacement increases. The porosity values at 0, 5, 10, 15 and 20% rice husk ash contents 3.45, 3.90, 4.20, 4.50 and 4.70% respectively, for M30 concrete mixtures without super plasticizers. But the addition of super plasticizers showed the porosity values vary from 3.80 to 5.20% for M30 grade concrete mixtures, with SP. The small RHA particles improved the particle packing density of the concrete mixture leading to a reduced volume of larger pores.

Table 2.21: Porosity of M30 Grade Concrete Mixtures with and without RHA and SP (Ramasamy, 2011)

Sr. No.	Mix	RHA Content (%)	SP Content By Weight of Binder (%)	Porosity @ 60 Days (%)	
				Without SP	With SP
1	BC	0	0.40	3.45	4.20
2	BR1	5	0.40	3.90	3.90
3	BR2	10	0.80	4.20	3.80
4	BR3	15	1.40	4.50	4.40
5	BR4	20	2.80	4.70	5.20

CHAPTER 3

EXPERIMENTAL PROGRAM

3.1 GENERAL

The aim of the experiment program is to compare the properties of concrete made of normal sand and stone dust as fine aggregates with replacement of cement by Rice Husk Ash as supplementary cementing material. The details of experimental programme in terms of material properties, test set-up for measuring different parameters and the testing procedure are discussed in this chapter.

3.2 MATERIAL USED

The physical and chemical properties of the materials used are discussed in the following sections.

3.2.1 Cement

Ordinary Portland cement of grade – 43 under industrial name (Jaypee) conforming to Indian standard IS:1489 -1991 Part-I that was used in the present study. The results of the various tests on cement properties are given in Table 3.1 and Table 3.2.

Table 3.1 Physical properties of 43 Grade Ordinary Portland Cement

S. No.	Characteristics	Units	Values obtained	Values as per IS 1489-1991
1.	Consistency	%	28.2	-
2.	Initial setting time	Minutes	128	Not less than 30
3.	Final setting time	Minutes	192	Not greater than 600
4.	Fineness	m^2/kg	286.3	Not leess than 225 m^2/kg
5.	Specific gravity	gm/cc	3.51	-
6.	Compressive. strength (MPa) 3 days 7 days 28 days	(MPa)	 30.2 41.6 45.2	 27 41 43

Table 3.2 Chemical properties of 43 Grade Ordinary Portland Cement

Sr. No.	Properties	Typical Range	Requirement as per IS: 8112 - 1989
1	Lime Saturation Factor (LSF)	0.88-0.90	0.66 to 1.02
2	Alumina to Iron Oxide ratio % (A/F)	1.40-1.60	0.66 min.
3	In soluble residue (% by mass)	1.20-1.60	3.00 max
4	Magnesium Oxide (% by mass)	2.50-3.20	6.00 max
5	Sulphuric Anhydride (% by mass)	1.60-1.80	3.00 max
6	Total Loss of Ignition (% by mass)	1.20-1.60	5.00 max
7	Total Chloride (% by mass)	0.010-0.014	0.05 to 0.1 max

3.2.2 Fine aggregates

The material which passes through 4.75 mm sieve is termed as fine aggregates. The sand used for the experimental works is locally procured and conformed to grading zone II. The sieve analysis and physical properties of fine aggregates are listed in Tables 3.3. and Table 3.4

Table 3.3: Sieve analysis of fine aggregates

Sr. No.	Sieve No.	Cumulative Weight retained (grams)	Cumulative Percentage retained (%)	Percentage Passing (%)	Limits of zone II as per IS-383
1.	4.75 mm	14	1.4	98.6	90-100
2.	2.36 mm	80	8.0	92.0	75-100
3.	1.18 mm	322	32.2	67.8	55-90
4.	600 mm	518	51.8	48.2	35-59
5.	300 mm	720	72.0	28.0	8-30
6.	150 mm	947	94.7	5.3	0-10
7.	Pan	1000	-----	-	-
			$\Sigma F = 260.1$		

Table 3.4: Physical properties of fine aggregates

Sr. No.	Characteristics	Value
1.	Type	Natural sand
2.	Specific Gravity	2.60
3.	Fineness Modulus	2.60
4.	Grading Zone	Type II
5	Water absorption	1.4 %

3.2.3 Natural coarse aggregate

The broken stone is generally used as a coarse aggregate. The nature of work decides the maximum size of the coarse aggregate. Locally available coarse aggregate of maximum size of 20 mm was used in the present work. The results of sieve analysis of the natural aggregate are presented in Table 3.5.

Table 3.5: Sieve analysis of natural coarse aggregates

Sr. No.	Sieve size	Cumulative weight retained (gms)	Cumulative % retained	%passing for NCA	Limits as per IS-383
1.	40 mm	0	0	100	100
2.	20. mm	44	1.47	98.53	95-100
3.	10 mm	1796	59.87	40.13	25-55
4.	4.75 mm	2835	94.5	5.5	0-10
5	pan	3000	------	---	---

3.2.4 Stone Dust/ Quarry Dust

The Stone Dust or Quarry Dust used for the experimental works is procured from Pathankot and conformed to grading zone II. The sieve analysis, physical properties and Chemical properties of fine aggregates are listed in Table 3.6., Table 3.7 and Table 3.8.

Table 3.6: Sieve analysis of Quarry Dust

Sr. No.	Sieve No.	Cumulative Weight retained (grams)	Cumulative Percentage retained (%)	Percentage Passing (%)	Limits of zone II as per IS-383
1.	4.75 mm	11	1.1	98.9	90-100
2.	2.36 mm	85	8.5	91.5	75-100
3.	1.18 mm	342	34.2	65.8	55-90
4.	600 mm	532	53.2	46.8	35-59
5.	300 mm	738	73.8	26.2	8-30
6.	150 mm	945	94.5	5.5	0-10
7.	Pan	1000	-----	-	-
			ΣF = 265.3		

Table 3.7: Physical properties of Quarry Dust

Sr. No.	Characteristics	Value
1.	Type	Quarry Dust
2.	Specific Gravity	2.65
3.	Fineness Modulus	2.67
4.	Grading Zone	Type II
5	Water absorption	1.0 %

Table 3.8: Chemical properties of Quarry Dust

Sr. No.	Parameters	Test Method	Unit	Results
1.	Loss of Ignition	IS: 4032-1968	%	2.67
2.	SiO_2	IS: 4032-1968	%	69.74
3.	Al_2O_3	IS: 4032-1968 followed by MP-AES	%	12.30
4.	Fe_2O_3	IS: 4032-1968 followed by MP-AES	%	4.40
5.	CaO	IS: 4032-1968 followed by MP-AES	%	4.56
6.	MgO	IS: 4032-1968 followed by MP-AES	%	1.68
7.	Na_2O	IS: 4032-1968 followed by Flame Photometer	%	0.04
8.	K_2O	IS: 4032-1968 followed by Flame Photometer	%	2.11

3.2.5 Supplementary Cementing material

Rice Husk Ash is obtained from Rice Sheller Mills, Nabha. The chemical composition of rice husk ash as per Atomic Absorption Spectrometer (AAS) and Microwave Plasma Atomic Emission Spectrometer analysis is shown in Table 3.6. Physical and chemical properties of rice husk ash is shown in Table 3.9 and 3.10. Plate 3.1 shows the rice husk ash used in the present study.

Plate 3.1: Rice husk ash used in the study

Table 3.9: Physical Properties of Rice Husk Ash (RHA)

Sr. No.	Properties	Value
1	Specific Gravity	2.1
2	Specific Surface Area (cm^2/g)	3500
3	Density (g/cm^3)	2.19
4	Color	Grey Black

Table 3.10: Chemical properties of Rice Husk Ash (RHA)

Sr. No.	Parameters	Test Method	Unit	Results
1.	Loss of Ignition	IS: 1727-1967, Reaffirmed-2004	%	2.54
2.	SiO_2	IS: 1727-1967, Reaffirmed-2004	%	89.34
3.	Al_2O_3	IS: 1727-1967, Reaffirmed-2004 and AAS	%	0.29
4.	Fe_2O_3	IS: 1727-1967, Reaffirmed-2004 and AAS	%	0.26
5.	CaO	IS: 1727-1967, Reaffirmed-2004 and AAS	%	3.93
6.	MgO	IS: 1727-1967, Reaffirmed-2004 and AAS	%	0.61
7.	Na_2O	Digestion followed by MP-AES	%	.05
8.	K_2O	Digestion followed by MP-AES	%	0.19

3.2.6 Water

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. Since it helps to form the strength giving cement gel, the quantity and quality of water is required to be looked into very carefully. Potable water is generally considered satisfactory. In the present investigation, tap water is used for both mixing and curing purposes.

3.2.7 Superplasticizer

Auramix 400 of FOSROC brand complies with IS: 9103 (1979), BS: 5075 (Part 3) and ASTM-C-494 Type 'F' as a high range water reducing admixture. Auramix 400 is a unique combination of the latest generation superplasticisers, based on a polycarboxylic ether polymer with long lateral chains. It is supplied as brown/yellow liquid instantly dispersible in water and specially formulated to give high water reduction. At the start of the mixing process an electrostatic dispersion occurs but the cement particle's capacity to separate and disperse. This mechanism considerably reduces the water demand in flowable concrete. Auramix 400 combines the properties of water reduction and workability retention. It allows the production of high performance concrete and/or concrete with high workability. Properties of Aura Mix 400 is given in table 3.11.

Table 3.11 Properties of Aura Mix 400

Appearance	Light yellow colored liquid
pH	Minimum 6.0
Volumetric mass @ 20^{o}C	1.09 Kg/litre
Chloride Content	Nil to IS 456 :2000
Alkali Content	Typically less than 1.5 g Na_2O equivalent/ litre of admixture

3.3 MIX COMBINATIONS

A mix of M30 grade was designed as per IS 10262:2009 and the same was used to prepare the test samples. Total twelve mix combinations, i.e. 4 mixes with Normal Sand (comprising 0%, 10%, 20% and 30% of RHA as cement replacement), 4 mixes with Stone Dust (comprising 0%, 10%, 20% and 30% of RHA as cement replacement) and 4 mixes with 50% Normal Sand and 50% Stone Dust (comprising 0%, 10%, 20% and 30% of RHA as cement replacement) were prepared. M30 grade mix is designed by keeping water-cement ratio = 0.4.

The water content of concrete is influenced by a number of factors, such as aggregate size, aggregate shape, aggregate texture an environment conditions. An increase in aggregate size, a reduction in water-cement ratio and slump, and use of rounded aggregate and water reducing admixtures will reduce water demand. On the other hand increased temperature, cement content, slump, water-cement ratio, aggregate angularity and decrease in the proportion of coarse aggregate to fine aggregate will reduce water demand.

Water content is kept constant for all the mixes at a fix w/c ratio i.e. 0.4. At a fix cement content, the water demand increases with addition of Rice Husk Ash. Accordingly, the adjustment of water requirement is done for the mixes with incorporating Super plasticizer. The super plasticizer was added to all mixtures for obtaining the desired workability. The slump test for workability of the mix was done by cone method and a desired slump of 50-75 mm was achieved. The Super plasticizer dosage is super plasticizer dosage varies from 0.5% to 2% for the desired slump value.

For each mix 10 nos. 150x150x150 mm cube samples were prepared i.e 3 no. for checking 3 days compressive strength, 3 No.s. for 7 days compressive strength, 3 nos. for 28 days compressive strength and 1 no. sample for sorptivity test.

Concrete mixture proportions are presented in Table 3.12.

Table 3.12: Mix proportions for different samples

Designation	Cement (kg/m³)	RHA (kg/m³)	RHA (%)	NS (kg/m³)	SD (kg/m³)	NS (%) + SD (%)	CA (kg/m³)	Water (kg/m³)	w/c	SP (kg/m³)	SP (%)
Control Mix-N-0	400	-	-	807	-	50% + 0%	1146	160	0.4	2	0.5
N-10	360	40	10	807	-	50% + 0%	1146	160	0.4	4.4	1.1
N-20	320	80	20	807	-	50% + 0%	1146	160	0.4	5.6	1.4
N-30	280	120	30	807	-	50% + 0%	1146	160	0.4	6.8	1.7
Control Mix –	400	-	-	-	807	0% + 50%	1146	160	0.4	2.8	0.7
SD-10	360	40	10	-	807	0% + 50%	1146	160	0.4	5.2	1.3
SD-20	320	80	20	-	807	0% + 50%	1146	160	0.4	6	1.5
SD-30	280	120	30	-	807	0% + 50%	1146	160	0.4	8	2.0
Control Mix – NSD-0	400	-	-	403.5	403.5	50% + 50%	1146	160	0.4	3.2	0.8
NSD-10	360	40	10	403.5	403.5	50% + 50%	1146	160	0.4	4.8	1.2
NSD-20	320	80	20	403.5	403.5	50% + 50%	1146	160	0.4	6.4	1.6
NSD-30	280	120	30	403.5	403.5	50% + 50%	1146	160	0.4	8	2.0

3.4. CASTING OF SPECIMENS

In this section the casting procedure for compressive test specimen are discussed.

3.4.1 Compressive strength test specimens

Three cube specimens of size 150×150×150mm were cast for static compressive testing. The quantity of cement, coarse aggregate, fine aggregate, rice husk ash and water for each mix is weighed separately. The cement and rice husk ash are mixed dry to attain a uniform mix separately. Fine aggregate is mixed to this mixture in dry form. The coarse aggregates were mixed to get uniform distribution throughout the batch. Water added to the mix firstly, 50 to 70% of water was added to the mix and then mixed thoroughly for 3 to 4 minutes then remaining water add in mixture and mixed. The cubes are filled with fresh concrete using vibrating Table. After casting cubes, the specimens are kept in lab for 24 hours. Next day the specimens are take out from mould and the specimen are kept in curing tank. For each mix 9 cubes were casted for 3 days, 7 days and 28 days compressive strength test. . The cubes after casting are shown in Plate 3.2.

Plate 3.2: Casting of cubes

3.4.2 Sorptivity Test specimens

For the test, 150x150x150 mm cube specimens were casted from the concrete mixes. After casting, the specimens are kept in lab for 24 hours. Next day the specimens are taken out from the mould and are kept in curing tank. After 28 days curing, the specimens were placed in an oven for drying at 50$\pm$ 2^o C for 3 days. Then, the concrete specimens were cooled down to room temperature for conducting test. Before the sorptivity test, the side faces of specimens were coated with epoxy coating. Measurements of capillary sorption were carried out using specimens pre-conditioned in the oven at about 50°C for 3days.

3.4.3 Microstructure Analysis

After conducting 28 days compressive strength test, the pieces of the broken samples was collected. Microstructure analyses of concrete specimens were done by scanning electron microscope (SEM: 6510-LV, JOEL, USA). Original microstructure and morphology of the hydrate mixes were observed on crushed sample surfaces. Crushed samples were mounted on the brass stubs using carbon tapes and were gold coated.
For X-ray diffraction (XRD) the samples, which were already cast and cured for 28 d, are crushed and pulverized to an average particle size of 10 µm. After that mass absorption coefficient of the sample was determined by X-Ray transmission (Xpert pro, Panalytical, USA). The XRD pattern was observed by scanning the sample from 10 to 80^o, 2 theta and having Cu radiation and graphite monochromatic with a current of 30 KV and a voltage of 40 MV by using a vertical X-ray diffraction meter.

3.5 TEST METHOD

In this section the test setup used obtaining the compressive strength test is discussed.

3.5.1 Compressive strength test

Apparatus: Testing Machine: The testing machine should be of sufficient capacity for the tests and capable of applying the load at the specified rate. The permissible error shall not be greater than 2% of the maximum load. The testing machine shall be equipped with two steel bearing platens with hardened faces. One of the plates shall be fitted with a ball seating in the form the portion of the sphere, the centre of which coincides with the central point of the face of the platen. The other compression plates shall be plain rigid bearing block. The bearing faces of both plates shall be at least as larger as, and it should preferably be larger than the normal size of the specimen to which the load is applied. The bearing surface of the plates, when new, shall not depart from a plane by more than 0.01 mm at any point, and they shall be maintained with a permissible variation limit of 0.02 mm, the movable portion of the spherical seated compression plates shall be held on the spherical seat, but the design shall be such that the bearing face can be rotated freely and tilted through small angles in any direction.

Procedure: Specimens stored in water shall be tested immediately on removal from the water and while they are still in the wet condition. Surface water and grit shall be wiped off the specimens and any projecting find removed specimens when received dry shall be kept in water for 24 h before they are taken for testing. The dimensions of the specimens to the nearest 0.2 mm and their weight shall be noted before testing. Placing the specimen in the testing machine the bearing surface of the testing machine shall be wiped clean and any loose sand or other material removed from the surface of the specimen, which are to be in contact with the compression platens. In the case of cubes, 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 axis of the specimen shall be carefully aligned with the centre of thrust of the spherically seated platen. No packing shall be used between the faces of the test specimen and steel platen of the testing machine. As the spherically seated block is brought to bear on the specimen, the movable portion shall be rotated gently by hand so that uniform seating may be obtained. The load shall be applied without shock and increased continuously at a rate of approximately 140 kg/cm2/min. until the resistance of the specimen to the increasing load breaks down and any unusual features in the type of failure shall be noted.

Calculation: Three identical specimens are crushed at 3days and three identical specimens are crushed at 7 days. The compressive strength is calculated by dividing the failure load by average cross sectional area. The average value of the three samples was taken as the compressive strength of the batch. .

The compressive strength testing machine of capacity 5000 KN is used for determining the maximum compressive loads carried by concrete cubes. The compressive strength test machine which used in all tests is shown in Plate 3.3. At the test age the specimens are taken out of the curing tank and kept outside for 10 minutes. Then one specimen is placed on the steel plate of the machine such that the specimen is tested perpendicular to the casting position. Then the test is carried out at the loading rate of 5 kN/s specified IS: 516 - 1959. Maximum load on the specimen was recorded as load at which specimen failed to take any further increase in load.

Plate 3.3: Testing for compressive strength

3.5.2 Water Sorptivity Test

Each concrete mix was tested for its water sorptivity by following basic testing procedure stipulated in ASTM C1585-2013. For the test, 150 mm cube specimens were cast from the concrete mixes. The cube specimens were demoulded at 1 day after casting and then water cured at a temperature of 27 ± 2^{o} C until the age of 28 days. After completion of curing, the cube specimens were conditioned. The condition applied was oven drying at 50^{o} ± 2^{o} C for 3 days and then natural cooling to room temperature in the oven to avoid temperature shock. Before the sorptivity test, the side faces of the specimens were coated with epoxy. The size of the concrete face in contact with water, i.e. the inflow surface, was 150 mm x 150 mm.

During the sorptivity test, the mass of each specimen was measured at various times using an electronic balance. From the increase in mass of the specimen due to water absorption (denoted by m_t), the absorbed volume of water per unit area of inflow surface (denoted by I) can be calculated using the following Eq. (1), where a is the area of the inflow surface and q is the density of water.

$$I = \frac{m_t}{A \times d} \qquad (1)$$

In general, the absorbed volume of water per unit area of inflow surface would increase with the time as a square root function of the time t after the start of the sorptivity test, as given by the following Eq. (2), where k is the sorptivity coefficient of the concrete specimen.

$$I = K\,(t)^{1/2} \qquad (2)$$

To determine the sorptivity coefficient k, I was plotted against the square root of t, the best-fit straight line was obtained by regression analysis, and then k was calculated as the slope of the best-fit straight line.

3.5.3 X-ray diffraction (XRD)

For X-Ray Diffraction (XRD) the samples which were already casted and cured for 28 days are crushed and pulverised to an average particle size of 10 microns. After that this crushed sample was mounted on the glass fibre filter using tubular aerosol suspension chamber (TASC). After placing the sample in the chamber the mass absorption coefficient of the sample was determined by X-Ray transmission (Xpert pro, Panalytical, United states). The XRD pattern was observed by scanning the ample from 10-80 degrees, 2 theta and having Cu radiation and graphite monochromatic with a current of 30 KV and a voltage of 40 MV by using a vertical X-ray diffract meter.

3.5.4 Scanning electron microscopy (SEM)

Scanning Electron Microscopy (6510-LV, JOEL, Japan) is conducted to study the micro-structure properties of the samples. The samples which were already casted and cured for 28 days are used for the test. This test is used to identify the changes which had occurred inside the micro-structure and also the formation and deformation of the phases.

CHAPTER 4

RESULT AND DISCUSSION

4.1 GENERAL

This chapter presents the results of Workability, compressive strength and microstructure analysis of various concrete mix proportions. All the tests were conducted in accordance with the test methods as described in Chapter 3.

4.2 EFFECT OF ADDITION OF RICE HUSK ASH ON PROPERTIES OF CONCRETE

Replacement of rice husk ash with cement on concrete is discussed in the following section. Reactivity of rice husk ash is basically due to the high amorphous silica content and also due to large surface area governed by porous structure of particles (Dakroury AE et al 2008). This makes rice husk ash a very reactive pozzolanic material. In chemical reaction of Portland cement in concrete, there is release of calcium hydroxide. Silica present in rice husk ash reacts with this calcium hydroxide to form additional binder material called as calcium silicate hydrate (C-S-H) similar to the C-S-H produced by Portland cement. It works as additional binder that gives rice husk ash concrete its improved properties. Mechanism of rice husk ash in concrete can be studied under three roles:

- *Matrix Densification and Pore size Refinement*: The presence of filler like rice husk ash in the Portland cement concrete mixes causes reduction in volume of large pores. RHA acts as filler due to its fineness. It fits into the spaces between grains in same way like cement grains fill the spaces between fine aggregates grains and sand fills the spaces between particles of coarse aggregates.
- *Reaction with free-lime (From hydration of cement):* CH crystals present in Portland cement pastes are a source of weakness. Cracks can easily propagate through or within these crystals without any significant resistance. This affects the strength, durability and other properties of concrete. Rice husk ash which is siliceous material reacts with CH results in reduction in CH content in addition to forming strength contributing cementitious products which in other words can be termed as ‘‘Pozzolanic Reaction’’.

- *Cement paste–aggregate interfacial refinement*: In concrete the transition zone between the aggregate particles and cement paste plays a significant role in the cement-aggregate bond. Rice husk ash addition influences the thickness of transition phase in mortars and the degree of the orientation of the CH crystals in it. The thickness compared with mortar containing only ordinary Portland cement decreases. Hence mechanical properties and durability is improved because of the enhancement in interfacial or bond strength. Mechanism behind is not only connected to chemical formation of C–S–H (i.e. pozzolanic reaction) at interface, but also to the microstructure modification (i.e. CH orientation, porosity and transition zone thickness) as well.

4.2.1 Workability

The workability is one of the physical parameters of concrete which affects the strength and durability and the appearance of the finished surface. The workability of concrete depends on the water cement ratio and the water absorption capacity of the aggregates. If the water added is more it will lead to bleeding or segregation of aggregates. The test for the workability of concrete is conducted as per Indian Standard IS 1199-1959 which gives the test procedure using various equipments. In the present study slump cone test was used for measuring the workability of concrete. The height of the fall of the cone of concrete is measured for various mixes and recorded the values for ordinary concrete. Then the same procedure was adopted with the concrete having the partial replacement of sand with raw quarry dust at various percentages.

Various mixes have been designed and tested for fresh concrete properties. Superplasticizer content was varied from 0.5-2.0% to achieve slump of 60-75 mm at a constant w/c ratio 0.4.

The results of superplasticizer demand and corresponding slump of all the concrete mixes are included in Table: 4.1.

Table 4.1 Dosage of super plasticizer and slump values

Designation	Super Plasticizer (%)	Slump (mm)
Control Mix-N-0	0.5	55
N-10	1.1	60
N-20	1.4	60
N-30	1.7	65
Control Mix – SD-0	0.7	60
SD-10	1.3	70
SD-20	1.5	75
SD-30	2.0	65
Control Mix – NSD-0	0.8	60
NSD-10	1.2	55
NSD-20	1.6	70
NSD-30	2.0	65

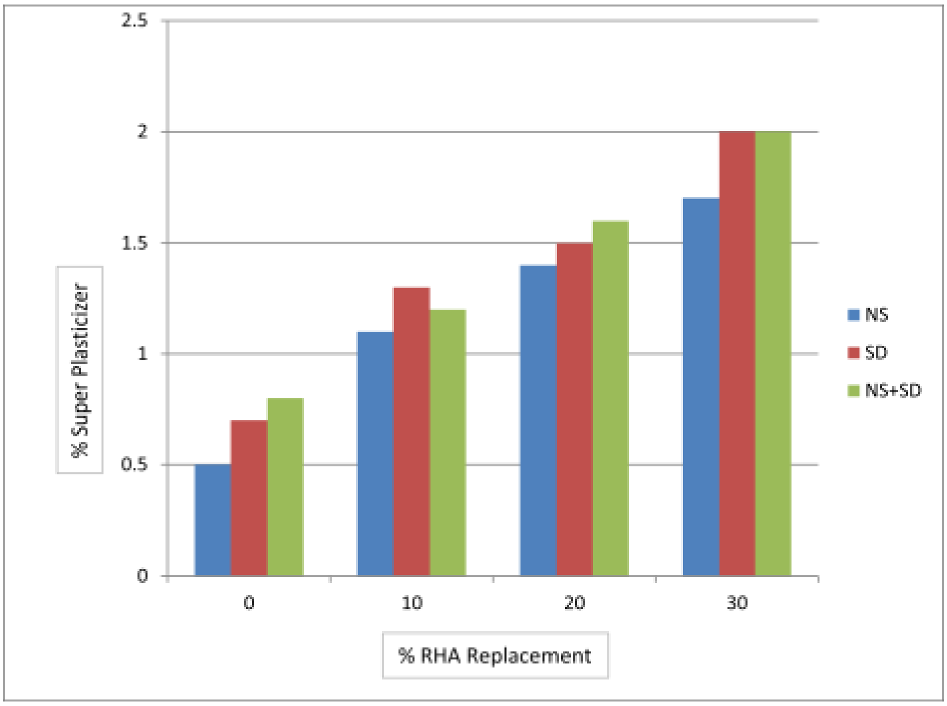


Fig 4.1: Comparison of Requirement of super plasticizer with variation of RHA for all mixes

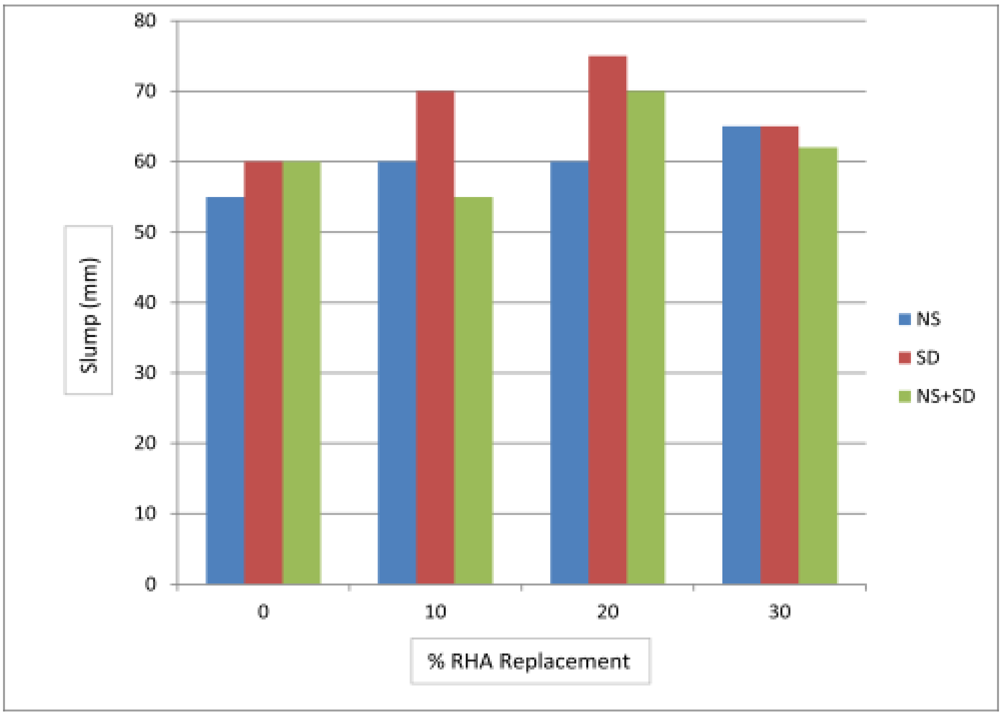


Fig 4.2: Comparison of slump values for all mixes

As the Rice Husk Ash was added as cement replacement, the powder content or fines content increases in the matrix, leading to increase of the Superplasticizer dosage needed to achieve the required workability. To reflect the effect of such increase in powder content, the Superplasticizer dosage is expressed as percentage by mass of the powder content. From the Superplasticizer dosage results in Fig. 4.1, it can be seen that the Superplasticizer dosage increased significantly with addition of RHA for all the mixes. Further, after adding superplasticizer, the slump of all the mixes was obtained in the desired range of 50 – 75 mm (Fig. 4.2).

4.2.2 Compressive Strength

Compressive strength test results of cube specimens for all mix proportion at 3, 7 and 28 days are presented in Table 4.2. The data is further represented in the form of graphs in Fig 4.3 - 4.5.

Table 4.2: Compressive strength of all mix combination at 3,7 and 28 days

Mix Type	3 days Comp. strength (MPa)	Average 3 days Comp. strength (MPa)	7 days Comp. strength (MPa)	Average7 days comp. strength (MPa)	28 days Comp. strength (MPa)	Average28 days comp. strength (MPa)
N-0	10.869	10.113	15.682	15.795	30.653	32.114
	11.383		13.490		31.528	
	8.086		18.214		34.250	
N-10	16.022	17.305	21.931	20.261	33.630	34.680
	18.549		14.282		35.828	
	17.344		24.569		34.582	
N-20	19.238	20.895	26.603	26.701	38.135	37.727
	21.937		28.086		35.859	
	21.510		25.415		39.187	
N-30	10.430	10.170	11.124	13.123	25.483	24.954
	9.044		14.844		27.154	
	11.037		13.401		22.25	
SD-0	27.744	26.483	33.265	27.439	37.795	33.755
	24.989		21.757		34.558	
	26.716		27.94		34.912	
SD-10	32.890	30.183	34.035	31.814	35.215	35.834
	28.436		31.160		38.669	
	29.224		30.246		33.619	
SD-20	36.229	30.562	29.759	33.344	41.370	40.473
	26.349		35.628		41.260	
	29.108		34.646		38.788	
SD-30	22.494	25.347	28.419	28.267	33.523	31.280
	26.811		27.116		28.447	
	26.735		29.266		31.870	
NSD-0	27.740	27.969	26.627	28.891	34.258	35.156
	28.607		29.783		35.579	
	27.561		30.263		35.630	
NSD-10	30.450	31.513	29.316	31.643	35.222	36.663
	33.393		32.938		38.490	
	30.695		32.675		36.278	
NSD-20	31.952	31.613	31.358	32.367	40.167	41.327
	32.779		34.028		42.943	
	30.108		31.714		40.871	
NSD-30	26.079	27.391	27.522	29.784	33.508	32.642
	27.701		31.228		33.970	
	28.394		30.600		30.448	

N-0: Mix with normal sand and 0% RHA as cement replacement

N-10: Mix with normal sand and 10% RHA as cement replacement

N-20: Mix with normal sand and 20% RHA as cement replacement

N-30: Mix with normal sand and 30% RHA as cement replacement

SD-0: Mix with stone dust and 0% RHA as cement replacement

SD-10: Mix with stone dust and 10% RHA as cement replacement

SD-20: Mix with stone dust and 20% RHA as cement replacement

SD-30: Mix with stone dust and 30% RHA as cement replacement

NSD-0: Mix with (50% normal sand + 50% stone dust) and 0% RHA as cement replacement

NSD-10: Mix with (50% normal sand + 50% stone dust) and 10% RHA as cement replacement

NSD-20: Mix with (50% normal sand + 50% stone dust) and 20% RHA as cement replacement

NSD-30: Mix with (50% normal sand + 50% stone dust) and 30% RHA as cement replacement

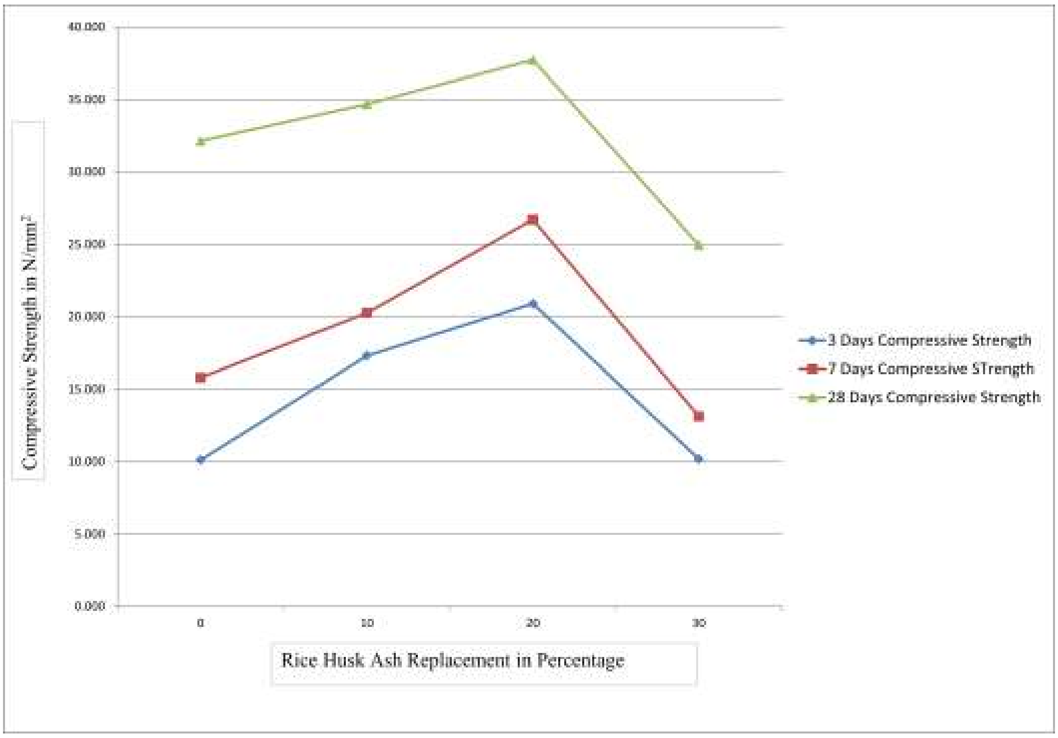


Fig 4.3: Average Compressive strength of mixes made with Normal Sand as fine aggregate

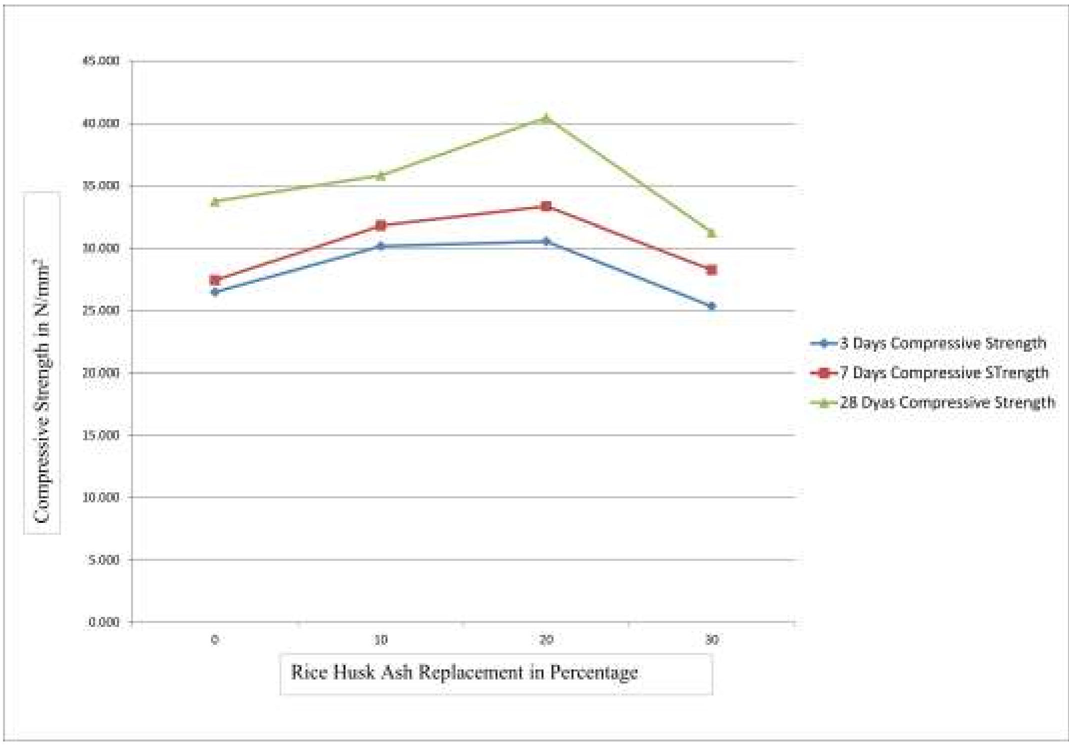


Fig 4.4: Average Compressive strength of mixes made with Stone Dust as fine aggregate

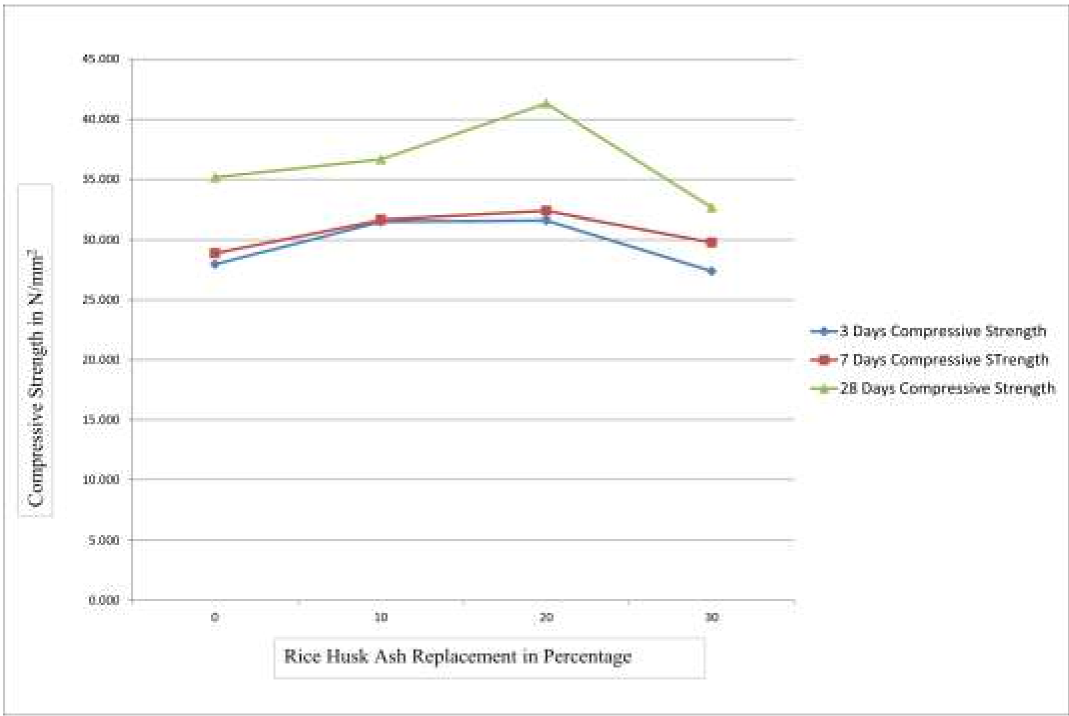


Fig 4.5: Average Compressive strength of mixes made with 50% Normal Sand and 50% Stone Dust

Compressive strength increases with increase in percentage addition of rice husk ash at corresponding values of water to cement ratio and age as can be seen in Fig. 4.3–4.5. This trend is pronounced for replacement level up to 20%. After this with further increase in addition of rice husk ash the compressive strength decreases.

The improvement of compressive strength is mostly due to micro filling ability and pozzolanic activity of rice husk ash. With a smaller particle size, the rice husk ash can fill the micro voids within the cement particles. Also the rice husk is highly reactive, it reacts with calcium hydroxide (a by product of cement hydration) and produces additional C-S-H gel. The additional C-S-H reduces the porosity of concrete by filling the capillary pores, and thus improving the microstructure of concrete in bulk paste matrix and transition zone leading to an increased compressive strength.

Decrease in compressive strength is observed at 30% rice husk ash replacement. In this case, the amount of silica available in the hydrated blended cement matrix is probably too high and the amount of the produced C-H is most likely insufficient to react with all the available silica and as a result of that, some amount of silica was left without any chemical reaction.

Similar observations were made by Alireza et.al (2010).

4.2.3 Water Sorptivity

The absorbed volumes of water per unit area of inflow surface are plotted against the square root of time in Fig. 4.6 to 4.8 for W/C ratios of 0.4. From the curves plotted, it can be seen that the slope of each curve changes little with the time; this agrees well with the recent results reported by Kubissa and Jaskulski (2013).

The slope of each curve is taken as the sorptivity coefficient of the concrete tested. The sorptivity coefficients so obtained are listed in Table 4.3. The results in Fig. 4.9 depict clearly that as rice husk ash was added as cement replacement, the sorptivity coefficient decreased quite substantially. The addition of rice husk ash as cement replacement without changing the W/C ratio not only decreases the sorptivity coefficient, but also increases the strength of the concrete. If a higher strength is not really required, the opportunity may be taken to adjust the W/C ratio upwards to improve the workability and further reduce the cement content.

Table 4.3: sorptivity coefficients for all mixes

Sr. No	Sample	sorptivity coefficients (mm/√s)
1	NO	0.022
2	N10	0.014
3	N20	0.008
4	N30	0.014
5	SD0	0.011
6	SD10	0.011
7	SD20	0.010
8	SD30	0.012
9	NSD0	0.017
10	NSD10	0.012
11	NSD20	0.010
12	NSD30	0.009

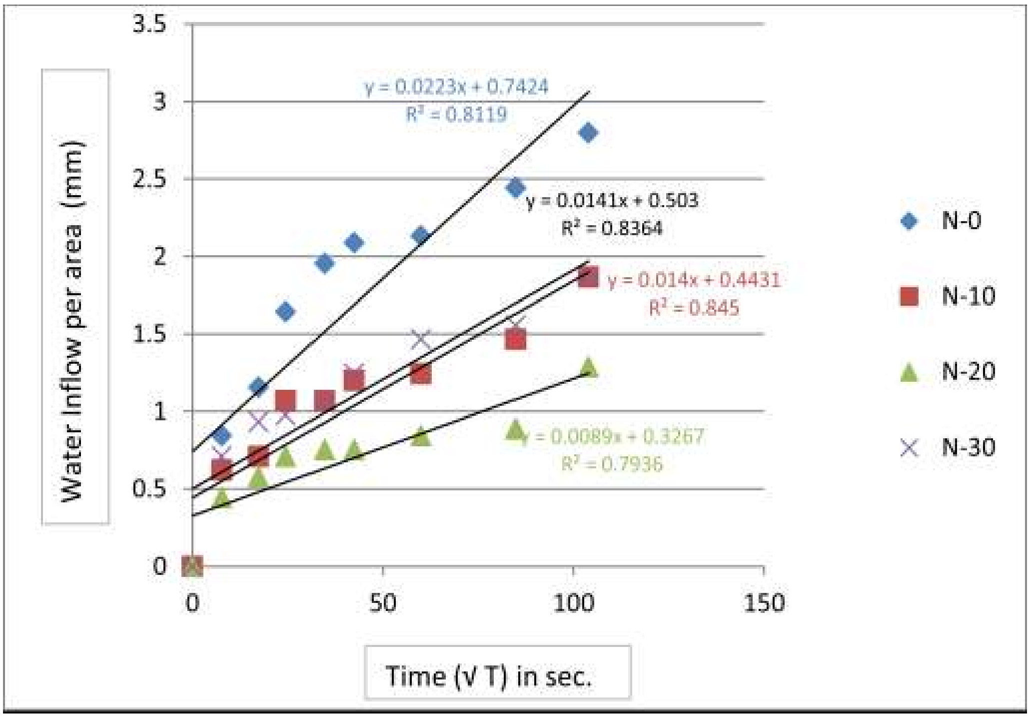


Fig. 4.6: Water inflow per area versus square root time for mixes made with normal sand

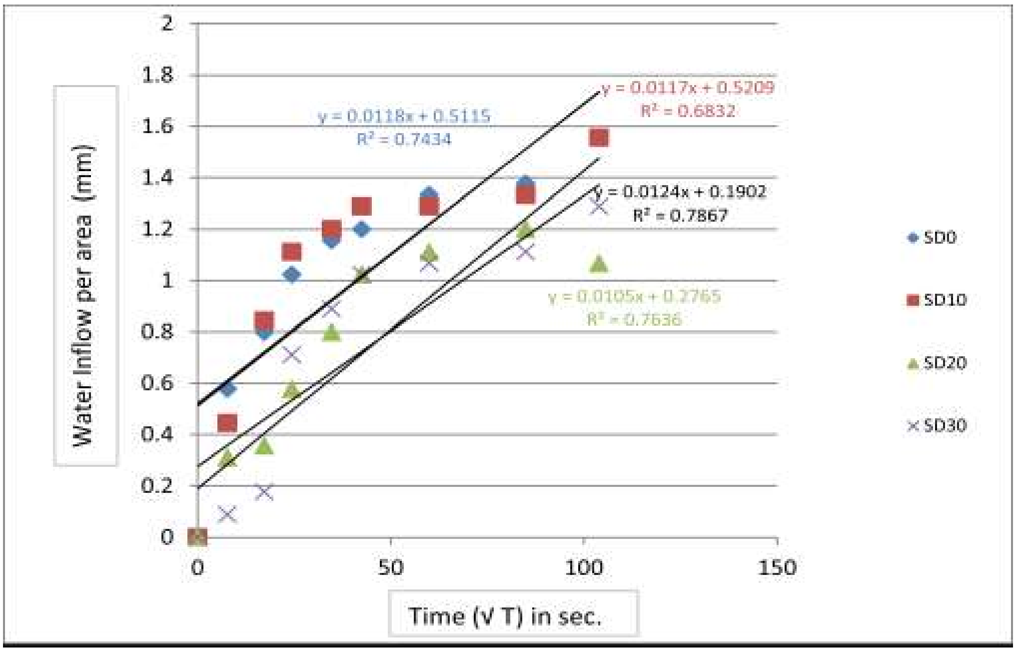


Fig. 4.7: Water inflow per area versus square root time for mixes made with Stone dust

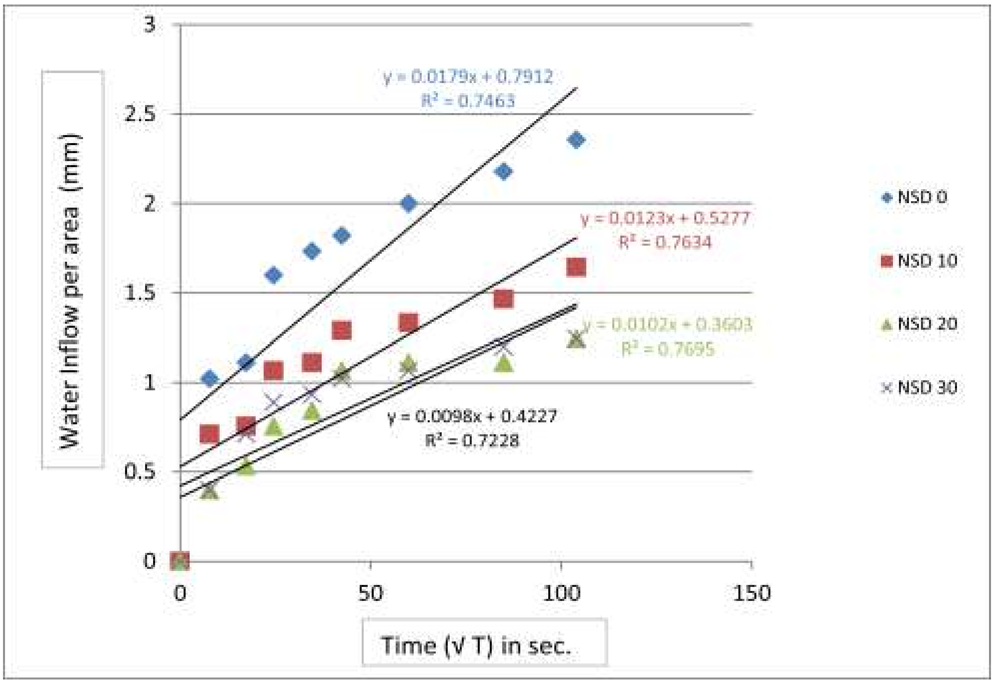


Fig. 4.8: Water inflow per area versus square root time for mixes made with normal sand and stone dust

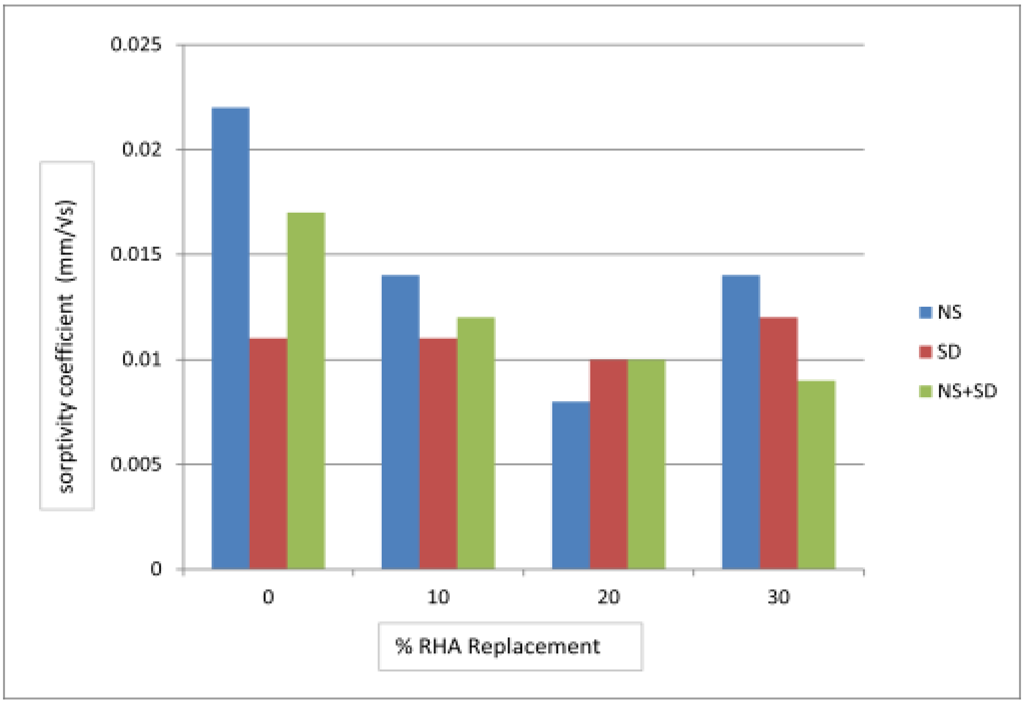


Fig 4.9: Comparison of water sorptivity for all the mixes

4.3 EFFECT OF ADDITION OF STONE DUST AS FINE AGGREGATE ON PROPERTIES OF CONCRETE

The objective of this study is to identify the possibilities of utilizing the quarry dust in concrete to obtain an improved strength and durability properties of concrete. In the present study, the addition of quarry dust as alternative for natural sand has been investigated, and the compressive strength and capillary water absorption of concrete is evaluated systematically by means of Compressive Strength test and Water Sorptivity test. Concrete mixes were casted using ordinary river bed sand and compared with 100% quarry dust substituted concrete. The addition of quarry dust significantly improved the concrete matrix properties in terms of strength and water sorptivity. The addition of fine quarry dust in concrete resulted in improved matrix densification compared to conventional concrete.Matrix densification has been studied qualitatively through SEM and XRD.

4.3.1 Workability

Some of the factors that may affect the workability of the concrete are grading and shape of fine aggregates, proportion of fine to coarse aggregates and characteristics of the materials. The main critical parameter in the workability is that natural aggregates absorb more water. Therefore, the correct quantity of water required for the mixes needs correction and depends on the mix proportions.The variations of slump value with quarry dust percentage are shown in Fig-4.2. It is observed that the slump values are within the desired range of 50-75 mm for all the mixes and the value increases with increase in percentage replacement of sand with quarry dust for the same w/c ratio. Concrete does not give adequate workability with increase of quarry dust. It can be due to the extra fineness of quarry dust (Jain et.al., 1999). Increased fineness require greater amount of water for the mix ingredients to get closer packing, results in decreased workability of the mix. The round shape and smooth surface texture of natural sand reduces the inter particle friction in the fine aggregate component so that the workability is higher in natural sand. Manufactured sand particles are angular in shape and their rough surface texture improves the internal friction in the mix. Because of that the workability is reduced. Hence, the demand of super plasticizer increases with replacement of stone dust as a fine aggregate as shown in Fig. 4.1.

As the replacement of the sand with quarry dust increases, the workability of the concrete is decreasing due to the absorption of the water by the quarry dust. Smooth surface texture of natural sand reduces the inter particle friction in the fine aggregate component so that the workability is higher in natural sand. Stone dust particles are angular in shape and their rough surface texture improves the internal friction in the mix. Because of that the workability is reduced.

4.3.2 Compressive Strength

Compressive strength test results of cube specimens for all mix proportion at 3, 7 and 28 days are presented in Table 4.2. The data is further represented in the form of graphs in Fig 4.10 - 4.12.

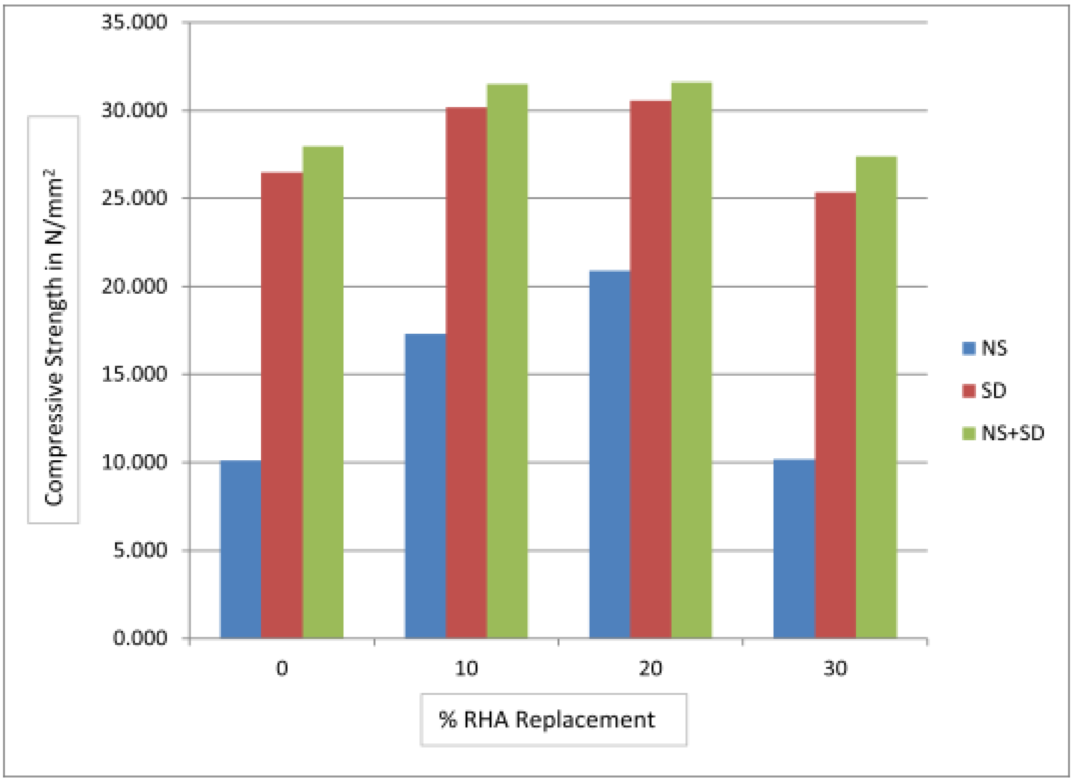


Fig 4.10: 3 days Compressive Strength of mixes made with different aggregates

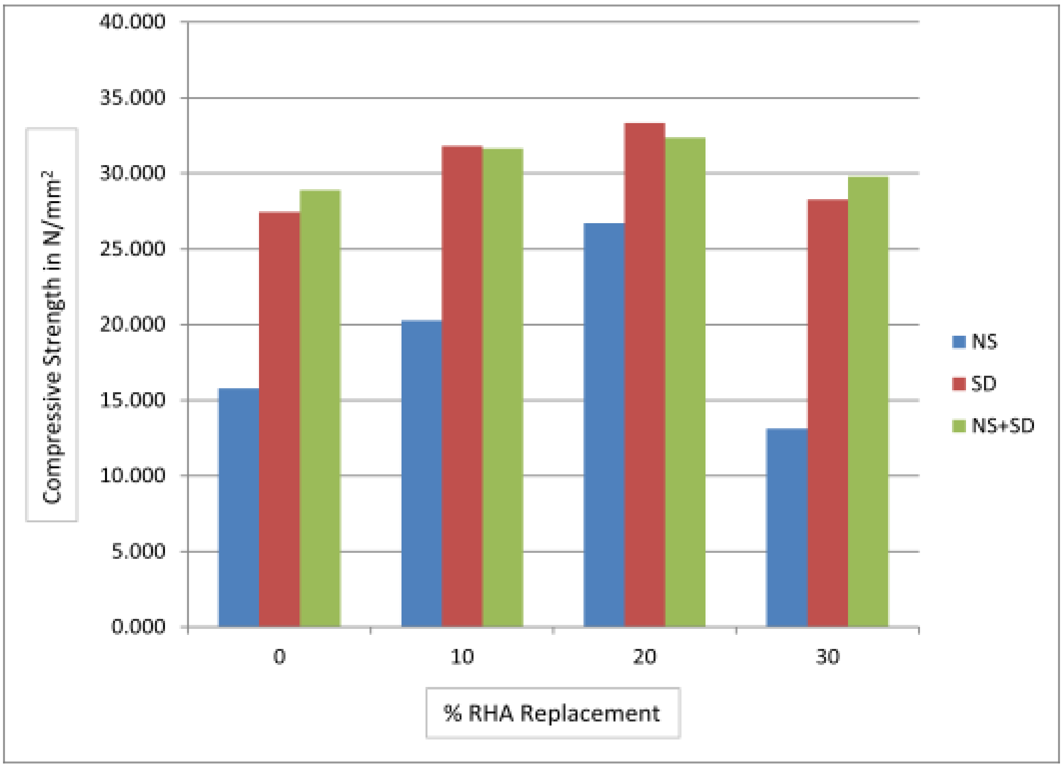


Fig 4.11: 7 days Compressive Strength of mixes made with different aggregates

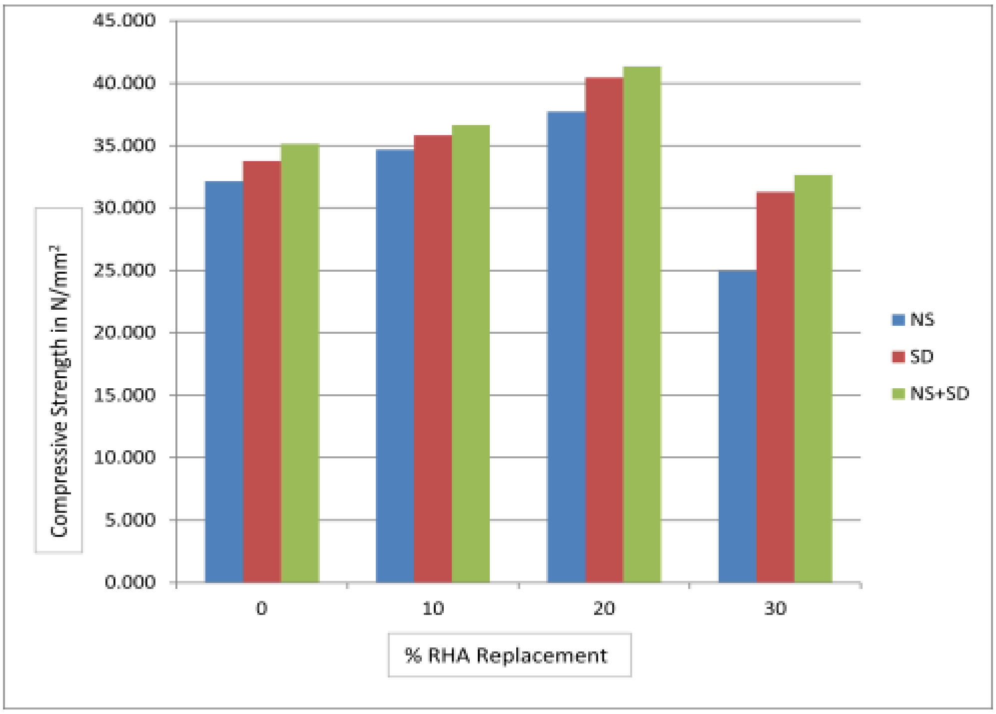


Fig 4.12: 28 days Compressive Strength of mixes made with different aggregates

The mechanical interlocking capacity between the fine aggregate particles and the matrix phase, which improves the mechanical performance of the transition zone, is related to the compressive strength. Both of these properties improve the microstructure in the bulk paste matrix and transition zone. It is observed that compressive strength of concrete continues to increase with age for all the mixes. The compressive strength for 3, 7 and 28 days of the controlled mix (i.e.with 0% rice husk) replacement is 10.113 MPa, 26.483 MPa and 25.347 MPa respectively.

As shown in table 4.2 and Fig. 4.10 - 4.12, the 28 days compressive strength increases for all the mixes but due addition of rice husk ash (beyond 20%) as cement replacement, the compressive strength decreases. The compressive strength of cubes at 28 days curing for mixes is 37.27 MPa, 40.437 MPa and 41.337 MPa for concrete made with Normal Sand, Stone Dust and Normal Sand and Stone Dust. Whereas the compressive strength results at all ages is higher for the concrete made with combination of 50% normal sand and 50% stone dust as compare to concrete made with normal sand and stone dust alone as a fine aggregate. The 3,7 and 28 days compressive strength noted for concrete made with combination of normal sand and stone dust (50%-50%) i.e. corresponding to mix NSD20 is 31.613 MPa, 32.367 MPa and 41.327 MPa respectively.

The increase in compressive strength can be related to the higher concentration of hydrated cement compounds within the available space for them to occupy. Furthermore, by acting as micro filler, the stone dust promoted an accelerated formation of hydrated compounds, thus resulted a significant improvement of compressive strength at earlier ages (7days). This reveals the fact that high matrix densification as a result of fine particles present in quarry dust provided good granular packing.

Regarding higher contents of stone dust (substitution of more than 50% of sand), the decrease of compressive strength values was significant. The incorporation of such amounts of very fine material did not permit the micro filler effect to prevail, which, in addition to a rather inappropriate grading, caused lower results.

The results achieved for compressive strength are comparable to Almeida et al (2007). Therefore, it is possible to conclude that full substitution of fine aggregate for stone dust is not reliable when compressive strength is a critical aspect to take in consideration.

4.3.3 Water Sorptivity

For assessing the effectiveness of adding RHA in reducing the water sorptivity on equal strength basis, the sorptivity coefficient is plotted against 28-day cube strengths for different RHA volumes in Fig.4.13.

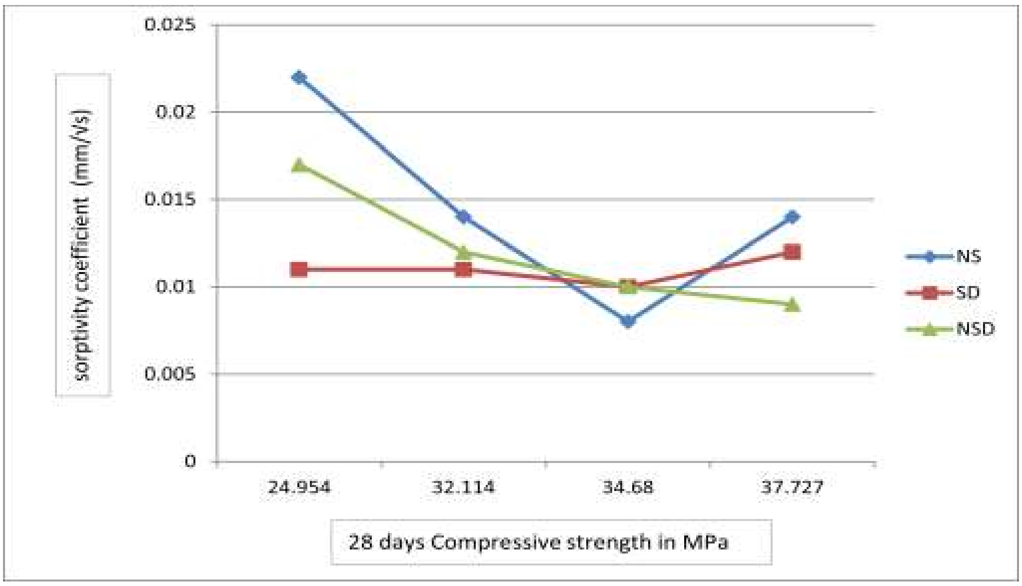


Fig. 4.13: Sorptivity coefficients vs cube compressive strength

It is observed that that the sorptivity decreases with increase of strength for all type of mixes. After initial decrease in sorptivity, the increasing trend in sorptivity is observed after 28 days curing for concrete made with normal sand and stone dust. The concrete made with combination of normal sand and stone dust (50%-50%) shows the reduction in sorptivity with age. The reduction in water sorptivity is due to the filling of the stone dust into the pores in the bulk cement paste and in the interfaces between the aggregate and cement paste. It is suspected that in the present case of adding rice husk ash as cement paste replacement, similar filling of the rice husk ash into the pores to reduce the porosity of the concrete had occurred and that was the main reason for the observed reductions in water sorptivity.

4.4 MICRO STRUCTURE ANALYSIS

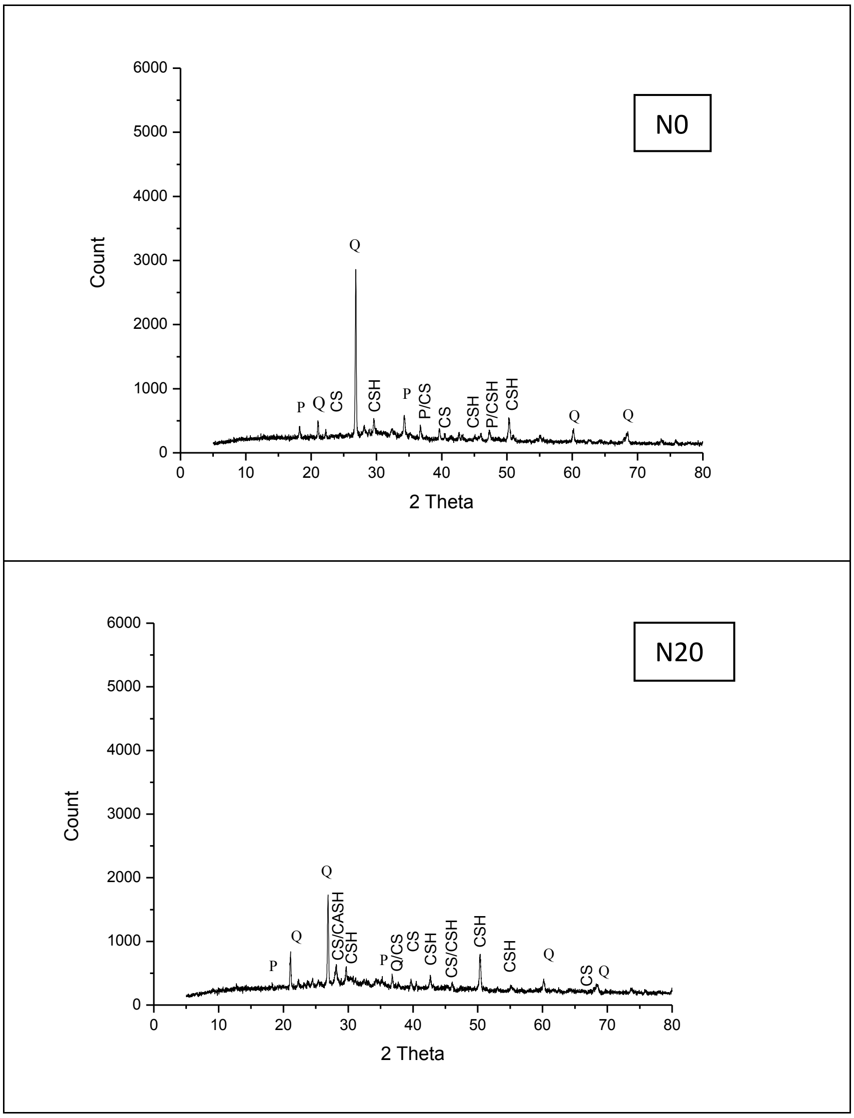
4.4.1 X-Ray Diffraction

The identification of crystalline phases such as calcium hydroxide, ettringites, and calcium silicate hydrates, calcium aluminium silicate hydrate, calcite etc. present in the concrete can be done by using X-ray diffraction technique. The diffractogram is made up of succession of diffraction maximum points in which intensity of the diffracted radiation is plotted on ordinate and angle 2θ on abscissa. Every crystalline phase has its own diffraction image. The diffraction image depends upon the material structure. The diffraction methods allow the study of the crystalline structures, phase quantitative and qualitative analysis, phase transformations, crystallographic texture, the size of the crystallites, the internal stresses in the sample, etc.

The microstructure of the interfacial transitional zone of concrete differs from that of bulk cement paste. The diffraction peaks of poorly crystalline calcium silicate hydrate phase of concrete are weak. The diffraction peaks of minerals present in aggregate interference with the peaks of poorly crystalline hydration phases of the concrete. The weak diffraction peaks of calcium silicate hydrate tend to be swamped by the diffraction peaks from calcium hydroxide. As such, the identification of hydration phases present in concrete more is a complicated process.

The X-ray diffraction technique was used for identification of various phases present in the hardened concrete at the age of 28 days. The XRD investigations were performed for diffraction angle 2θ ranged between 5° and 80° in steps of 2θ = 0.017°. The phase identification was carried out using Xpert High Score Plus software.

Fig.4.14 shows the XRD spectrum of control concrete made with natural sand, concrete containing 20 and 30% Rice Husk Ash as replacement of cement. The major phases observed in concrete mixtures are Quartz, calcium silicate, calcium hydroxide, calcium silicate hydrate, calcium aluminum silicate hydrate and calcite. It is also observed that the peak intensity of portlandite ($Ca(OH)_2$) has been decreased on addition of rice husk ash as replacement of cement. The phases present in concrete mixture did not changed qualitatively on incorporation of rice husk ash as binder material. Assuming the intensity of peak of the phase is connected with the amount of that phase present in the concrete, the lower intensities of portlandite indicate that the influence of rice husk ash is significant on portlandite phase. Although qualitatively there is no change in the phases present in the concrete, but the quantitative change in phases is there on addition of rice husk ash.



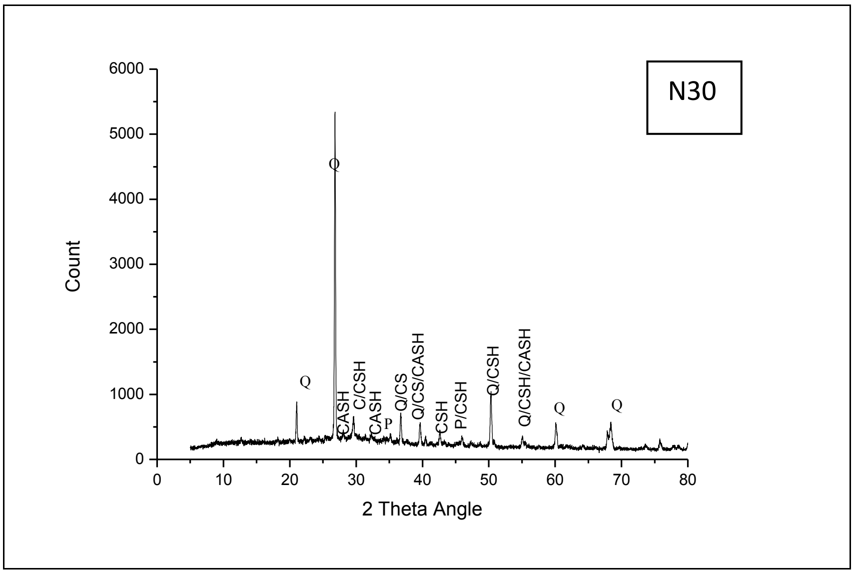
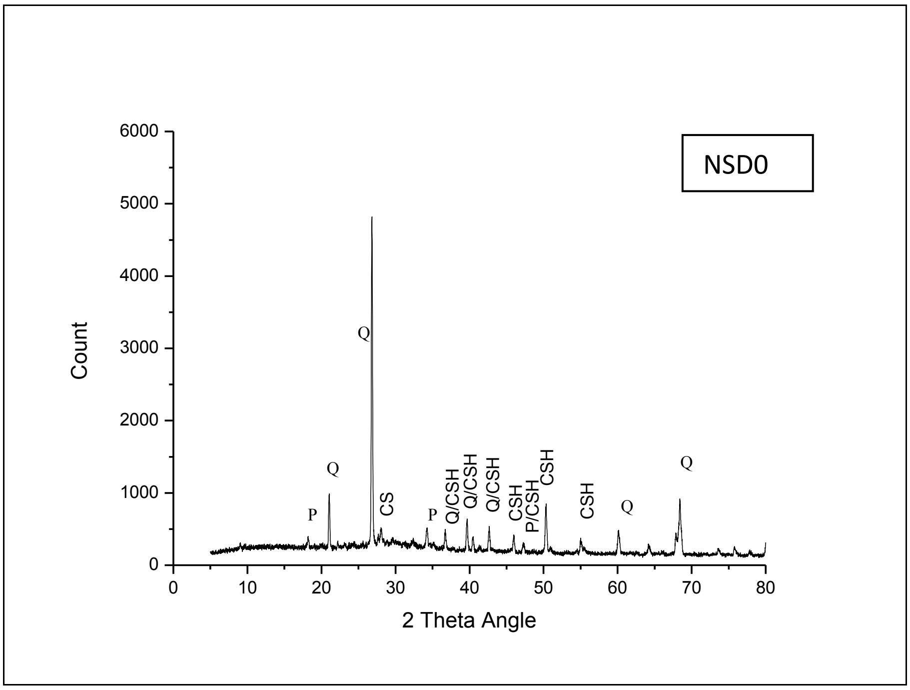


Fig. 4.14: XRD spectrum of concrete mixtures N0, N20 and N30 at 28 days

Fig.4.15 shows the XRD spectrum of concrete mixtures NSD 0 (50% natural sand + 50% stone dust and without rice husk ash) and NSD 20 (50% natural sand + 50% stone dust and with 20 % rice husk ash as replacement of cement). Similar concrete made with natural sand, XRD analysis reveals that there is also no qualitative change in phases present in concrete on replacement of natural sand with stone dust and cement with rice husk ash. Comparing the peaks of portlandite at 4.9 Å and 2.62Å, total quantity has decreased from 4.24% to 2.24% on inclusion of rice husk ash as cement replacement.



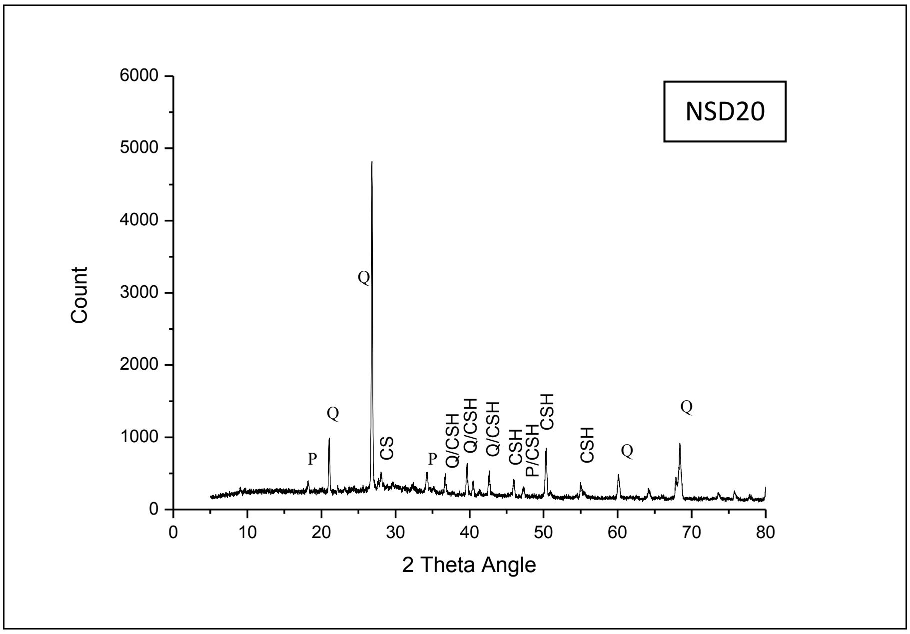
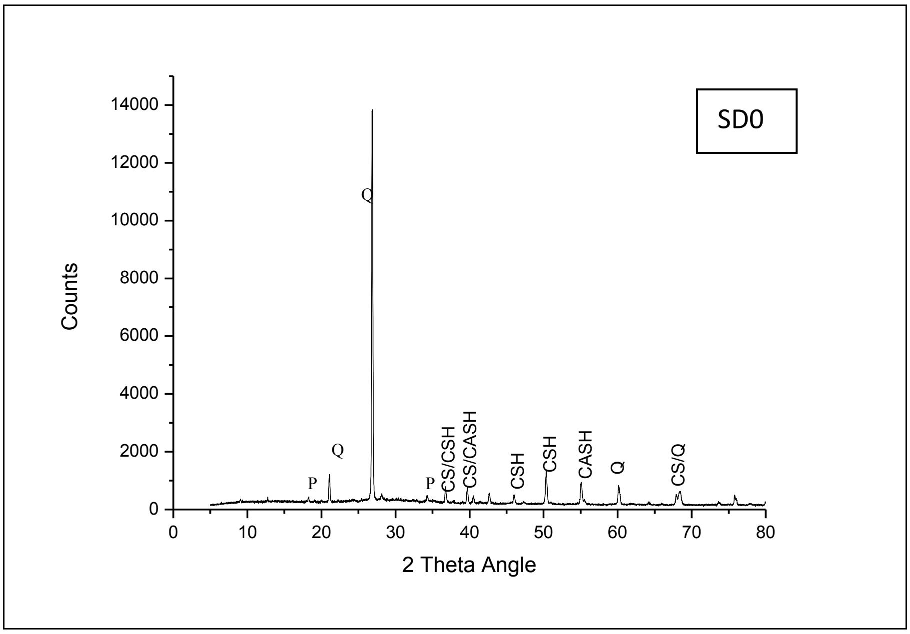


Fig. 4.15: XRD spectrum of concrete mixtures NSD0 and NSD20 at 28 days

Fig. 4.16 presents the XRD spectrum of concrete made stone dust as replacement of sand without and with 20% rice husk ash as replacement of cement. Similar results have been observed in concrete made with stone dust as fine aggregate and rice husk ash as cement replacement.



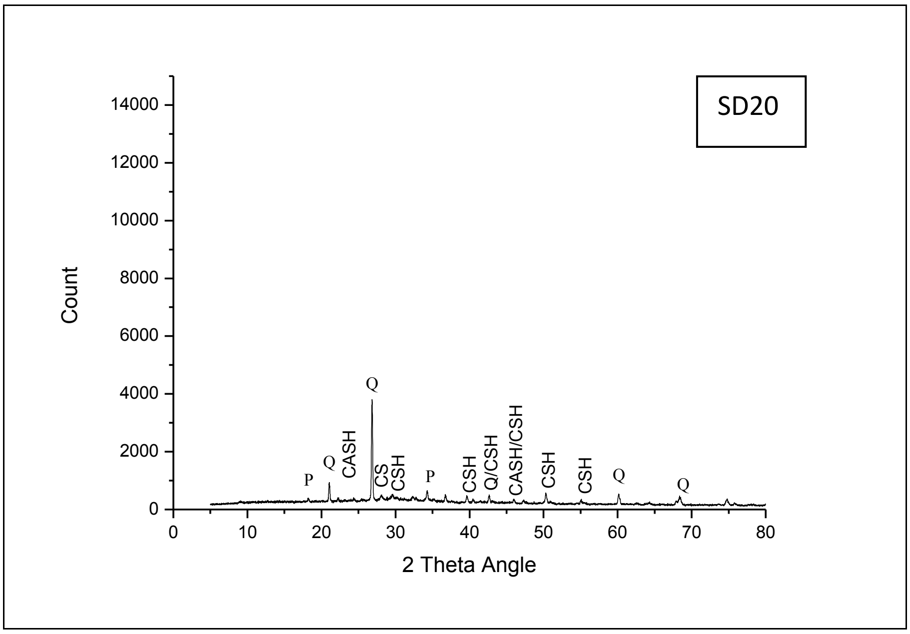


Fig.4.16: XRD spectrum of concrete mixtures SD0 and SD20 at 28 days

4.4.2 Scanning Electron Microscopy

The scanning electron microscopy (SEM) plays a significant role in resolving the microstructure of concrete. This provides both topographic and compositional analysis of materials. The concrete microstructure is integrated system consisting of CSH gel, calcium hydroxide, calcium sulfoaluminate hydrate (ettringite and monosulfate), coarse and fine aggregate and interfacial transition zone between aggregate and cement hydration products. Morphology structure of CSH varies from common fibrous type to irregular grains forming a reticular network. At the early age of cement hydration, prominent morphology structure of CSH is fibrous type but reticular network also occurs occasionally. Equant grain morphology of CSH appears as the hydration of cement proceeds. Another type of morphology of CSH has a dimpled appearance with either regular pores or closely packed equant grains. The calcium hydroxide appears in many shapes such as massive, platy crystals, large thin elongated crystals and blocky masses to finely disseminated crystals. Calcium sulfoaluminate hydrates have two morphologies that are ettringites and monosulfate. Ettringites appears as needle like crystals whereas monosulfate appears as hexagonal platy crystals.

In this study, fractured pieces of concrete generated from the compressive strength tests were used for obtaining SEM images. The concrete specimens were coated with thin layer of gold to make them electrically conductive before placing on the scanning electron microscopy (SEM) stem. Figs. 4.17-4.25 show the scanning electron micrographs of concrete mixtures made with natural sand, stone dust, 50% natural sand and 50% stone dust, with and without rice husk ash as cement replacement. Fig. 4.18 shows compact and monolithic CSH gel spread over the entire image. The voids present in concrete mixture containing 20% rice husk ash are less than the voids present in control concrete and concrete mixture containing 30% rice husk ash as cement replacement. SEM image of concrete incorporating 30% rice husk ash taken at higher resolution shows the formation of ettringites in the voids.

Compared to SEM image of control concrete mixture made with natural sand, Fig.4.20 shows dense CSH gel and less voids present in concrete mixture made with stone dust without rice husk ash. Figs. 4.22, 4.24 and 4.25 show the morphology of ettringite formation on inclusion of rice husk ash as cement replacement in concrete.

Energy Dispersive Spectrometry (EDS) analysis of concrete mixtures shows calcium silicate (Ca/Si) ratio as 0.97 for N 0 (control concrete), 1.0 for N 20, 1.34 for N 30, 1.29 for SD 0, 1.30 for SD 20, 1.28 for NSD 0 and 1.27 for NSD 20. Low calcium silicate (Ca/Si) ratio CSH gel phase in concrete mixtures demonstrates higher reactivity and thus achieving higher strength.

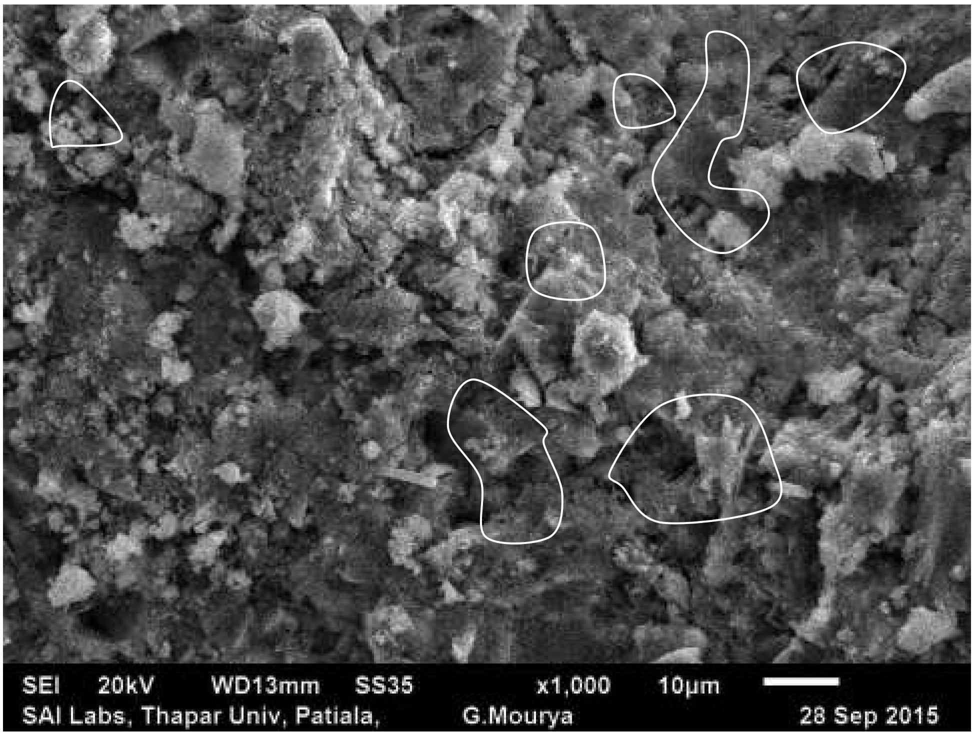


Fig. 4.17 SEM image of concrete mix N0 (concrete made with normal sand as fine aggregate and 0% rice husk ash as cement replacement)

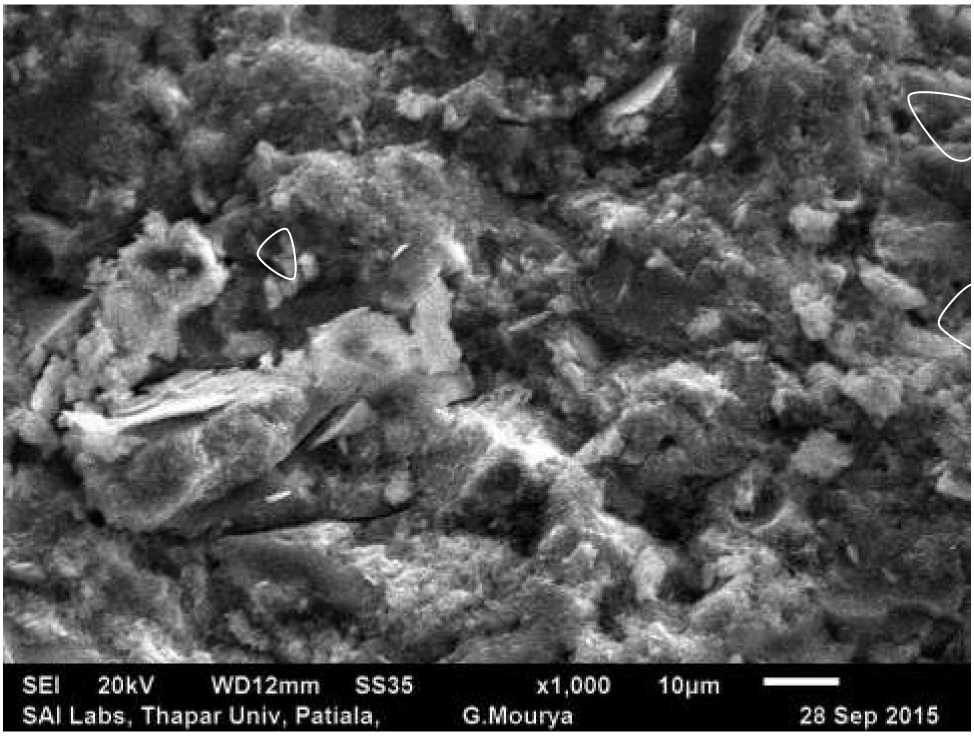


Fig. 4.18: SEM image of concrete mix N20 (concrete made with normal sand as fine aggregate and 20% rice husk ash as cement replacement)

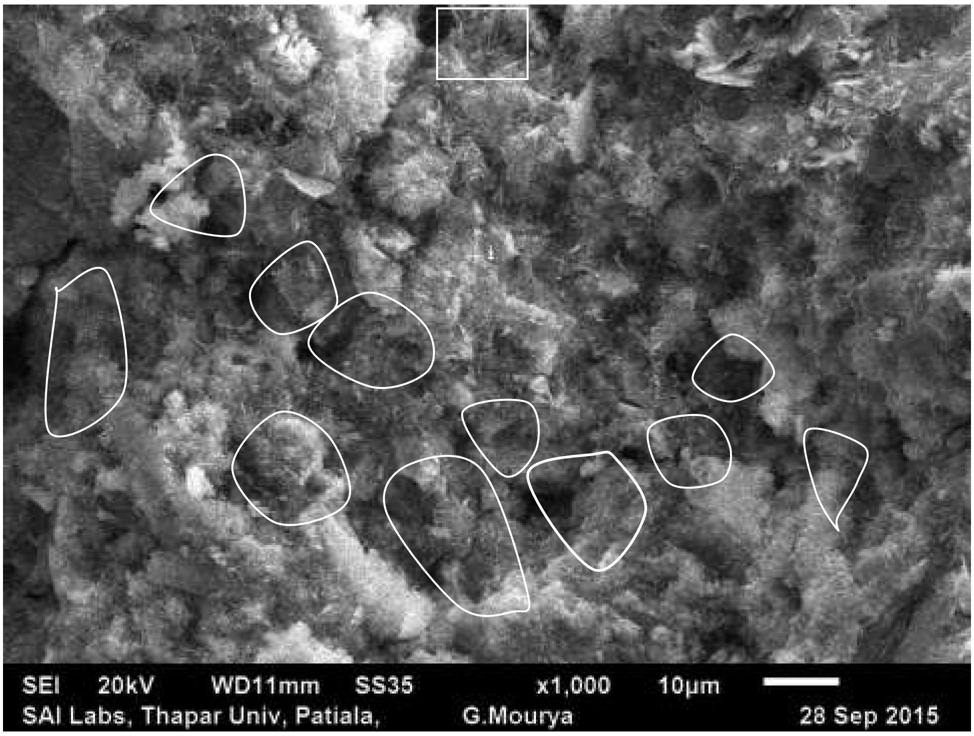


Fig. 4.19: SEM image of concrete mix N30 (concrete made with normal sand as fine aggregate and 30% rice husk ash as cement replacement)

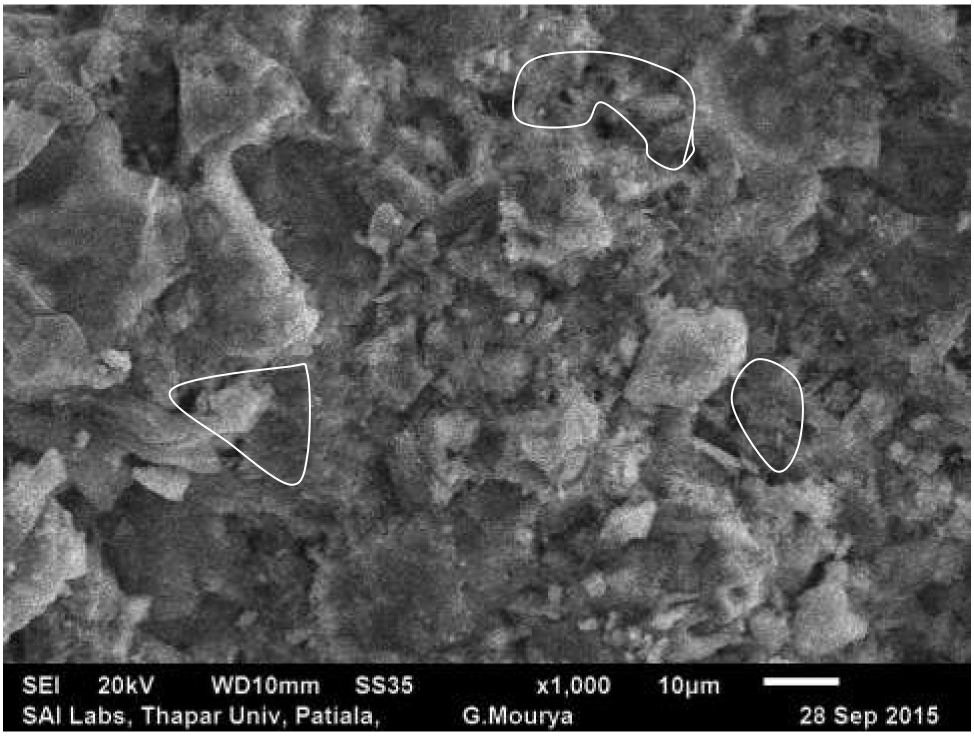


Fig.4.20 SEM image of concrete mix SD0 (concrete made with stone dust as fine aggregate and 0% rice husk ash as cement replacement)

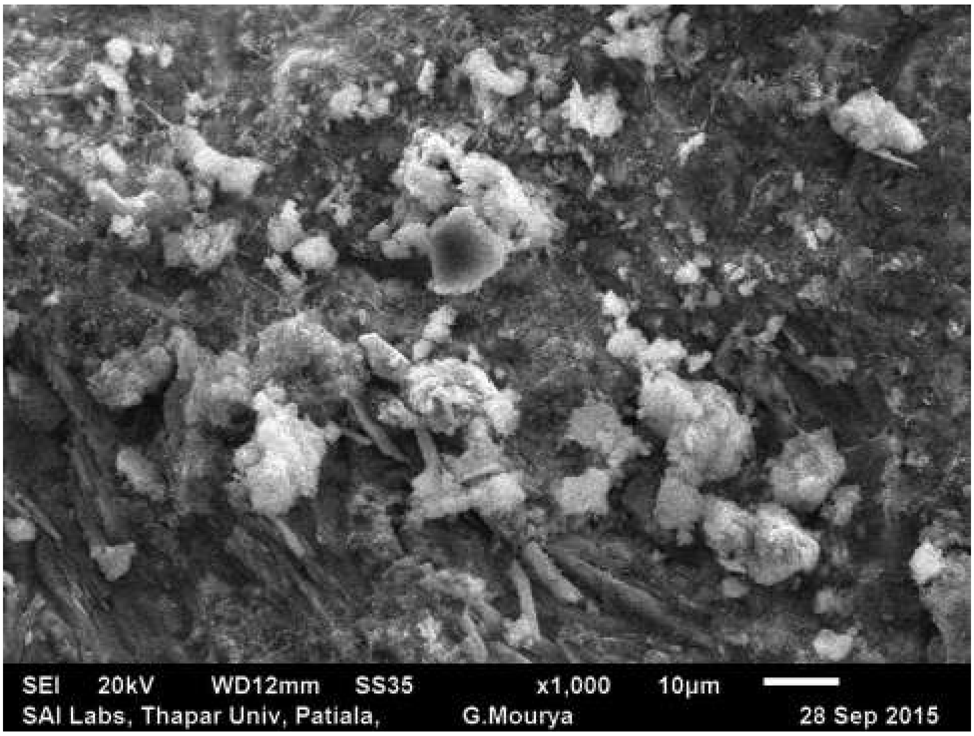


Fig. 4.21 SEM image of concrete mix SD20 (concrete made with stone dust as fine aggregate and 20% rice husk ash as cement replacement)

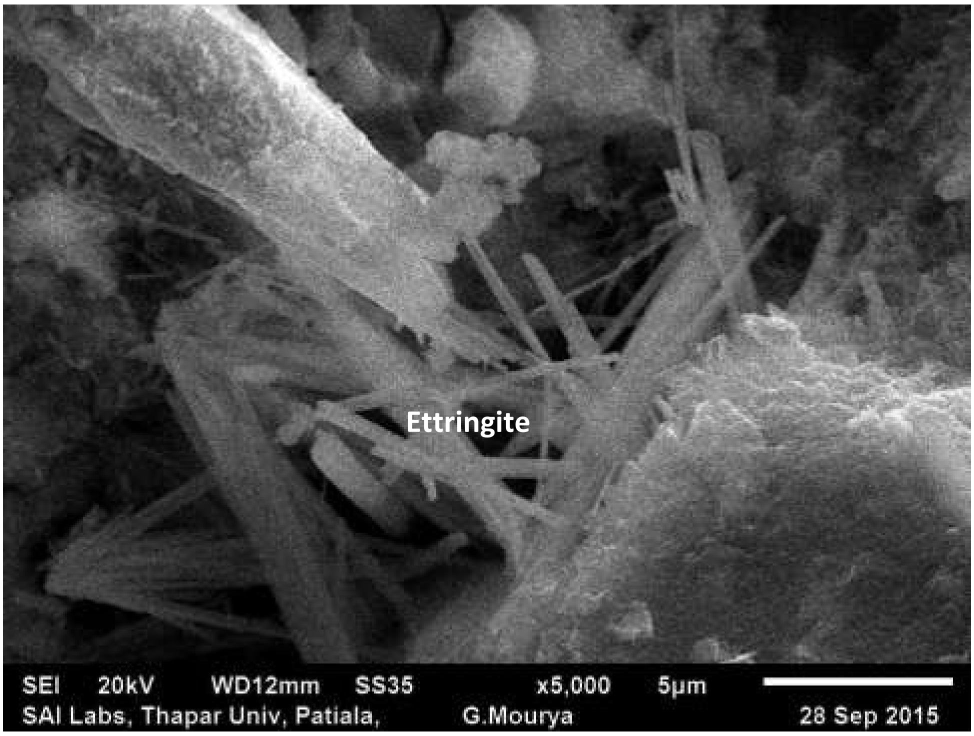


Fig. 4.22 Magnified SEM image of concrete mix SD20 (concrete made with stone dust as fine aggregate and 20% rice husk ash as cement replacement)

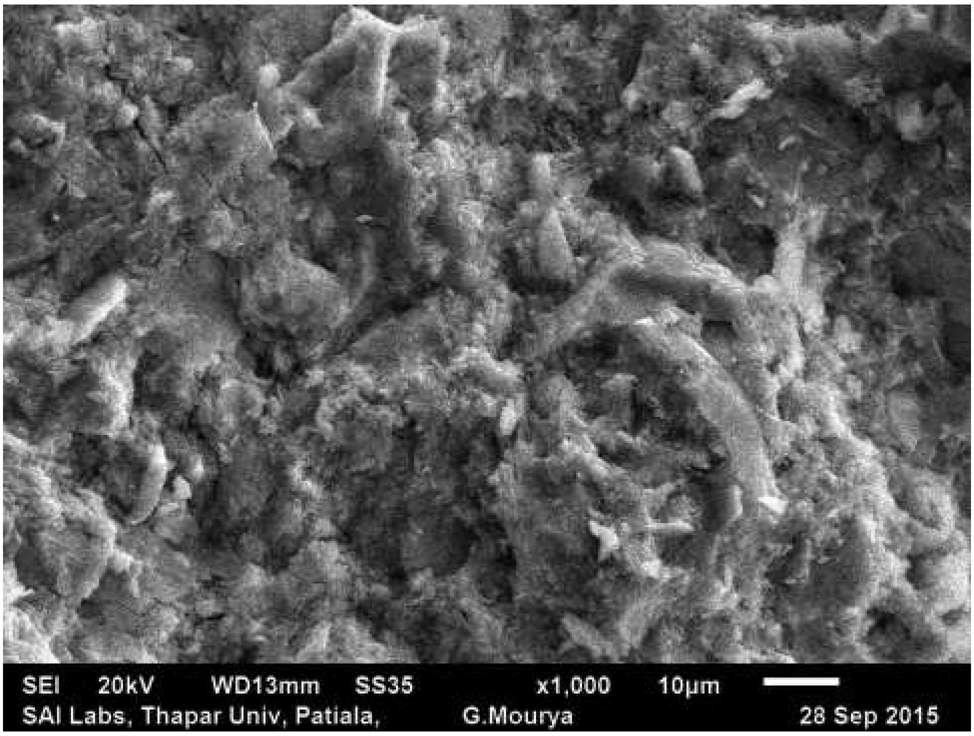


Fig. 4.23 SEM image of concrete mix NSD0 (concrete made with 50% normal sand and 50% stone dust as fine aggregate and 0% rice husk ash as cement replacement)

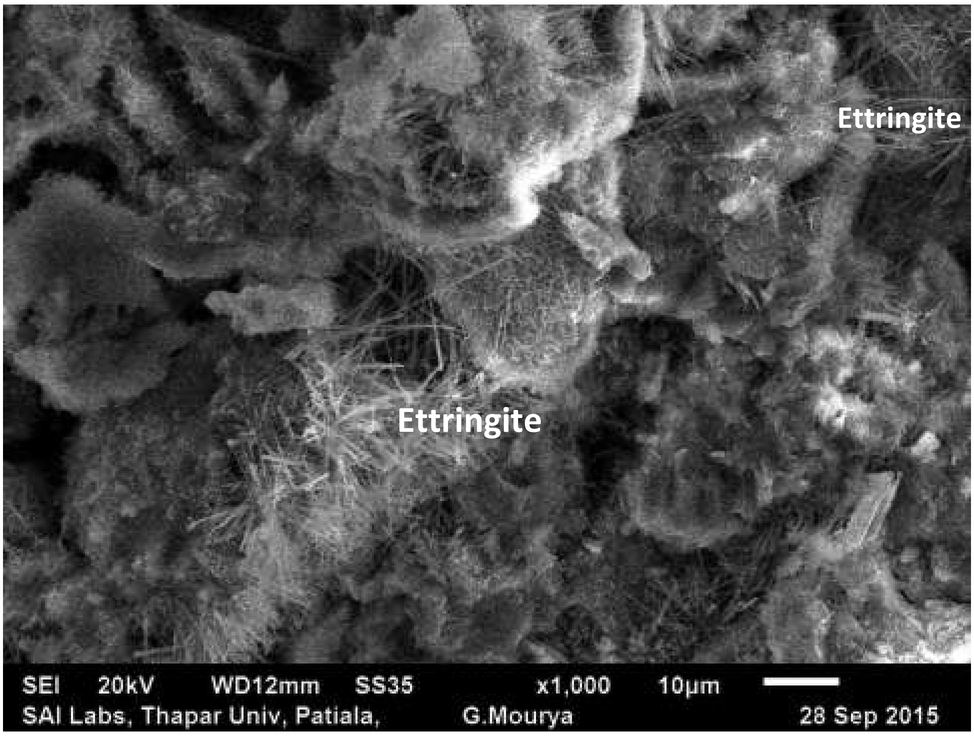


Fig. 4.24 SEM image of concrete mix NSD2 (concrete made with 50% normal sand and 50% stone dust as fine aggregate and 20% rice husk ash as cement replacement)

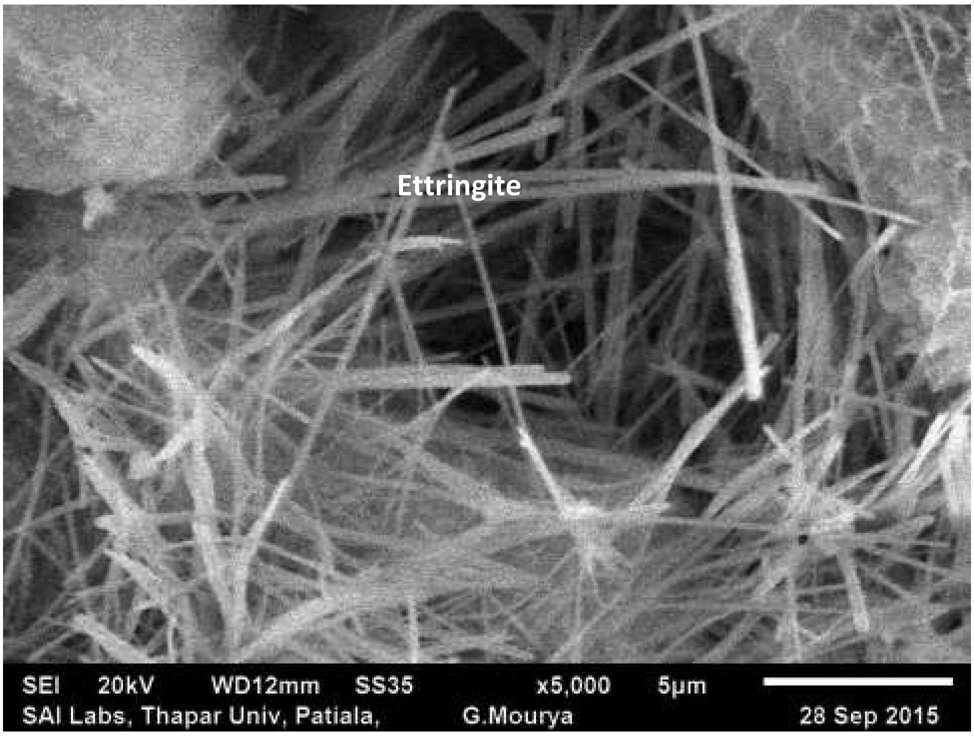


Fig. 4.25 Magnified SEM image of concrete mix NSD2 (concrete made with 50% normal sand and 50% stone dust as fine aggregate and 20% rice husk ash as cement replacement)

CHAPTER 5

CONCLUSION

5.1 GENERAL

The strength and durability characteristics of concrete made with different type of aggregate are discussed in the present study. The possibility of using quarry dust/ stone dust in concrete as a fine aggregate replacement have been studied. The mixes of M30 grade concrete was prepared with normal sand, stone dust and combination of normal sand and stone (50%-50%) as a fine aggregate. Additional cementing material i.e. rice husk ash was used as a cement replacement with 0%, 10%, 20% and 30% substitution by weight of cement. Based on the study discussed, the following conclusions are drawn:-

5.2 PHYSICAL PROPERTIES

The Physical and chemical properties of quarry rock dust satisfies the requirements of Indian Standard code provision for fine aggregate and hence, can be used as possible replacement of fine aggregate.

5.3 FRESH CONCRETE PROPERTIES

It is observed that the slump values are within the desired range of 50-75 mm for all the mixes and the value increases with increase in percentage replacement of sand with quarry dust for the same w/c ratio. On the other hand, as the Rice Husk Ash was added as cement replacement, the powder content or fines content increases in the matrix, leading to increase of the Super plasticizer dosage needed to achieve the required workability. When both stone dust and rice husk ash are used as fine aggregate and cement replacement, the workability characteristics are compensated hence, leading to a workable mix.

5.4 COMPRESSIVE STRENGTH

Addition of stone dust leads to large increase in compressive strength of concrete. This increase is nearly 73% as compared to corresponding concrete made with normal sand. It can be due to large amount of silica present in stone dust. Similarly addition of rice husk ash initially increases the compressive strength. However, as the replacement level of rice husk ash increased beyond 20%, the compressive strength tends to decrease.

5.5 SORPTIVITY

The sorptivity of mixes decreases with addition of stone dust. The best performance is shown by a mix containing combination of normal sand and stone dust. Similarly when rice husk ash is added as cement replacement, the sorptivity coefficient decreases quite substantially. However, the decrease is observed till 20% replacement of cement by rice husk ash.

5.6 X-RAY DIFFRACTION (XRD)

The major phases observed in concrete mixtures are Quartz, calcium silicate, calcium hydroxide, calcium silicate hydrate, calcium aluminum silicate hydrate and calcite. Similar concrete made with natural sand, XRD analysis reveals that there is also no qualitative change in phases present in concrete on replacement of natural sand with stone dust and cement with rice husk ash. It is also observed that the peak intensity of portlandite ($Ca(OH)_2$) has been decreased on addition of rice husk ash as replacement of cement. The phases present in concrete mixture did not changed qualitatively on incorporation of rice husk ash as binder material.

5.7 SCANNING ELECTRON MICROSCOPY (SEM)

Compared to SEM image of control concrete mixture made with natural sand, the mix with stone dust has dense CSH gel and less voids present in concrete. With the addition of rice husk ash, the voids in the mix decreases. The voids present in concrete mixture containing 20% rice husk ash are less than the voids present in control concrete and concrete mixture containing 30% rice husk ash as cement replacement. SEM image of concrete incorporating 30% rice husk ash taken at higher resolution shows the formation of ettringites in the voids.

CHAPTER 5

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