IMPACT OF TERNARY BLENDS AS VISCOSITY MODIFYING ADMIXTURES ON SELF-COMPACTING CONCRETE (SCC)

BLENDS CONTAINING RICE HUSK ASH (RHA) AND GROUND GRANULATED BLAST FURNACE SLAG (GGBFS)

FINAL YEAR PROJECT UG 2019

By

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Thesis titled

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DEDICATIONS

We dedicate this research work to our supervisor Dr. Hammad Anis Khan and our parents.

ABSTRACT

Self-Compacting Concrete (SCC) is a modern concrete system known for its high flowability and high segregation resistance without the need for mechanical vibration. The American Concrete Institute (ACI) defines SCC as ‘A concrete mixture that possesses excellent flowability and does not separate, enabling it to effortlessly spread, fill the desired mold, and fully surround the reinforcement without the need for any mechanical consolidation. This means that SCC can effectively achieve compaction on its own, resulting in dense and durable concrete.

In the present study, the focus is placed on the experimental research of Self-Compacting Concrete systems (SCCs) produced by replacing Ordinary Portland Cement (OPC) with ternary blends of Rice Husk Ash (RHA) and Ground Granulated Blast Furnace Slag (GGBFS). By using RHA and GGBFS, environmental contamination will be kept to a minimum while also protecting natural resources. Additionally, there will be less need for storage and disposal facilities.

In this research, OPC is replaced by different blends of RHA-GGBFS (0%, 5%, 10%, 15), and concrete’s fresh and hardened properties was investigated. Nine formulations were studied at varying amounts of RHA and GGBFS. The water-to-binder ratio and super-plasticizer content was kept constant for the whole research process.

The findings of the tests on the fresh characteristics show that the viscosity of the freshly mixed SCC increases with an increase in the replacement levels of RHA-GGBFS blends while the hardened properties of SCC decrease with such replacements. The overall results suggest that RHA-GGBFS blends can be used as a replacement of cement to produce structural self-compacting concrete.

LIST OF NOTATIONS

ACI	American Concrete Institution
ASTM	American Society for Testing and Materials
RHA	Rice Husk Ash
GGBFS	Ground Granulated Blast Furnace Slag
SCP	Self-Compacting Paste
SCM	Self-Compacting Mortar
SCC	Self-Compacting Concrete
XRD	X-ray Diffraction
XRF	X-ray Fluorescence
SP	Super-plasticizer
WD	Water Demand
W/C	Water to Cement Ratio
SCCS	Self-Compacting Cementitious System
OPC	Ordinary Portland Cement

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CHAPTER 1:

INTRODUCTION

1.1 General:

Concrete is a mixture of paste and aggregates. The paste, composed of Portland cement and water, coats the surface of the fine and coarse aggregates. Through a chemical reaction called hydration, the paste hardens and gains strength to form the rock-like mass known as concrete.

Concrete has become the most widely used construction material of the 21st century due to its strength, economy, durability, and ability to cast into any shape. Energy conservation, greenhouse buildings, sustainability, and the economy are the major focus in the present world. A huge quantity of construction waste is produced every year from construction sites, material factories, demolition sites, earthquakes, and natural disasters. Storage and disposal of these wastes have become a serious environmental problem. For infrastructure development, recycling of concrete is the new step in developing concrete for construction practices.

1.2 Self-Compacting Concrete:

Self-compacting concrete (SCC) as defined by ACI 237R – 07 is "a highly flowable, non-segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation". The time required for SCC concreting is incredibly reduced as compared to normal concrete. SCC is highly workable concrete that can flow through densely reinforced and complex structural elements under its own weight and adequately fill all voids without mechanical vibration and segregation, excessive bleeding, or other separation of materials.

One disadvantage of SCC is the increased cost as compared to normal concrete but for larger projects like multi-story buildings, roads, dams, etc. SCC is presently used because of its obvious advantage and is described as a milestone in modern concrete technology. There are a lot of site conditions and working limitations in the construction industry that make self-compacting concrete a better substitute to conventional high-slump concrete, most general are cost-effectiveness or efficiency of concrete. SSC has also gained popularity in recent years because of its incorporation of secondary raw materials.

1.3 Materials:

1.3.1 Cement:

BESTWAY Ordinary Portland Cement of Grade 53, Type 1 conforming to ASTM-150 was used throughout the research process. The cement has the fineness modulus of 3100-3200 cm^2/g and sieve residue greater than 45 µm.

1.3.2 Secondary Cementitious Materials:

1.3.2.1 Ground Granulated Blast Furnace Slag (GGBFS):

Granulated blast furnace slag (GBFS) is a by-product of the iron-making process in a blast furnace. It is a non-metallic material that is obtained by quenching molten iron slag from the furnace with water or steam, which rapidly cools the slag and turns it into a glassy, granular material.

GBFS is primarily composed of silica, alumina, calcium, and other minor constituents. Due to its high glass content, it has cementitious properties, which means it can be used as a supplementary cementitious material (SCM) in concrete production. When used in concrete, GBFS can improve the workability, durability, and strength of the concrete, as well as reduce its carbon footprint.

GBFS is also used in other applications, such as soil stabilization, road construction, and as a raw material to produce glass and ceramics. Overall, GBFS is a versatile and sustainable material that has a range of uses and benefits.

1.3.2.2 Rice Husk Ash (RHA):

Rice husk ash (RHA) is the byproduct of burning rice husk, which is the outer covering of rice grains. It is produced when rice husk is burnt in a controlled environment to generate heat and energy. Rice husk is an abundant agricultural waste material that is generated during rice milling.

RHA is primarily composed of amorphous silica and small amounts of carbon, potassium, and other trace elements. Due to its high silica content, RHA has pozzolanic properties and can be used as a supplementary cementitious material in concrete production. When used in concrete, RHA can improve the workability, durability, and strength of the concrete, as well as reduce its carbon footprint.

RHA can also be used as a raw material to produce insulation materials, refractories, and ceramics. In addition, it has applications in agriculture as a soil conditioner, fertilizer, and pesticide. RHA is a sustainable and cost-effective alternative to traditional construction materials and has the potential to reduce waste and lower greenhouse gas emissions.

1.3.3 Super-plasticizer:

Sika-ViscoCrete-3110 is a high-performance superplasticizer that is used to improve the workability and performance of concrete. It is part of the Sika ViscoCrete range of admixtures, which are designed to enhance the properties of concrete and reduce its water content without compromising its strength. It is a polycarboxylate-based superplasticizer that is highly effective in reducing the viscosity of concrete mixtures, which makes them more flowable and easier to place and finish. It is typically used in high-strength concrete applications, such as precast concrete, ready-mix concrete, and self-consolidating concrete.

Overall, Sika-ViscoCrete-3110 is a versatile and effective superplasticizer that can improve the performance and quality of concrete in a wide range of applications.

1.4 Objectives:

This research aims to achieve the following objectives by conducting the study:

1. To investigate the influence of blends of GGBFS and RHA on SCC production.
2. Compare the fresh and hardened properties of RHA-GGBFS blended SCC and SCC from chemical VMA.
3. Identify the curing conditions providing optimal results.
4. Find out the cost-effectiveness of RHA-GGBFS blended SCC.

1.5 Scope of the research:

The scope of research is limited to the study of the effects of RHA and GGBFS blends as Cement replacements on fresh and hardened properties of Self-Compacting Concrete.

CHAPTER 2:

LITERATURE REVIEW

2.1 Historical Background:

Self-compacting Cementitious Systems (SCCS) were first developed in Japan in the 1980s. The Japanese construction industry had a lot of trouble in the middle of the 1980s meeting the demands of concrete structure serviceability and durability. Proper vibration is required during construction to ensure the durability of concrete structures, especially in areas with dense and heavy reinforcement, such as densely reinforced columns, deep foundations, tunnel linings, and bridge piers. But there was a severe labor shortage that made it difficult to place and compact concrete using machines. Due to differential compaction brought on by a lack of uniform compaction, durability was decreased. As a result, a concrete type that didn't need human labor for compaction and placement was desperately needed.

Self-compacting concrete was created because of the difficulties the Japanese construction industry was facing; Professor Hajime Okamura first proposed the idea in 1986. Later, in 1988, Professor Ozawa of the University of Tokyo created the first sample. After carefully examining this concrete's characteristics, Professor Okamura gave it the moniker "High-Performance Concrete." But Professor Aticin had already used this phrase to describe durable concrete with a low water-to-cement ratio. As a result, Professor Okamura gave this kind of concrete the name "Self-Compacting High-Performance Concrete". Because self-compacting concrete can be placed anywhere without the aid of machinery, the demand for skilled labor has been greatly reduced. Japan successfully adopted this type of concrete in its construction sector in the early 1990s; it flowed under its own weight without the need for any manual vibration. Compared to conventional methods of placing concrete, this new technology offered better travel rates, a smooth and easy flow of concrete around dense and heavy reinforcement, as well as economic and environmental advantages.

2.2 Advantages of SCC

- The use of self-compacting concrete allows for faster construction and reduces the need for manual labor, ultimately resulting in cost savings for the project.
- Self-compacting concrete can be easily placed in complex formwork and areas with dense reinforcement, making it a versatile material for a wide range of construction applications.
- Self-compacting concrete's low water-cement ratio makes it highly workable and results in rapid strength development, improved durability, and high-quality finished products.
- The self-compacting nature of the concrete eliminates the need for mechanical vibrators, reducing noise pollution and eliminating the health risks associated with the use of vibrating equipment.
- Self-compacting concrete is highly resistant to bleeding and segregation, resulting in a more uniform and consistent final product.
- Self-compacting concrete produces smooth and well-finished surfaces without the need for additional plaster or finishing treatments, improving the overall aesthetic appeal of the structure.
- Faster construction: The high workability and faster placement of SCC can lead to faster construction times and reduced project costs.
- Increased safety: The reduced need for vibration during placement reduces the risk of injury to workers and damage to nearby structures.

Heavy reinforced concrete sections, such as the massive columns of long-span bridges, high-rise buildings, mass concrete, mat/raft footings, tunnels, and repairs to existing structures, frequently use SCC.

2.3 Water-Reducing Agents

2.3.1 Super-plasticizer

A type of admixture called a superplasticizer is added to concrete mixtures to improve workability without reducing strength. Superplasticizers are high-range water reducers that can lower the water content of concrete mixtures without affecting the consistency of the final product. By lowering the water-cement ratio, the resulting concrete gains strength, and durability.

Superplasticizers come in a variety of forms, such as polycarboxylate ether (PCE), sulfonated melamine formaldehyde condensate (SMF), and sulfonated naphthalene formaldehyde condensate (SNF). Depending on the application and performance requirements, each type has a unique set of benefits and drawbacks.

Superplasticizers, also referred to as high-range water reducers, are water-soluble polymers that are intended to significantly lower the water content (up to 12-30%) in concrete mixes while maintaining the desired level of workability or slump, according to Gagne et al. [5]. Unlike what was previously stated, these polymers have a high molecular weight. Superplasticizers' efficacy is influenced by several variables, including their chemical makeup, dosage, and compatibility with other admixtures and cementitious materials.

Superplasticizers (SP) are chemical admixtures that improve the workability of cementitious systems, according to Rizwan et al. [6], particularly in High-Performance Self-Consolidating Concrete (HP SCCS), where a low mixing water content is necessary for improved durability of the resulting structures. Superplasticizers are therefore thought to be necessary for achieving the desired level of workability without sacrificing the concrete's strength and durability.

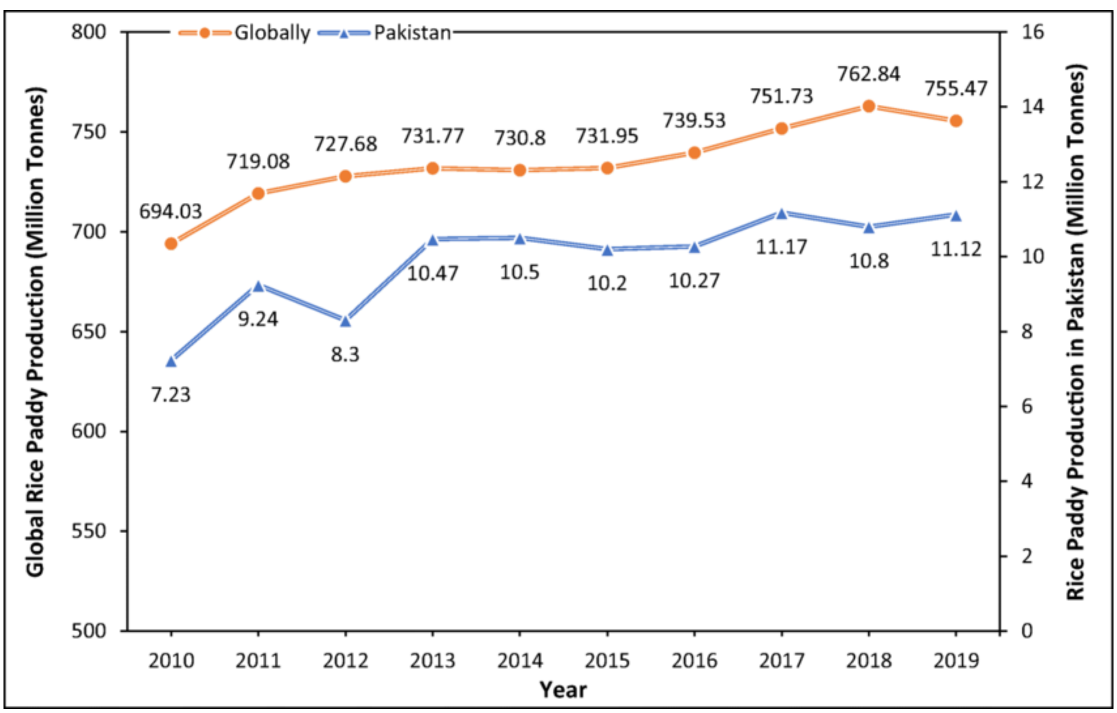
2.4 Secondary Raw Materials:

2.4.1 Rice Husk Ash (RHA):

The tough protective coverings on rice grains known as "rice husks" are removed from the grains during the milling process. All nations that produce rice have access to the waste product known as rice husk, which has a 30% to 50% organic carbon content. A typical milling procedure begins with the removal of the husks from the raw grain to reveal whole brown rice. This rice is then further milled to remove the bran layer to produce white rice**.** RHA has a significant amount of silica (SiO_2) in it. RHA is a highly reactive pozzolanic material that can be used in controlled burning chambers.

Global rice production is thought to be 700 million tons now. About 20% of the weight of rice is made up of rice husk, which is made up of the following ingredients: cellulose (50%), lignin (25%–30%), silica (15%–20%), and moisture (10%–15%). The bulk density of rice husk is low, ranging from 90 to 150 kg/m3. The world's rice-growing regions, such as China, India, and the nations of the far east, are sources of rice husk ash (RHA). The result of burning rice husk is RHA. When rice husk is burned, most of its evaporable components slowly disappear, leaving mostly silicate residues behind.

2.4.1.1 RHA Production (Globally vs Pakistan):



2.4.1.2 Application:

- RHA, or rice husk ash, has two uses in the production of concrete. First, it can be used to replace Portland cement at a lower cost, bringing down the overall price of the concrete. In addition, RHA can be added as an admixture when making high-strength concrete.
- It is important to note that the crystalline form of RHA is not used in the production of concrete; only the amorphous form, which is appropriate for pozzolanic activity, is.
- RHA is a good pozzolanic material and can be used as a substitute for Portland cement in the production of concrete. It can also be used as a filler in the production of bricks and as an additive to improve the strength and durability of construction materials.
- Strength and durability improvements: RHA can make concrete's compressive and flexural strengths better, which results in a stronger and more long-lasting structure.
- Increased workability: RHA can make concrete more workable, making it simpler to compact and place.
- Reduced risk of cracking: The use of RHA can lessen the likelihood of thermal cracking and shrinkage cracks in large concrete pours.
- RHA can aid in reducing the number of voids and the permeability of concrete, resulting in a more durable structure.
- Workable mixture: RHA can offer a mix that is less difficult to handle and uses less water.
- Enhanced flexural strength: The use of RHA can enhance concrete's flexural strength.

2.4.2 Ground Granulated Blast Furnace Slag (GGBFS)

When added to concrete, the by-product of making iron called ground granulated blast furnace slag (GGBFS) gives it better workability, strength, and durability. Iron ore, limestone, and coke are heated to a temperature of about 1500 degrees Celsius to produce this substance. The operation takes place in a blast furnace. The origins of GGBFS are indirect. Slag and molten iron are the byproducts of the production of iron. Alumina and silica, along with a specific number of oxides, make up the molten slag. Later, this slag is granulated through cooling.

It is permitted to do so by passing through a high-pressure water get. This causes the particles to be quenched, resulting in granules with a diameter smaller than 5 mm. Blast furnace slag is primarily composed of CaO, SiO2, Al2O3, and MgO. Most cementitious materials contain these minerals. To create ground granulated blast furnace slag cement, the particles are further dried and ground in a rotating ball mill. Now, various techniques can be used to carry out the main quenching process. It may be referred to as palletized slag, foamed or expanded slag, GGBFS, or air-cooled blast furnace slag (ACBFS), depending on the method used.

2.4.2.1 Application:

The ultimate strength of concrete made with GGBS cement is higher than that of Portland cement. Compared to Portland cement-only concrete, it contains more calcium silicate hydrates (CSH), which increase concrete strength, and less free lime, which has no such effect. Over time, concrete made with GGBS keeps getting stronger. Its benefits include.

- GGBFS in concrete boosts the structure's tensile strength and durability.
- It lessens concrete voids, which lessens permeability.
- GGBFS provides a usable mixture.
- It has good compaction and pumpability properties.
- The GGBFS structure contributes to an increase in sulfate attack resistance.

- Chloride penetration may be lessened.
- When compared to conventional mix hydration, the heat of hydration is lower.
- Alkali-silica reaction is strongly resisted.
- These increase the chemical stability of the concrete.
- The life cycle of concrete structures is extended because of lower maintenance and repair costs.
- GGBFS doesn't emit carbon dioxide, sulfur dioxide, or nitrogen oxides, in contrast to cement.

It has been discovered that using GGBFS is simple due to its greater mobility features. This is because of its fineness and the GGBFS particles' shape. These have a lower relative density as well. The extremely glassy texture of the GGBFS particles increases their workability. This can help reduce the amount of water and Superplasticizers needed to achieve adequate workability in everyday circumstances. Additionally, they are less likely to become separated during material handling and pumping.

2.4.3 Mineralogical composition of RHA and GGBFS:

Chemical Composition	CaO	SiO2	Al2O3	MgO	SO3	K20	TiO2	Fe2O3	Na2O	Loss on Ignition
RHA	0.9	90.5	0.3	0.4	0.4	2.0	-	0.2	0.1	3.8
GGBFS	43.7	29.4	11.2	6.9	1.8	0.9	0.7	0.4	1.0	2.4

2.4.4 Recent Research on RHA and GGBFS Incorporation in SCC:

As discussed earlier, RHA and GGBFS can be incorporated in SCC as a replacement for cement acting asviscosity-modifyingg admixtures. However, different researchers have used above mentioned mineral admixtures individually in theirresearchs to study specific properties of concrete. Therefore, belowise some of the mentioned research conducted recently on SCC properties using RHA and GGBFS:

[1] “The Effect of Water-Binder Ratio and RHA on the Mechanical Performance of Sustainable Concrete”-Saleem Khoso (University of Toledo)

The study of the mechanical characteristics of cement concrete mixtures using rice husk ash (RHA) as a cement substitute is discussed in the current paper. For economic, environmental, and technical reasons, the use of such industrial and agricultural byproducts has been the focus of waste reduction. In this study, concrete's compressive and split tensile strengths were examined by replacing 15% of the cement with RHA at water-binder ratios of 0.40, 0.45, and 0.50. For the applied water-binder ratios, it has been discovered that adding RHA significantly enhances the mechanical properties of concrete. At a water-binder ratio of 0.50, the maximum compressive and tensile strength was noted.

[2] “Influence of rice husk ash (RHA) on the properties of self-compacting concrete”-Ravindra Kaur Sandhu (Thapar University 2017)

According to this research, RHA in SCC will not only increase its utilization in SCC but also lower the cost of land-filling and offer a more sustainable and energy-efficient solution to the problem of carbon dioxide emissions from cement consumption.

[3] “GGBS as a Cement Replacement in Concrete”-Adek Ainie Mat Dom1, Norwati Jamaluddin2, Noor Azlina Abdul Hamid2 and Chew Siok Hoon3

In line with earlier studies, this paper emphasizes the viability of GGBS for a specific value in cement. The iron and steel industries produce GGBS as a waste product. Given that GGBS has comparable cement fineness and cementitious properties to cement, using it as a cement substitute in concrete is a desirable option. This study covered the specific gravity, specific surface, chemical makeup, and effects of GGBS on water absorption. The highest point heat of hydration rate and time were reduced when GGBS was substituted in the production of concrete. When used as a 30% to 60% partial cement replacement, GGBS developed strength over longer hardening times’

CHAPTER 3:

EXPERIMENTAL PROGRAM

3.1 General:

All tests were carried out in controlled lab conditions of temperature and humidity. The required quantities of Cement, Rice Husk Ash, Ground Granulated Blast Furnace Slag, and Super-plasticizer were stored in plastic containers with airtight caps so that moisture won't affect the efficiency and homogeneity of materials.

3.2 Materials:

3.2.1 Cement:

BESTWAY Ordinary Portland Cement of Grade 53, Type 1 conforming to ASTM-150 was used throughout the research process. The cement has the fineness modulus of 3100-3200 cm^2/g and sieve residue greater than 45 µm.

D_{50} of Ordinary Portland Cement Grade 53 was around 19.54 microns (Taken from the previous research of Shozab Mustafa 2016).

3.2.2 Secondary Raw Materials:

3.2.2.1 Rice Husk Ash (RHA):

Rice Husks are the coverings of rice grains that protect rice from the external atmosphere. During the milling process, these coverings are separated from the rice grains, and they are regarded as the waste material of the rice industry. These rice husks are burnt at a temperature between 550-800º C, turning grayish-black in color. For this study, Los Angeles Abrasion Machine was used for grinding purposes. RHA was ground in Los Angeles Abrasion Machine for a total of 2500 revolutions. The resulting ash was passed through sieve no. 100 and then ground for 500 revolutions. The ash was further passed through sieve no. 200 and was used for experimental purposes.

Rice Husk Ash was used as 0%, 5%, 10%, and 15% as a replacement for cement content. For the whole research, super-plasticizer and water content are placed constant.

3.2.2.2 Ground Granulated Blast Furnace Slag (GGBFS):

Ground Granulated Blast Furnace Slag is an industrial waste formed when limestone, iron ore, and coke are heated up to a temperature of 1500º C in the blast furnace. It mainly consists of mineral constituents such as calcium oxides, silicates, aluminates, etc. The slag formed in the furnace is then cooled and Los Angeles Abrasion Machine is used for its grinding purposes. For a total of 1000 revolutions, the slag is placed in LA Machine after which it is passed through sieve no. 200. Mass of GGBFS passing through sieve no. 200 is then used for experimental works.

3.2.2.3 Super-plasticizer:

To achieve superior workability and flowability, liquid Sika-Viscocrete-3110 W, a third-generation water-reducing admixture conforming to ASTM C-494 is being used. It is based on polycarboxylic ether. Sika Viscocrete-3110 W is suitable for use in concrete mixes containing micro silica and other pozzolanic materials. The dosage of SP varies between 3 to 4 percent of cement content.

Properties of Super-plasticizer

Sika Viscocrete-3110 W	
Physical Shape	Liquid
Color	Colorless to Yellowish
Chloride content	Nil
Bulk Density	1.08-1.10 kg/lt
Dosage	Mainly 0.4-1.5 % but depends on mix design
pH value of 20º C	6.5-8.5

3.2.2.4 Coarse Aggregate:

The coarse aggregates used in this project are obtained from the Margalla Hills and have a maximum size of 12.5 mm. To analyze the size distribution of these aggregates, we conducted a sieve analysis following the ASTM C-136 standard. We determined the specific gravity and percentage absorption of the aggregates according to the ASTM 127-01 standard. The results of these tests and the gradation curve are attached below.

3.2.2.5 Fine Aggregate:

For our research, we used natural sand obtained from a quarry site located in Lawrencepur as our fine aggregate. To determine the size distribution of this sand, we conducted a sieve analysis following the ASTM C-136 standard. We also determined the specific gravity and percentage absorption of the sand by the ASTM 127-01 standard. The maximum size of the fine aggregate is 2mm and its D50 value is 450 microns.

3.2.2.6 Mixing Water:

Ordinary tap water was used in all concrete mixes and the temperature of water was between 19-26º C.

3.3 Formulations Studied:

Mixes used in this research approach are abbreviated in two basic forms, namely CC-3.5 and 10R50G50-3.5. In the case of CC-3.5, CC refers to the control concrete mix prepared by incorporating a chemical viscosity modifying agent and 3.5 is the amount of super-plasticizer in percent by weight of binder content. This designation represents a control mix using VMA and 2 percent of SP by weight of binder content.

Similarly, in the second designation, 10R50G50-3.5 shows 10 percent of cement replaced by 50 percent of Rice Husk Ash and 50 percent of Ground Granulated Blast Furnace Slag replacing cement binder content and 3.5 represents a percent of super-plasticizer by weight of binder content. So, this designation shows 5 percent of RHA, 5 percent of GGBFS with 3.5 percent of super-plasticizer in SCC.

3.4 Mix Proportions:

The SCC mix proportions were designed following EFNARC guidelines 2005 [4] and ACI 237R-07 [21].

In this research, several trial mixes were prepared using different super-plasticizer dosages for controlling concrete and concrete from RHA-GGBFS. The selection criteria for mix design are based on the concrete's filling ability, passing ability, and segregation resistance. Looking for these properties, a mix design is selected with various replacement levels of cement (0%, 5%, 10%, and 15%) by Rice Husk Ash and Ground Granulated Slag. The basic mix proportion for concrete was selected to produce $1m^3$ of concrete. The water-to-binder ratio selected for our samples was kept constant at 0.45. The fine-to-coarse aggregate ratio was observed to be 1.166:1 for all mixes of concrete. All the other compositions were set constant for every type of mix to study the effects of different percentage replacement of cement.

Mix Name	Water (Kg/m^3)	Cement (Kg/m^3)	RHA (Kg/m^3)	GGBFS (Kg/m^3)	Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Viscosity Modifying Agent (%)	Super-plasticizer (%)
CC-3.5	200	500	0	0	875	750	2	3.5
5R50G50-3.5	200	475	12.5	12.5	875	750	0	3.5
5R70G30-3.5	200	475	17.5	7.5	875	750	0	3.5
5R30G70-3.5	200	475	7.5	17.5	875	750	0	3.5
10R50G50-3.5	200	450	25	25	875	750	0	3.5
10R70G30-3.5	200	450	35	15	875	750	0	3.5
10R30G70-3.5	200	450	15	35	875	750		3.5
15R50G50-3.5	200	425	37.5	37.5	875	750	0	3.5
15R70G30-3.5	200	425	52.5	22.5	875	750	0	3.5
15R30G70-3.5	200	425	22.5	52.5	875	750	0	3.5

3.5 Mixing Regime:

The duration and order in which materials are mixed play a crucial role in producing Self-Compacting Concrete (SCC) as they have a significant impact on the concrete's properties. Laboratory Concrete Mixer from NICE lab is used for mixing purposes.

Following is the sequence by which materials are placed in the mixer with coarse aggregates being placed first followed by sand and cement to ensure sufficient mixing.

Time	Mixing Regime
1 minute	Dry mixing of constituents at 180 rpm (slow rate).
2 minutes	Add 80% of water to the dry constituents and mix again at 180 rpm (Slow Mixing).
3 minutes	Add SP and/or Viscosity Enhancing Agent (VEA) in the remaining 20% water; mix again thoroughly at 360 rpm (Fast Mixing).

3.6 Preparation and Casting of Specimens:

From each concrete mix, three 100mm X 100mm XX cubes and three 100mm X 200mm cylinders were cast. These cubes and cylinders are used for the determination of compressive and tensile strength at 28 days. After casting, these samples are covered with plastic sheets and kept in a room for 48 ± 8 hours. Then they were de-molded and transferred to a moist room at 23 ± 2^{o} C and 100 percent relative humidity until required for testing.

3.7 Testing Procedures:

It is necessary to note that none of the SCC tests has yet been standardized. The methods below are descriptive rather than detailed procedures. These methods are devised specifically for SCC (EFNARC 2002). The following tests were carried out to find the fresh and hardened properties of self-compacting concrete.

3.7.1 Fresh Tests on SCC:

3.7.1.1 Slump Flow Test:

The slump flow test was carried out to investigate the filling ability of Self-Compacting Concrete. The slump flow test is used to measure the flow time and flow spread of self-compacting concrete (SCC). The main components that govern assessing the flowability of concrete are super-plasticizer dosage and water-to-binder ratio.

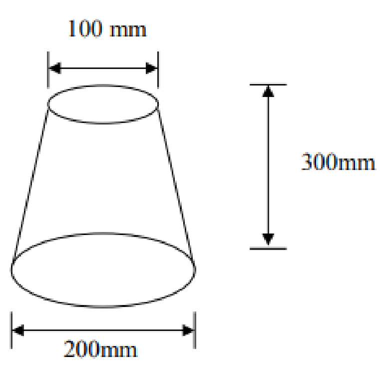
According to ASTM C1611, there are two positioning of the cone, which are upside-down and downside-up. In this research, we are using the downside-up approach.

3.7.1.1.1 Procedure:

To conduct the Slump Flow Test, approximately 6 liters of concrete are required. The process begins by moistening the inner side of the cone and the surface where the cone will be placed. The cone is then positioned upside down and filled with fresh concrete. Any excess concrete on the top and sides of the cone is carefully removed. Next, the cone is lifted in a vertical motion, allowing the concrete to flow freely. The diameter of the spread concrete is measured in two perpendicular directions. These two measurements are then averaged to determine the slump flow of the concrete, measured in millimeters.

3.7.1.1.2 Interpretation of Result:

The higher the slump flow value, the greater the concrete's ability to fill the formwork under its weight. As per EFNARC guidelines (2005), the slump flow range for SCC is from 650mm to 800mm. It is observed that above 700mm, concrete might segregate and at less than 650mm, it is not able to pass through congested reinforcements under its weight.



3.7.1.2 V-Funnel Test:

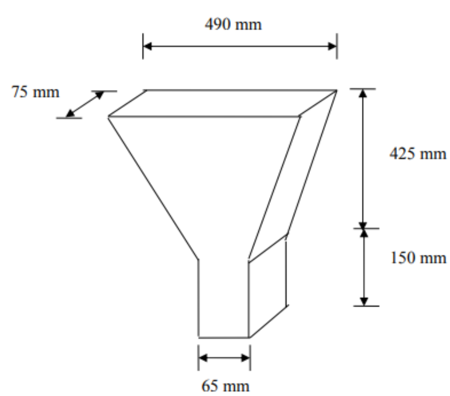
V-Funnel Test is used to measure the flowability and segregation resistance of concrete. This test was specifically designed to measure flowability, but the result is affected by concrete properties than flow. V-Funnel Test gives the interval required for the concrete to fall under the effect of gravity through a small opening. The v-Funnel apparatus is shown below.

3.7.1.2.1 Procedure:

V-Funnel Test needs 12 liters of freshly prepared concrete to provide flowability properties. V-Funnel apparatus should be placed on a flat smooth surface, with the top opening horizontally positioned. Firstly, the inner side of the V-Funnel apparatus is cleaned and moistened with the help of a towel or sponge. Close the opening at the bottom of the funnel and place a bucket to accumulate concrete falling from the V-Funnel. Fill the funnel with freshly prepared concrete. After an interval of 10 ± 2 seconds, open the gate and allow concrete to fall under its weight. Measure the time between opening the gate and till the whole V-Funnel becomes empty. This time is known as V-Funnel time.

3.7.1.2.2 Interpretation of Result:

The shorter the V-Funnel time, the greater is concrete's flowability. According to the EFNARC guide (2005), the minimum and maximum time of flow are 6 and 12 seconds for self-compacting concrete. It is observed that concrete with a V-Funnel time greater than 12 seconds is difficult to be placed under its weight, without tamping.



3.7.1.3 L-Box Test:

For assessing the filling and passing ability of concrete, an L-Box Test is used. The L-Box apparatus is a rectangular-section box in the shape of 'L' with vertical and horizontal sections, separated by a movable gate, in front of which vertical lengths of reinforcement bars are fitted. The vertical section of the L-Box is filled with concrete, and then the gate is lifted to let the concrete flow in the horizontal section. When the flow of concrete is stopped, the height of concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section. This is an indication of passing ability or the degree to which concrete can pass through reinforcement bars.

3.7.1.3.1 Procedure:

Approximately 14 liters of concrete are needed to perform this test. The apparatus is set on leveled firm ground, and it is ensured that the sliding gate can be opened and closed freely. The inside surfaces of the apparatus are moistened. The vertical section of the apparatus is filled with concrete and is left for 1 minute. Then the sliding gate is lifted, and the concrete is allowed to flow out into the horizontal section. When the concrete stops flowing, the distance 'H1' and 'H2' are measured. The 'H2/H1' is the blocking ratio. The whole test has to be performed within 5 minutes.

3.7.1.2.2 Interpretation of Result:

If the concrete flows as freely as water, at rest it will be horizontal, so the ratio H2/H1 will be equal to one. Therefore, closer to the unit value of ratio H2/H1 indicates a better flow of concrete. The EFNARC guide (2005) gives a range of 0.8 to 1.0 for this ratio. Moreover, obvious blocking of coarse aggregate behind the reinforcing bars can be detected visually.

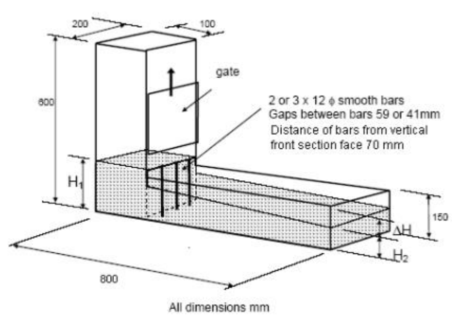


Fig. 3.2. L - box apparatus

3.7.1.4 J-Ring Flow Test:

The purpose of the J-Ring Test is to measure the passing ability of self-compacting concrete. In this test, a ring having steel bars, called J-ring is placed around the slump flow cone for checking the passing ability of concrete. J-Ring Test is specified in ASTM C1621.

3.7.1.4.1 Procedure:

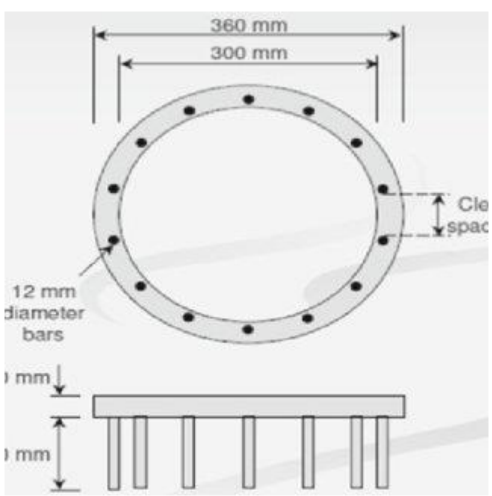
J-ring is placed outside the base plate of the Slump flow cone before the cone is lifted containing freshly mixed concrete. Once the cone is lifted, the concrete flows through the steel bars of the J-Ring. J-ring flow spread after passing through the j-ring must be measured in orthogonal directions, J ring flow is the average of two diameters measured in orthogonal directions.

Moreover, the Blocking Step (BJ) can be measured which quantifies the effect of blocking. For this purpose, a straight rod with a flat side is placed on the top side of the J-Ring, and the relative height difference between the lower edges of the straight rod and the central position ($\Delta h0$) of concrete surfaces and at the four positions outside the J-ring, two ($\Delta hx1$, $\Delta hx2$) in the x-direction and the other two ($\Delta hy1$, $\Delta hy2$) in the y-direction (perpendicular to x).

$$BJ = \frac{\Delta hx1 + \Delta hx2 + \Delta hy1\ \Delta hy2}{4} - \Delta h0$$

3.7.1.4.2 Interpretation of Result:

The greater the value of Blocking Step BJ, the greater the ability of concrete to maintain its homogeneity while passing through reinforcement. The EFNARC guide (2005) gives a range of



values for the Blocking Step from 0mm to 10mm. SCC’s BJ value between these points shows that concrete has acceptable passing property.

3.7.2 Hardened Tests on SCC:

3.7.2.1 Compression Test:

To determine the compressive strength of concrete, cylindrical specimens measuring 100mm X 200mm were utilized. These specimens were removed from the curing tank and allowed to dry for a period of one day before testing. The compression testing machine was set to a loading rate of 0.25 MPa/sec. The compressive strength was determined by taking the average of three samples and the testing was conducted at the 28-day mark.

3.7.2.2 Split-tensile Test:

For the determination of the split tensile strength of concrete samples, cylindrical specimens measuring 100mm X 200mm were used, like the compression testing. The load was applied perpendicularly to the cylinder’s longitudinal axis at a rate of 0.25 MPa/sec. The maximum load applied to the sample was recorded. This load is then utilized in a formula provided in the subsequent section to calculate the split tensile strength of the concrete. The tensile strength is obtained by averaging the results from three samples, and the testing is conducted at the 28-day mark.

3.7.2.3 Flexural Strength:

Beams of 100mm X 100mm X 400mm were tested to find out the flexural strength of concrete after being removed from the curing tank. Samples were dried for one day before any prior testing on them. The loading rate was set to 0.025 MPa/sec. Flexural Strength was taken to be the average of three samples for 28 days.

3.7.2.4 Density:

The density of hardened concrete is obtained by measuring the weight of the sample and dividing it by its respective volume. We have calculated two types of densities in our research i.e., Dry and Wet Density based on the weights we have measured. The Dry Weight was measured before immersing the sample in water. After submerging the sample in water for a duration of one day, we obtained the Wet Weight by measuring its weight again.

3.7.2.4 Absorption Capacity:

Dry and Wet weights of samples are used to calculate the absorption capacity of each sample. We will discuss this topic in next in detail.

3.8 Curing conditions:

Curing is the key to preventing much of the mixed water from evaporating before the required hydration can be achieved (ACI-308, 2001). From a stability and safety perspective, researchers and engineers worldwide have examined the damage incurred by buildings during earthquakes. It has been observed that elements leading to collapse often possess compressive strength lower than the intended strength, indicating inadequate curing practices for structural components. Improper curing is recognized as a major factor contributing to concrete failures, which are often evident through visible cracks that can be easily observed.

To quantify the best curing technique on different specimens, concrete sample with maximum compressive, tensile, and flexure strength is selected for further experimental tasks. The concrete sample is cured by different concrete practices and strength tests (compressive, tensile, and flexure) are performed on each sample. Each sample is passed through scanning electron microscopy (SEM) and x-ray diffraction (XRD) test and results were compared.

To evaluate and compare the effectiveness of different curing techniques in concrete, an experimental program was developed. This program involved conducting various tests and microstructural analyses, including scanning electron microscopy (SEM) and X-ray diffraction (XRD), to quantify the strengths and analyze the microstructure of the concrete. The casting and testing of specimens were carried out following the ASTM standards mentioned previously.

Following are some of the techniques used for curing our self-compacting concrete (SCC) in this research:

3.8.1 Plastic Sheeting (Room Temperature Sealed):

Plastic sheeting acts as a barrier to keep moisture in the concrete, which helps it cure properly and prevent cracking. Concrete samples are water cured for one or two days after demolding. Polyethylene sheets are firmly wrapped around the samples with each edge and corners covered. After placing plastic sheets on concrete, the samples are placed in a room away allowing no light to fall on them. The concrete cover should comply with ASTM C-171 for light reflection, hold moisture and provide constant hydration for the time it is wrapped around concrete. They are designated as ‘PS’ in our research.

3.8.2 Air-Drying (Room Temperature Cured):

Air drying, also known as air curing, is a common method to cure concrete. It involves allowing the concrete to dry naturally, without the use of external heat or moisture. Concrete samples after being de-molded, are left open in the atmosphere without any curing applied to them. The concrete must be kept damp and should be protected from direct sunlight, wind, and extreme temperatures to prevent cracking and ensure proper strength development. For our research, concrete samples air-dried are indicated as ‘AD’.

3.8.3 Oven-Drying (Oven Cured):

The oven-drying method involves heating concrete samples in the oven at a specific temperature for some time. For this purpose, samples are covered with plastic bags. At a temperature of 45^o

C, these plastic bags having concrete samples are placed in an oven for 7 days. After the required time duration, the samples are stored at a place away from direct sunlight and extreme temperatures and covered with plastic bags. Samples cured by oven drying technique are named ‘OD’.

CHAPTER 4:

RESULTS AND DISCUSSION

4.1 General:

The formulations have been studied by replacing a percentage of OPC in the Self-Compacting Paste system with a blend of RHA and GGBFS. First, it is done by determining the fresh properties and 28-Day strengths of different replacement percentages. And then, the mix or replacement giving better fresh and hardened properties is undertaken for its response to different curing conditions. i.e., Plastic Sheeting, Air curing, and Oven Curing. The results are then compared to the results obtained from the control sample corresponding to the same curing method implied.

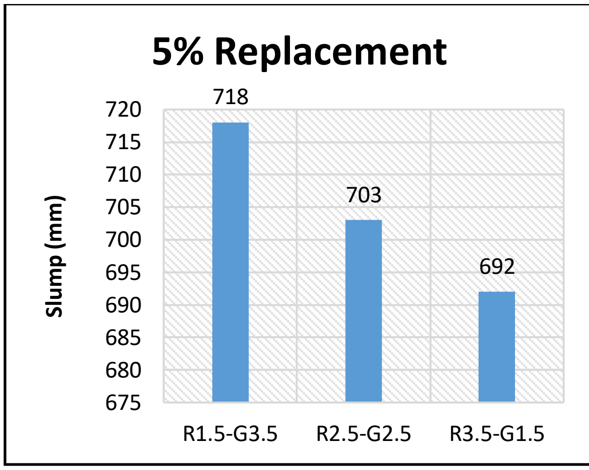
4.2. Fresh properties test on SCC:

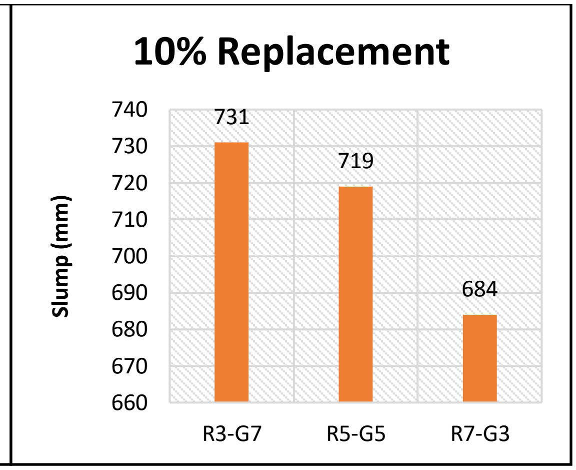
4.2.1. Slump flow test:

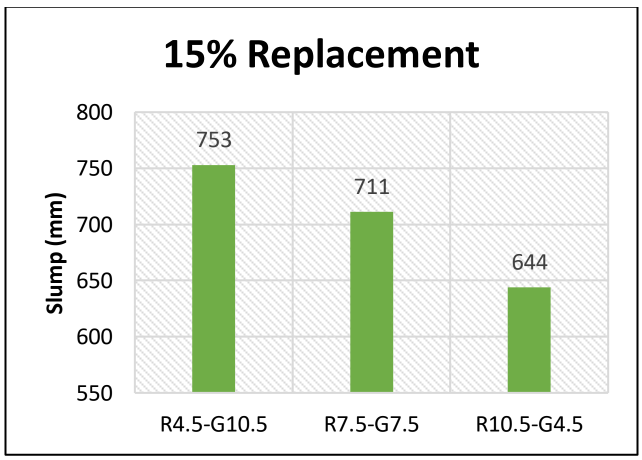
The result of slump flow for all SCC mix formulations is shown in the figures below. The slump flow values of SCC containing RHA and GGBFS as cement replacement were observed in the range between 620-730 mm at constant water-to-cement ratio and superplasticizer content values of 0.40 and 4% respectively which comply with the EFNARC guidelines. There is a decreasing trend of slump flow values with increasing RHA content respectively at constant water-to-cement ratio depicting the loss of flow due to the highly adsorptive nature of RHA which attributed the higher viscosity to the SCC mixes. The reason for workability reduction is probably due to finer particles of RHA as compared to cement. In other words, with the increase of RHA content, the surface area and volume fraction of the binder increase, therefore, due to a higher surface area more amount of water adsorbs, and the quantity of free water in the mortar decreases [6-9,6-10,6-14,6-31]. Moreover, the effect of GGBFS i.e. increases followability complies with the literature. We observe that GGBFS increases slump even greater than control. As it has been observed in a study when cement is partially replaced by GGBFS, the followability increases [2]. This can justify the change in trend between mix R3.5-G1.5, R5-G5 and R3-G7, R4.5-G10.5 where despite greater replacement in later samples, they have equal or greater slump value. A study was concluded by T.C Ling with the finding that as GGBFS increases, SP decreases due to early slow hydration which reduces water requirement [3-43]. A similar study carried out on self-compacting concrete revealed that with increasing GGBFS content slump value of concrete is considerably hiked [3-33]. Dadsetan and Bai [1-74] asserted that the GGBFS grains increase the paste volume between cement paste and the aggregate in concrete by reducing the friction at the interfacial transition zone (ITZ), thus maximizing the workability, and enabling the slump-flow diameter to reach high values without segregation.

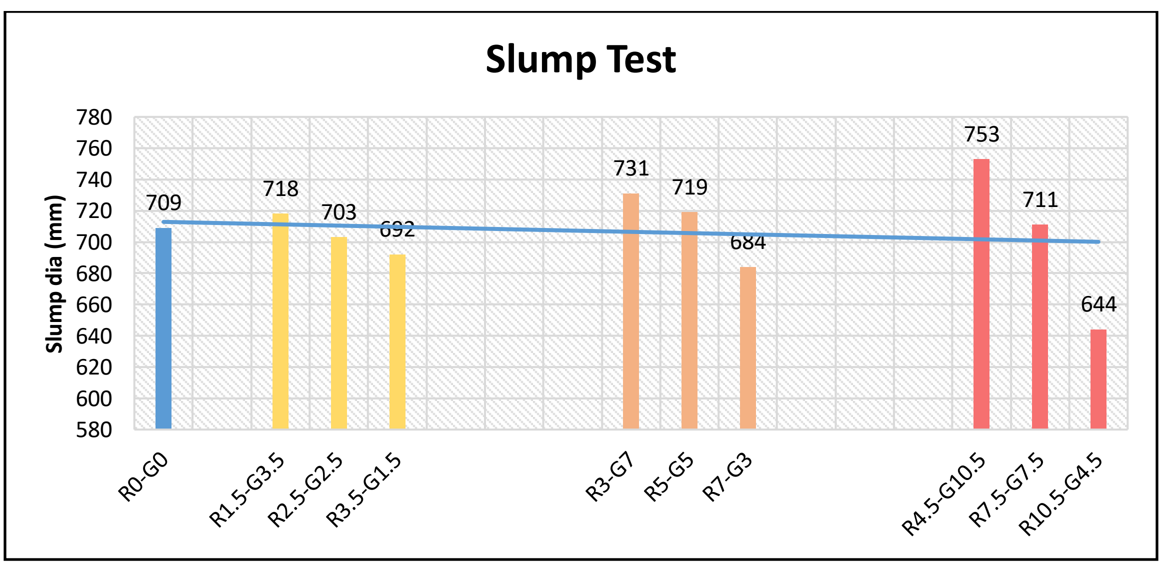
The observations are given below:

Composition	RHA-GGBFS (%)	Slump Flow (mm)
Type A (5%Replacement)	R50-G50	718
	70-30	703
	30-70	692
Type B (10% Replacement)	50-50	731
	70-30	719
	30-70	684
Type C (15% Replacement)	50-50	753
	70-30	711
	30-70	644


5% Replacement
Slump (mm)
720
715
710
705
700
695
690
685
680
675
718
703
692
R1.5-G3.5
R2.5-G2.5
R3.5-G1.5


10% Replacement
Slump (mm)
740
730
720
710
700
690
680
670
660
731
719
684
R3-G7
R5-G5
R7-G3


15% Replacement
Slump (mm)
800
750
700
650
600
550
753
711
644
R4.5-G10.5
R7.5-G7.5
R10.5-G4.5


Slump Test
Slump dia (mm)
780
760
740
720
700
680
660
640
620
600
580
709
718
703
692
731
719
684
753
711
644
R0-G0
R1.5-G3.5
R2.5-G2.5
R3.5-G1.5
R3-G7
R5-G5
R7-G3
R4.5-G10.5
R7.5-G7.5
R10.5-G4.5

4.2.2. V-Funnel Test:

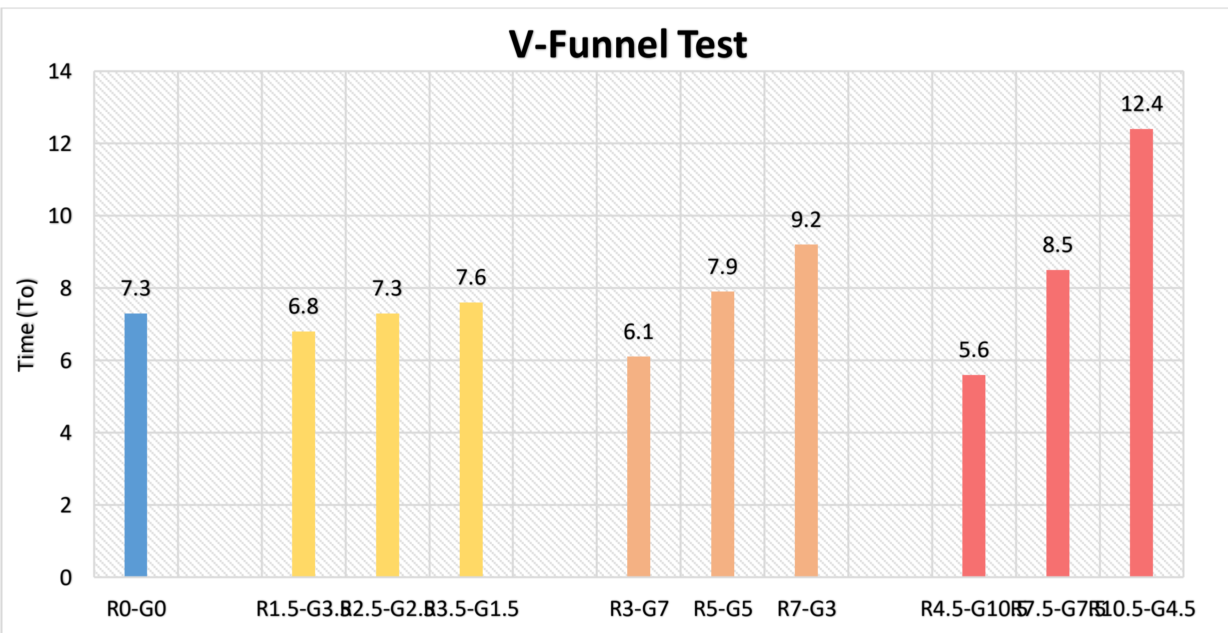
The flow ability and stability of SCC were assessed by the V-funnel test. According to EFNARC guidelines, the values of V-Funnel flow time must exist between 6-12 s. This test corresponds to both internal and external friction which is due to cohesive forces among SCC constituents and adhesive forces between SCC and funnel.

The results obtained from the fresh concrete experiments showed that both the physical characteristics and the dosages of mineral additives were effective on the rheological behavior of SCCs. It can be observed that the incorporation of RHA increased the frictional forces between paste and aggregate phases attributed to their higher surface area while GGBFS had the reverse effect. Therefore, the increasing values of V-funnel flow by the replacement of ashes ranged between 5.6 to 12.4s depicting the higher viscosity of SCC upon the incorporation of due to the higher surface area, adsorptive, irregular, and abrasive nature of ashes, thus increased the V-funnel flow time. Kannan and Ganesan [50] revealed that RHA incorporation reduced the V-funnel flow values. The reduced V-funnel flow values are attributed to the irregular shape, abrasive, high surface area, and adsorptive nature of RHA. The distribution of GGBFS particles, their spherical shape and size characteristics, and the smoothness of the surface texture are among the reasons why SCCs containing GGBFS have the highest slump-flow diameters.

It is observed that V-Funnel time decreases with increasing GGBFS content and decreases with increasing RHA content. The maximum time was observed for R10.5-54.5 and the minimum for R4.5-G10.5. 10.55 percent of RHA along with GGBFS increased time from 7.3s to 12.4s.

The observations are given below:

Composition	RHA-GGBFS (%)	V-Funnel Test (sec)
Type A (5%Replacement)	R50-G50	6.8
	70-30	7.3
	30-70	7.6
Type B (10% Replacement)	50-50	6.1
	70-30	7.9
	30-70	9.2
Type C (15% Replacement)	50-50	5.6
	70-30	8.5
	30-70	12.4

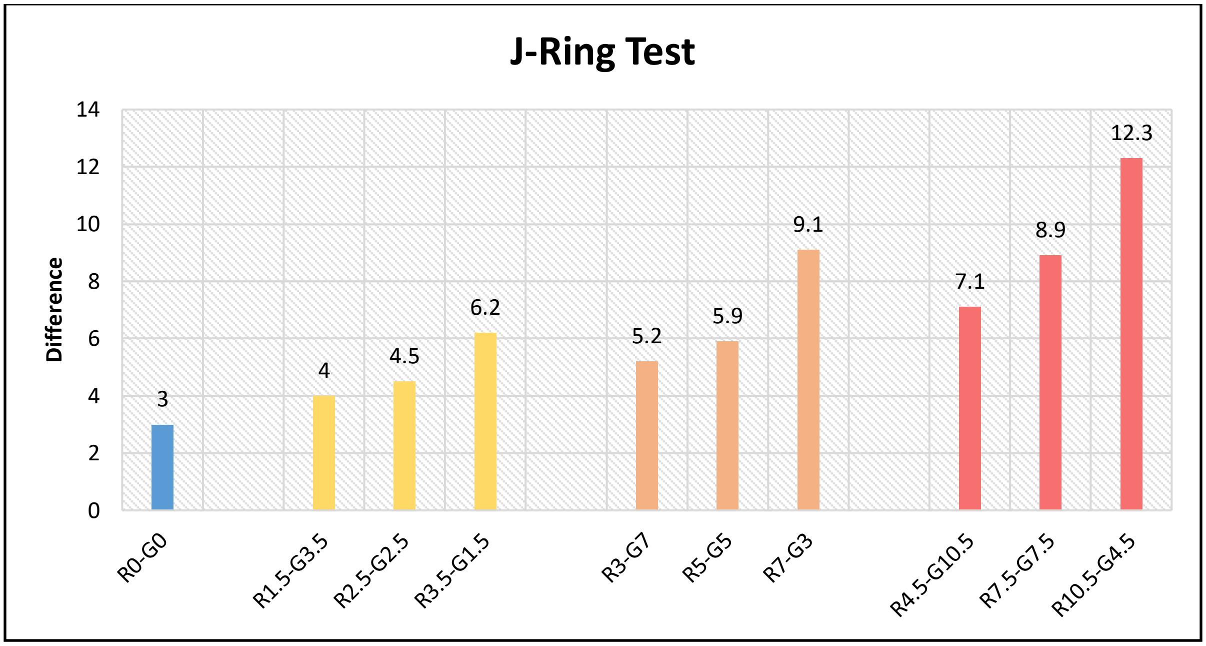


4.2.3 J-Ring Flow Test:

The rheological characteristics such as the passing ability and viscosity of SCC formulations were evaluated using the J-ring test. When the slump cone is lifted the SCC tends to flow through the network of reinforcements and the J-ring slump flow is recorded. The passing ability of the SCC mixes was evaluated by taking the difference in the height of the SCC at the center and circumferential point on the J-ring slump flow. The standard range of difference for evaluating passing ability exists between 0-10, therefore the difference of all the tested mix formulations lies within the standard except for R10.5-G4.5. Similarly, Rahman et. al. [47] reported the passing ability of SCC mixes containing RHA as a supplementary cementitious material complying with the EFNARC guidelines [48]. Generally, the SCC mixes containing the mixture of RHA and GGBFS depicted adequate passing ability.

The observations are given below:

Composition	RHA-GGBFS (%)	J-Ring Test (mm)
Type A (5%Replacement)	R50-G50	4
	70-30	4.5
	30-70	6.2
Type B (10% Replacement)	50-50	5.2
	70-30	5.9
	30-70	9.1
Type C (15% Replacement)	50-50	7.1
	70-30	8.9
	30-70	12.3

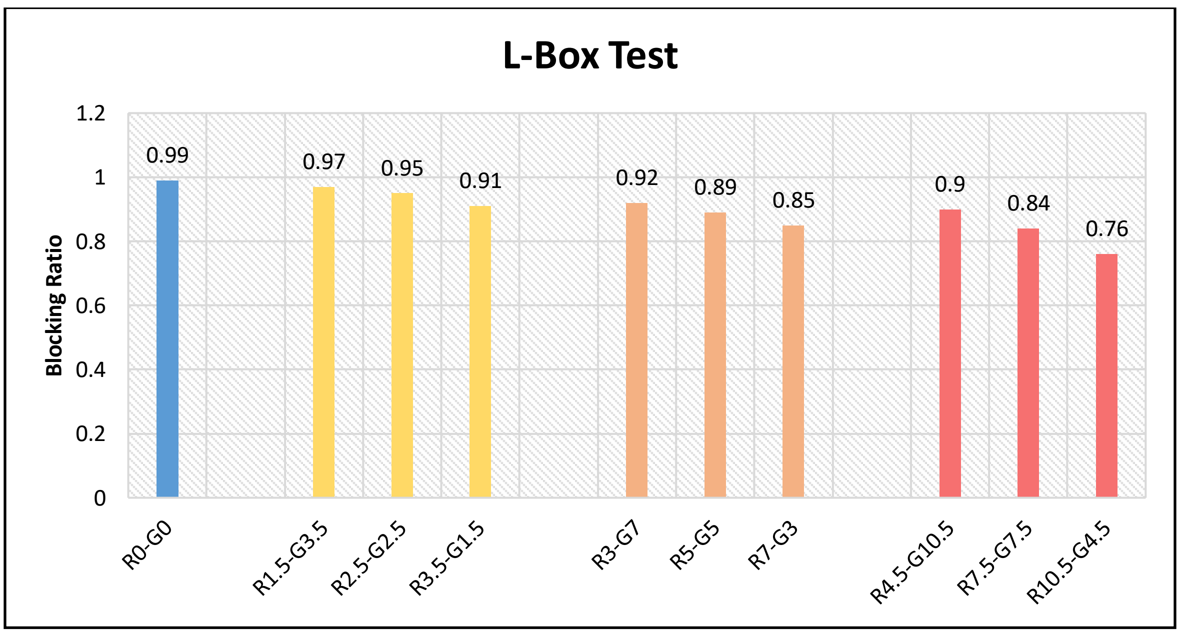


4.2.4. L-Box Test:

The passing ability and filling ability of SCC mix formulations are measured using the L-box test. The results of the H2/H1 values of different mix formulations revealed the decrease in the L-box ratio from 0.99 to 0.76 for minimal to maximum replacement SCM respectively, therefore the L-box ratio existed within the prescribed limits (0.8-1.0) of EFNARC guidelines except for R10.5-g4.5 which are shown the chart below. The increasing trend of loss in filling and passing ability of the SCC mixes by incorporation of RHA and GGBFS increases the demand for water and superplasticizer attributed to the adsorptive nature of incorporated ashes. The incorporation of RHA in SCC increased the viscosity of formulations due to the adsorptive nature of ashes. The results of RHA added SCC reported that 11% inclusion of RHA along with 5% GGBFS produced a blocking ratio of 0.76. Kannan and Ganesan [50] reported that H2/H1 ratio ranged between 0.9 to 0.6 from 0 to 25% of cement replacement. Therefore, the passing ability of almost all mix formulations is fulfilling EFNARC criteria.

The observations are given below:

Composition	RHA-GGBS(%)	L-Box Test (H2/H1)
Type A (5%Replacement)	R50-G50	0.97
	70-30	0.95
	30-70	0.91
Type B (10% Replacement)	50-50	0.92
	70-30	0.89
	30-70	0.85
Type C (15% Replacement)	50-50	0.9
	70-30	0.84
	30-70	0.76



4.3. Hardened properties test on SCC:

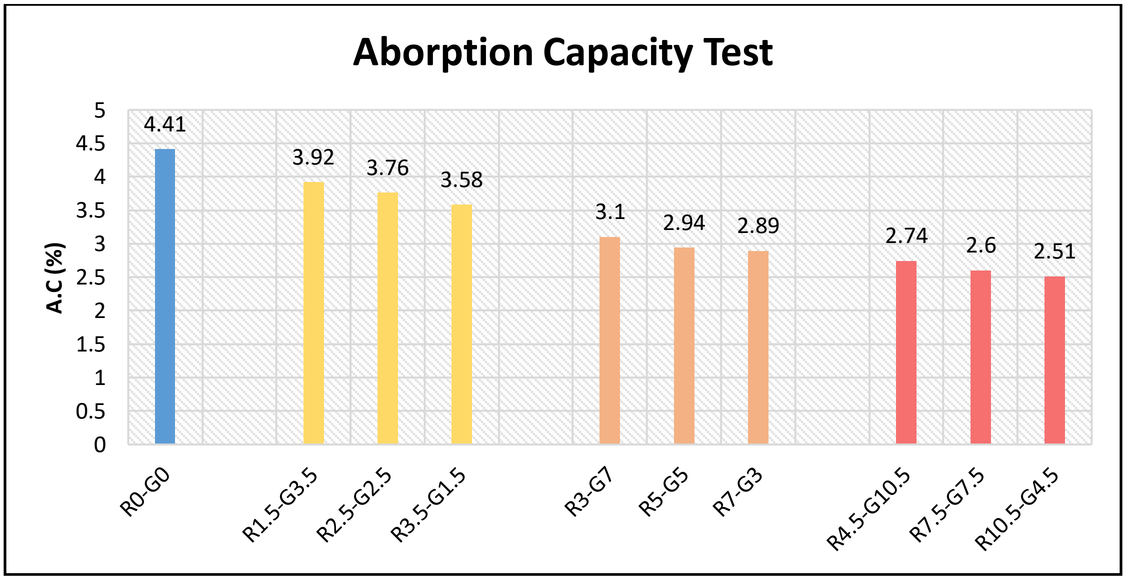
4.3.1. Absorption capacity:

The water absorption decreased with the increase in RHA and GGBFS content. This is due to (1) micro filler effect and additional C–S–H products filling the pores leading to reduced volume of large pores. At 4% SP content the control concrete had an absorption capacity of 4.41% which is greater than mixes with the incorporation of RHA and GGBFS. These results comply with several studies that have shown that incorporating RHA in SCC can help decrease its permeability. For example, a study by Hossain et al. found that incorporating RHA at 5-10% replacement levels can reduce the water permeability of SCC. Another study by Chen et al. found that incorporating 15% RHA in SCC can reduce its water permeability by up to 60%. Also, a study by Siddique and Klaus showed that incorporating GGBFS at 10-30% replacement levels can significantly reduce the water permeability of SCC. Another study by Safi Uddin et al. found that incorporating 20% GGBFS in SCC can reduce its water permeability by up to 70%. A study by Shazim Ali Memon [4] showed that water absorption decreased with an increase in RHA content.

Note that as the quantity of GGBFS increased in concrete as cement replacement water absorption of concrete decreased when compared to the control mix [3-19]. Concrete mixes with slag replacements having strength similar to nominal mix at 50% replacement level resulted in reduced chloride penetrability [3-52]. Although GGBFS particles can act as nucleation sites for reactions in the later stages of the hydration, however, at the initial time it acts only as an inert filler and plays no significant role in strength development thus no formation of secondary CSH. So the absorption capacity is more likely to vary depending upon the percentage of RHA in the early stages though the filling ability of GGBFS may contribute to the reduced permeability in the early stages as we observe here. The observations chart is shown below. The maximum reduction in absorption capacity was observed for R10.5-G4.5 (43%) for the 15% replacement of cement by SCM.

The observations are given below:

Composition	RHA-GGBS (%)	Absorption Capacity (%)
Type A (5%Replacement)	R50-G50	3.92
	70-30	3.76
	30-70	3.58
Type B (10% Replacement)	50-50	3.1
	70-30	2.94
	30-70	2.89
Type C (15% Replacement)	50-50	2.74
	70-30	2.6
	30-70	2.51



4.3.2. Compressive Strength:

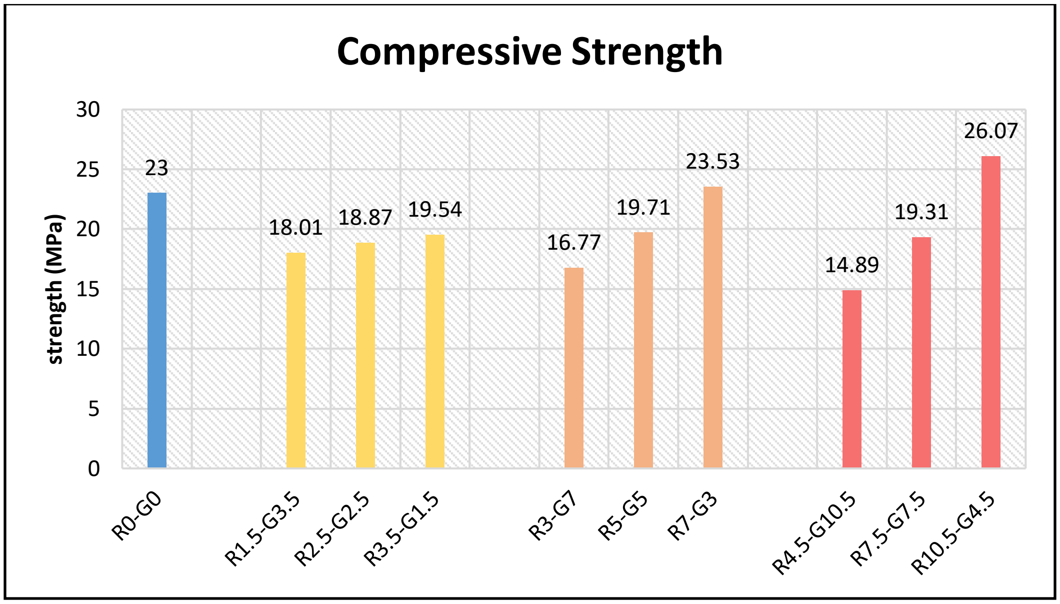
The margin of Compressive strength increase depends on the pozzolanic activity of SRM. Better packing decreases the porosity of hardened paste in the vicinity of the walls of aggregates. Improved and finer microstructure results in increased strength and offers Higher Resistance to fracture under loads.

It was observed in a study by Farshad Ameri [5], The 28-day compressive strength of the optimal mix containing 15% RHA increased by 12% compared to the control mix, and the increase in strength reached 21% with the inclusion of bacteria at the optimal concentration at constant SP content. A study by Shazim Ali Memon [4] showed that at 4% SP content, a mix having an RHA content of 10% gave better fresh and hardened properties. Study [4] also showed that the greater the dosage of superplasticizer than the required quantity, the lesser the strength would be.
A general evaluation was made by H. Alperen and Remzi [1], and it can be identified that the GGBFS replacement rates have a decreasing effect on the compressive strength of the SCCs. However, as expected, the compressive strengths of the mixtures with the same GGBFS ratio increased as the experiment aged. They observed that the 28-day strength of formulations with GGBFS as cement replacement decreased as GGBFS content was increased. Other researchers also reached findings parallel to the results obtained in this study on the effects of GGBFS on the compressive strength of concrete. Boukendakdji et al. [1-88] stated that with the increase in slag content, the compressive strengths of the concretes weaken especially at early ages, but the strength values become comparable to the control concrete at later ages (56 and 90 days). Zhao et al. [1-89] and Vivek and Dhinakaran [1-90] also reported that the compressive strengths of SCCs with GGBFS were weaker than that of the control concrete at all ages. Zhao et al. [1-89] stated that calcium hydroxide (CH), which originates from primary cement hydration in later ages, reacts with GGBFS to form a secondary hydration product resulting in more comparable results with the control concrete. Djelloul et al. [1-91] argued that the weakening of compressive strength of the concretes with the increase in slag content can be attributed to the low pozzolanic activity of GGBFS at early ages. The study [1-92] stated that these results may be due to a weak interfacial transition zone (ITZ), the porosity of the mortar during adhesion to fine and coarse aggregates, and the crack formation in the aggregates.

The maximum strength observed was for R10.5-G4.5 though it couldn’t fulfill EFNARC Guidelines for SCC and the minimum for R10.5-G4.5. A study concluded with the finding that as GGBFS increases, SP decreases due to early slow hydration which reduces water requirement [3-43]. Mix with fresh properties within the allowable range of EFNARC along with comparable compressive strength was R7-G3. Based on the literature and studies discussed above, the trend in strength can be explained as the GGBFS has little or no significant pozzolanic activity in the initial days up to 28 therefore the strength is mainly a function of RHA content. But as GGBFS has a significant effect on fresh properties and it also decreases SP requirement, it contributes as a superplasticizer in the formulations. Excess water in the sample results in the reduction of strength so in R4.5-G10.5, Relatively higher content of GGBFS along with already greater superplasticizer content (4%) result in the reduction of strength. But as the RHA content increased up to 10.5% and GGBFS content decreased to 4.5%, the SP content and RHA got optimized, with pozzolanic reaction forming secondary CSH resulting in enhanced durability and compressive strength. The same can be said for R7-G3, where an increase in strength was observed for the same reasons as that of R10.5-G4.5. Therefore, we concluded that the best optimal mix with fresh and hardened properties is R7-G3. This sample is further undergone through 3 different methods of curing to study what possible effects different curing methods may have on it.

The observations are given below:

Composition	RHA-GGBFS (%)	Compressive Strength (MPa)
Type A (5%Replacement)	R50-G50	18.01
	70-30	18.87
	30-70	19.54
Type B (10% Replacement)	50-50	16.77
	70-30	19.71
	30-70	23.53
Type C (15% Replacement)	50-50	14.89
	70-30	19.31
	30-70	26.07



4.4. Effect of Curing on Hardened Properties:

4.4.1. Compressive Strength:

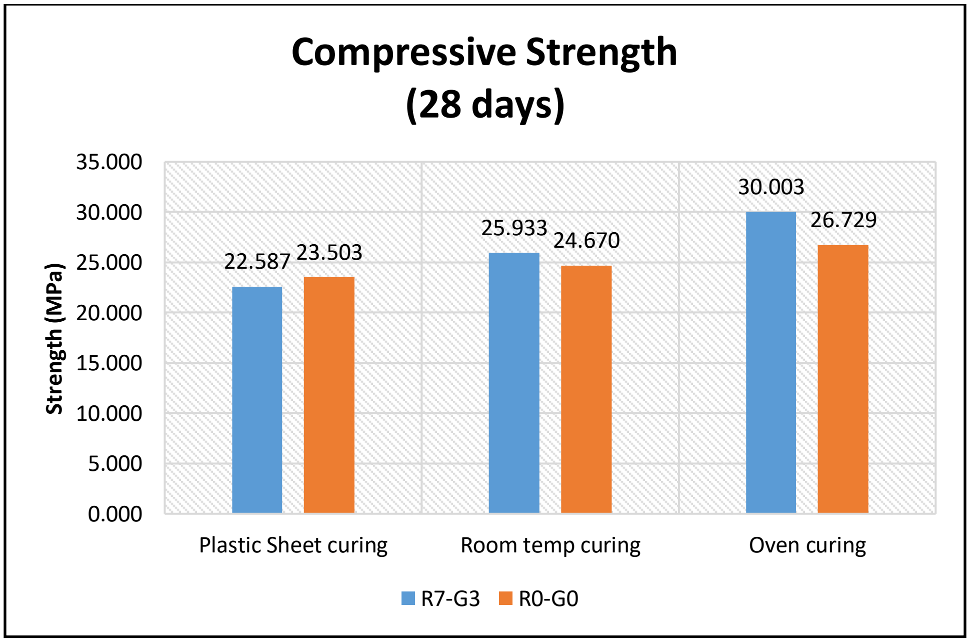
It was deduced in a study that incorporating GGBFS into concrete would significantly enhance the material's fire resistance. Adding GGBFS to the mix allowed for increased compressive strength when subjected to high temperatures [2]. In all mixes containing 22.5 % GGBFS and exposed to 225 ◦C elevated temperature, the superplasticizer content was shown to have a noticeable role in influencing the compressive strength, as it increased with increasing the superplasticizer content [2]. This result reaffirms the findings of Swami [2-62] and Hooton and Emery [2-63], which found that hydration can be sped up with heating for samples with GGBFS. Gideon Turuallo in a study stated that the strength development of concrete cured at higher curing temperatures at an early age is higher than that of concrete cured at a lower temperature; however, their strength is lower at later ages [C1].

The compressive strength of R7-G3 is greater than the control for any curing method. When compared against *room temperature cures samples*: The oven-cured samples had compressive strength 15% greater in the case of R7-G3 and 8.3% in the case of the control sample. Also, when compared against *room temperature cures samples:* The plastic sheeting resulted in a 4.7% reduction of strength in the case of control and a 13% strength reduction in R7-G3 samples.

The plastic sheeting method must have slowed down the hydration process as it was kept in an environment with a temperature below the standard of 20 Celsius.

The observations are given below:

Type of Mix	Type of Curing Conditions	Compressive Strength (MPa)			
		Sample 1	Sample 2	Sample 3	Mean
10% Replacement (70% RHA, 30% GGBFS)	Plastic Sheet curing	22.56	22.42	22.78	22.587
	Room temp curing	26.3	25.6	25.9	25.933
	Oven curing	30.06	29.97	29.98	30.003
2% Chemical VMA	Plastic Sheet curing	23.17	23.73	23.61	23.503
	Room temp curing	24.53	24.34	25.14	24.670
	Oven curing	26.8	26.57	26.816	26.729

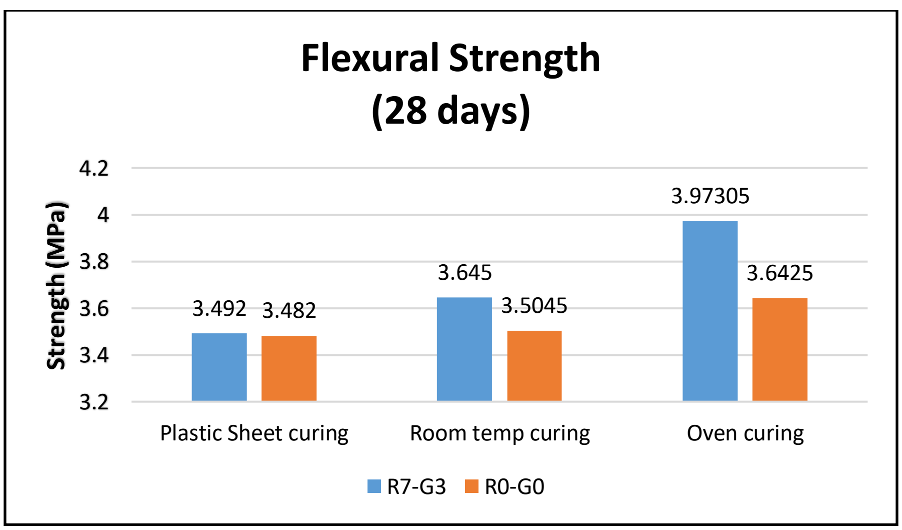


4.4.2. Flexural Strength:

The flexural strength of R7-G3 is greater than the control for any curing method. When compared against *room temperature cures samples*: The oven cures samples had split tensile strength 9% greater in the case of R7-G3 and 3.8% in the case of the control sample. Also, when compared against *room temperature cures samples:* The plastic sheeting resulted in no significant reduction of strength in the case of Control and a 4% strength reduction in R7-G3 samples.

Thus, it can be deduced that the effect of oven curing was more significant in R7-G3 than in control due to the presence of RHA and GGBFS whose activity seemed to be dependent on the curing temperature.

Type of Mix	Type of Curing Conditions	Flexural Strength (MPa)		
		Sample 1	Sample 2	Mean
10% Replacement (70% RHA, 30% GGBFS)	Plastic Sheet curing	3.469	3.514	3.492
	Room temp curing	3.687	3.603	3.645
	Oven curing	3.9729	3.9732	3.97305
2% Chemical VMA	Plastic Sheet curing	3.479	3.485	3.482
	Room temp curing	3.478	3.531	3.5045
	Oven curing	3.64	3.645	3.6425



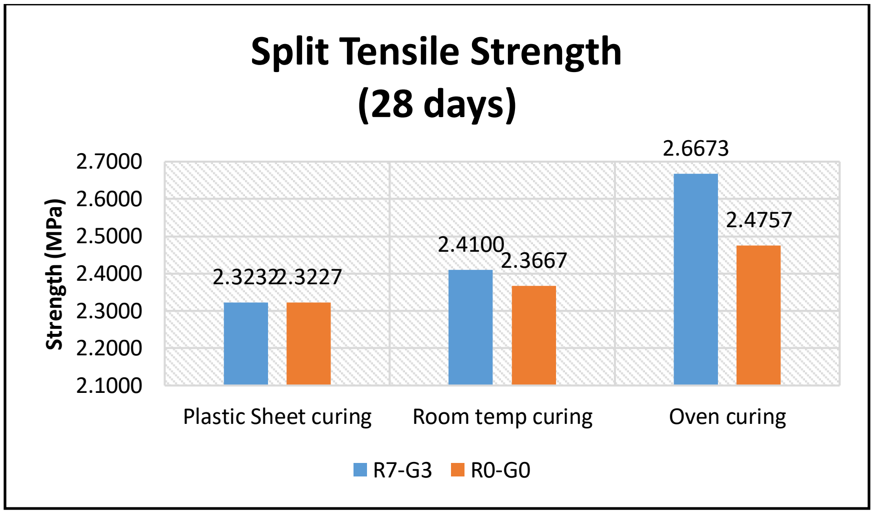
4.4.3. Tensile Strength:

Note that the split tensile strength of R7-G3 is greater for any curing method than that of the control(R0-G0). When compared against *room temperature cures samples*: The oven cures samples had split tensile strength 10.67% greater in the case of R7-G3 and 4.6% in the case of the control sample. Also, when compared against *room temperature cures samples:* The plastic sheeting resulted in a reduction of 1.7% strength in the case of Control and a 3.6% strength reduction in R7-G3 samples.

A study [5] reported that the split tensile strength of SCC increases up to a replacement level of 15%. Previous studies confirmed the positive effect of RHA on splitting tensile strength [5-16,5-62,5-63]. Therefore, the higher values of strength depict the formation of pozzolanic hydrates. The GGBFS contribution to tensile strength in the first two curing methods must be negligible but becomes apparent at elevated temperatures that raise the pozzolanic activity of both GGBFS and RHA. Both compressive and split tensile strengths are proportionate with each other.

The observations are given below:

Type of Mix	Type of Curing Conditions	Split Tensile Strength (MPa)			
		Sample 1	Sample 2	Sample 3	Mean
10% Replacement (70% RHA, 30% GGBFS)	Plastic Sheet curing	2.3227	2.3233	2.3235	2.3232
	Room temp curing	2.48	2.34	2.41	2.4100
	Oven curing	2.677	2.653	2.672	2.6673
2% Chemical VMA	Plastic Sheet curing	2.404	2.251	2.313	2.3227
	Room temp curing	2.34	2.31	2.45	2.3667
	Oven curing	2.476	2.481	2.47	2.4757



4.4.4. Ultrasonic Pulse Velocity (UPV) Test:

The density, stiffness, and integrity of Samples are revealed by the UPV test findings. Under various curing circumstances, R7-G3, which substituted 10% of the cement with RHA and GGBS, displayed acceptable UPV values, indicating satisfactory density and stiffness. The UPV values, however, were further elevated by the addition of a chemical VMA in Sample 2, indicating greater density, stiffness, and integrity of the concrete.

Under varied curing settings, there were discrepancies in the UPV values between the R7-G3 and the controlled sample (R0-G0) that can be attributed to several reasons.

Viscosity Modifying Agent (VMA): controlled sample (R0-G0) included a chemical VMA that is specially made to improve the density and stiffness of concrete. The addition of VMA may have enhanced cement particle dispersion and compaction, producing a more uniform and dense concrete structure. In comparison to R70-G30, R0-G0 can have greater UPV readings due to its increased density and stiffness.

Cement Replacement: For R70-G30, an interim blend of RHA and GGBS was used to replace 10% of the cement. The total density and rigidity of the concrete may change if cement is substituted. The cement substitution may have caused differences in the density and stiffness of R70-G30, resulting in differing UPV values compared to the controlled sample, depending on the precise characteristics and ratios of RHA and GGBS used.

Curing Conditions: The hydration and growth of the concrete can be affected differently by the various curing conditions.

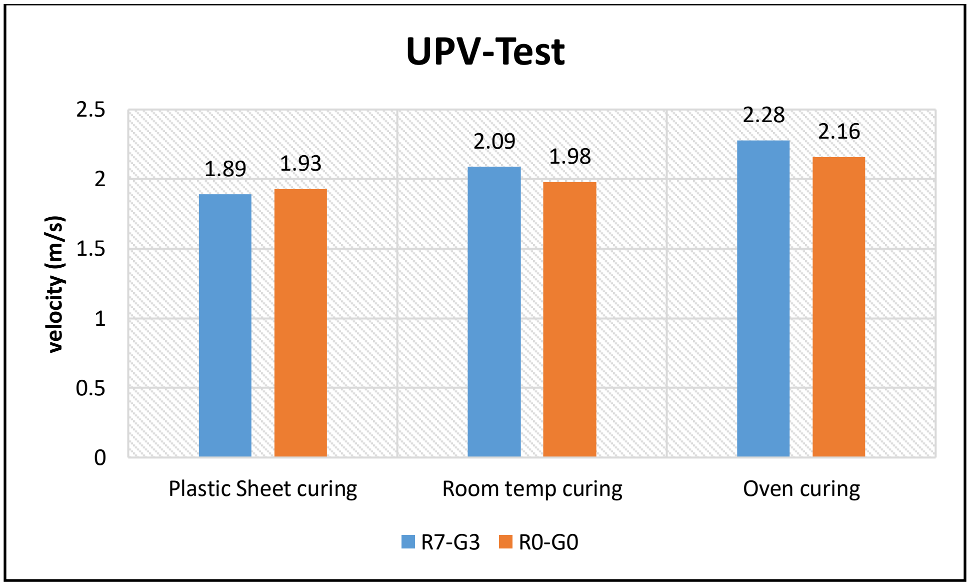
Plastic Sheets Curing: In comparison to R70-G30, the controlled sample (R0-G0) displayed a greater UPV value during the curing of plastic sheets. This might be the result of the VMA's enhanced dispersion and compaction, which produce denser and stiffer concrete structures with higher UPV values.

Room Temperature Curing: In comparison to R70-G30, the controlled sample (R0-G0) showed a reduced UPV value during room temperature curing. This might be explained by variations in the hydration kinetics and microstructure formation. A higher UPV value compared to the controlled sample may be due to Sample 1's particular selection of additional materials creating a microstructure that is more suited to room-temperature curing.

Oven Curing: In comparison to R70-G30, the controlled sample (R0-G0) displayed a greater UPV value during oven curing. The drying and hydration processes are accelerated by oven curing, which could lead to a denser and more rigid concrete construction. Compared to R70-G30, the controlled sample(R0-G0) VMA may have improved compaction and lower porosity, resulting in greater UPV values.

The observations are given below:

Type of Mix	Type of Curing Conditions	UPV (m/s)
		Mean
10% Replacement (70% RHA, 30% GGBFS)	Plastic Sheet curing	1.89
	Room temp curing	2.09
	Oven curing	2.28
2% Chemical VMA	Plastic Sheet curing	1.93
	Room temp curing	1.98
	Oven curing	2.16



The observed discrepancies in UPV values between the controlled sample and Sample 1 under varied curing settings may be the result of the interaction of several elements, including VMA, cement replacement, and curing conditions. In addition to UPV values, other significant criteria such as strength, durability, and workability should also be taken into account when evaluating the overall performance and suitability of concrete mixtures for certain applications.

4.4.1. Absorption Capacity Test:

Interesting insights have been revealed from the results of SCC samples' absorption capacities. R7-G3 with 10% replacement of cement with RHA and GGBS showed appropriate absorption capacity values under various curing conditions, with a 10% replacement of cement with RHA and GGBS. But the controlled Sample's ability to absorb material was greatly improved by the addition of a chemical VMA, creating a stronger barrier against the infiltration of moisture and water.

There are various explanations for why the controlled sample had a higher absorption capacity than the replaced one:

Viscosity Modifying Agent (VMA): Controlled sample contained a substance called a VMA that was created expressly to improve the characteristics of concrete, including lowering permeability. With better cement particle dispersion and suspension, VMAs produce denser concrete with fewer cavities and capillaries. This denser matrix narrows the channels via which water can enter, increasing its capacity to absorb.

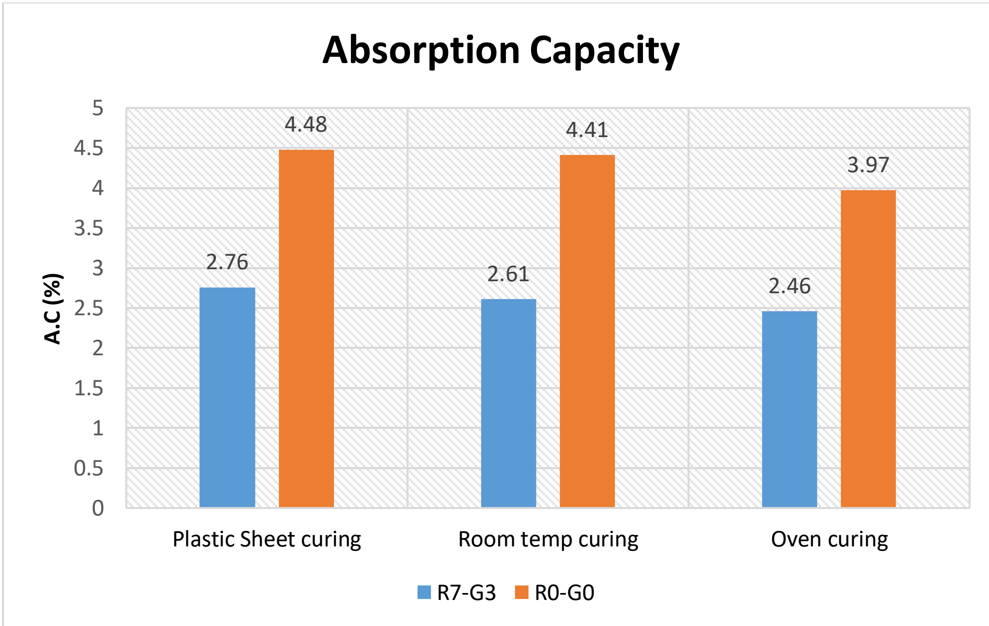
Reduced Cement Content: In the Replaced sample, an interim blend of RHA and GGBS was used to replace 10% of the cement. A partial replacement of cement can have an impact on the overall pore structure and porosity of the concrete, even if RHA and GGBS can help to increase the strength and durability of concrete. In comparison to the controlled sample with a higher cement content, the existence of extra voids and capillaries can increase the routes for water absorption, decreasing the absorption capacity.

Different Curing Conditions: Despite the identical curing conditions (plastic sheets, room temperature, and oven curing) applied to both samples, the controlled sample may have benefited from greater hydration and compaction as a result of the addition of VMA. A denser, less permeable concrete structure with improved compaction and hydration can have a better absorption capacity.

Itinerary Blend makeup: The itinerary blend employed in Sample 1—which contained 70% RHA and 30% GGBS—may have had an impact on the absorption capacity due to its makeup. Even while RHA and GGBS are advantageous, their combination in this specific ratio would not have offered the ideal balance to increase absorption capacity to the same degree as the VMA in the controlled sample.

The observation is given below:

Type of Mix	Type of Curing Conditions	Absorption Capacity (%)
10% Replacement (70% RHA, 30% GGBFS)	Plastic Sheet curing	2.76
	Room temp curing	2.61
	Oven curing	2.46
2% Chemical VMA	Plastic Sheet curing	4.48
	Room temp curing	4.41
	Oven curing	3.97


Absorption Capacity
A.C (%)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
2.76
4.48
2.61
4.41
2.46
3.97
Plastic Sheet curing
Room temp curing
Oven curing
R7-G3
R0-G0

CHAPTER 5:

CONCLUSION

Incorporation of RHA and GGBFS blend as cement replacement in SCC concrete has eco-friendly aspects that include the reduction of disposal issue of RHA and GGBFS along with beneficial impacts on microstructural, physic mechanical, and durability properties of SCC by physical effects (micro-filling, clogging) and chemical contribution through the enhanced microstructure of concrete mix due to the pozzolanic reaction. The summarized conclusions of this research are shown below:

- The absorptive quality of RHA caused a decrease in workability, whereas GGBFS improved workability when used as a blend with cement at varying percentages of 5, 10, and 15.
- When used as a substitute at a 10% level, RHA caused the SCC mix to fall outside the EFNARC range in terms of workability, whereas GGBFS had a similar effect on viscosity and segregation criteria.
- RHA had visible effects on both fresh and hardened properties. As the RHA content increased, workability decreased, and there were negative effects on some other fresh properties. However, an increase in RHA content also resulted in increased strength and durability of the sample which can be attributed to the pozzolanic activity of RHA which resulted in a dense structure through the formation of secondary SCH gel.
- GGBFS had a noticeable impact on the fresh properties of the material, such as workability, passing ability, etc. Although an increase in GGBFS content was found to have a negative impact on the strength of SCC initially, it may have to enhance properties in the later stages. However, after 28 days, the strength of the SCC with GGBFS continued to decrease, which can be attributed to its very low pozzolanic reactivity in the early stages.

- Both GGBFS and RHA had a positive effect on the durability of SCC, as evidenced by a decrease in the absorption capacity of samples with an increase in RHA and GGBFS content that depicts the pores to be less linked.
- Although the sample with 15% cement replaced with a blend containing 70% RHA and 30% GGBFS had the highest strength, it could not be subjected to further curing studies as it failed to meet the EFNARC guidelines for fresh properties of SCC.
- A blend consisting of 70% RHA and 30% GGBFS, used as a 10% substitute for cement, resulted in the desired fresh and hardened properties. The compressive strength of this sample was even slightly higher than that of the control concrete sample.
- When the sample with 10% replacement of cement with a blend containing 70% RHA and 30% GGBFS was cured using plastic sheeting, air drying, and oven curing methods, the sample that underwent oven curing demonstrated the highest strength in terms of compression, flexure, split tensile, and UPV. This suggests that the oven-curing method is the most effective for enhancing the strength of SCC with this blend.
- It is worth noting that the temperature in the oven was set to 55 degrees Celsius for the specific sample tested. Further studies are needed to investigate the effects of oven curing at temperatures higher than this for this blend.

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