STUDY OF SELF COMPACTING GEOPOLYMER CONCRETE BLENDED WITH MARBLE DUST AND RECYCLED COARSE AGGREGATES

Thesis Submitted for the Award of the Degree of

DOCTOR OF PHILOSOPHY

in
Civil Engineering

By

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LOVELY PROFESSIONAL UNIVERSITY, PUNJAB
2024

DECLARATION

I, hereby declared that the presented work in the thesis entitled **Study of Self Compacting Geopolymer Concrete blended with marble dust and recycled coarse aggregates**” in fulfilment of degree of **Doctor of Philosophy (Ph. D.)** is outcome of research work carried out by me under the supervision of Dr. Anshul Garg, working as Associate Professor, in the School of Civil Engineering of Lovely Professional University, Punjab, and Co-supervisor Dr. Sanjay Kumar Sharma, working as Professor in Civil Engineering department of NITTTR, Chandigarh,India. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

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CERTIFICATE

This is to certify that the work reported in the Ph. D. thesis entitled **Study of Self Compacting Geopolymer Concrete blended with marble dust and recycled coarse aggregates** ” submitted in fulfillment of the requirement for the award of degree of **Doctor of Philosophy (Ph.D.)** in the Civil Engineering, is a research work carried out by Geeta Mehta, 41800509, is bonafide record of his/her original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

(Signature of Supervisor)	**(Signature of Co-Supervisor)**
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ABSTRACT

To support the concept of Environment-Friendly materials and sustainable development, the low-carbon cementitious materials have been extensively studied to reduce the amount of CO_2 emission to the atmosphere. One of the efforts is to promote alternative cementitious binders by utilizing abundant alumina-silicate wastes from the industrial sectors like fly ash or furnace slags “GGBFS” or metakaolin etc. Recent studies have demonstrated that geopolymer concrete (GPC), which is concrete that is activated immediately by alkali solution and only contains mineral admixtures containing silica and alumina-silicates, may be created without the need of OPC. Fly ash-based geopolymer concrete has garnered significant attention due to its ability to perform a wide range of behaviours, lower costs, and have less detrimental environmental effects. One of its main benefits is that it produces fewer greenhouse gas emissions when compared to OPC.

Due to the high viscosity, GPC tends to fail due to a lack of compaction. To resolve this issue, “Self-Compacting Geopolymer Concrete “SCGPC” has been introduced. “SCGPC” is an innovative concrete that holds the benefit of cement free production of concrete and it does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. Many researchers have studied experimentally to combine the advantages of both self-compaction and the use of geopolymer concrete to work in direction of sustainability goals. Collected works show that very few attempts have been made on “SCGPC” with partial replacements of fine and coarse aggregates. There are many waste materials available from different resources that have the potential to be used as fine and coarse aggregate replacements. Observing through the available industrial wastes, marble dust “MD” is also one of the potential substitutes for fine aggregates. “MD” is a by-product which is typically produced during the sawing and polishing of marble blocks. It has been reported that approximately 25% of the processed marble is converted into waste form as dust or powder. The production of marble has been increasing; thus, the “MD” generation is on the rise as well. Like other waste materials, the disposal of the marble powder has become a serious environmental problem. Dumping of “MD” is causing the soil pollution as well as it is making the soil strata impervious leading to challenge for ground water table. Hence, effective use of marble waste as construction material substitute can be helpful to resolve the issue of dumping of same up to certain level.

Regarding replacement of natural coarse aggregates, there are various industrial waste are available. Due to renovation and upgrading of concrete structures, a lot of waste is generated which is to be dumped at landfill sites. Dumping of demolished waste contributes to load on landfill and reduces the land resource for future constructions. Moreover, application of recycled coarse aggregates “RCA” to replace coarse aggregates in Geopolymer concrete was available in very limited studies. Hence, the blended effect of replacement of fine aggregates and coarse aggregates with “MD” and recycled coarse aggregate respectively is carried out in “SCGPC” in present study.

This research also focuses on to explore the effect on workability, strength and durability properties of “SCGPC” at different NaOH molarities and SS/SH ratio. The present research tends create “SCGPC” by using byproduct from industrial process FA (Class F), and Granulated Ground Blast Furnace Slag (GGBFS) fully or in combination with partly replacing fine and coarse aggregate with “MD” and recycled coarse aggregate (“RCA”) respectively at ambient curing temperature. It has been targeted to achieve a compatible self-compacting concrete mix with appreciable response to various characteristics of “SCGPC” with durability behaviour within permissible range. Cost of the optimized mix is also another important parameter studied in research.

After performing the detailed experimental study it has been observed that the SCGPC with a sole binder content (GGBFS) of 440 kg/ m^3, AA/B ratio of 0.45, SS/SH ratio of 2.5, and NaOH concentration of 12 M achieved the highest 28-days compressive strength (44.28 MPa) at ambient curing conditions. In comparison to Flyash as sole binder with similar other conditions GGBFS as sole binder gives 98.5% rise in compressive strength, 93.1% rise in split tensile strength and 63% rise in flexural strength. The developed G100 mix has been refereed as control mix for further testing regarding blending of fine aggregate with marble dust and coarse aggregates with recycled coarse aggregates respectively. G100M30 has been identified as most reliable choice for “SCGPC”. G100M30 has compressive strength 7.16% higher than G100 after 28 days at ambient curing. Similar trend has been seen in split tensile strength and flexural strength. G100M30 has split tensile strength 15.8% higher and flexural strength 6.1% higher than G100. Durability behaviour has also been satisfactory for G100M30 as compared to G100 mix. Rise in cost for G100M30 is 20.8% higher than conventional SCC of similar grade.

Keywords: *“Self-Compacting Geopolymer Concrete “, GGBFS, “MD”, “RCA”, Molarity, Ambient Curing.*

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TERMINOLOGY

Abbreviation	Dilatation
SCGPC	Self-Compacting Geopolymer Concrete
GGBFS	Granulated Ground Blast Furnace Slag
GPC	Geopolymer Concrete
MD	Marble dust
FA	Flyash
RCA	Recycled coarse aggregate
Na_2SiO_3	Sodium silicate
NaOH	Sodium Hydroxide
CO_2	Carbon Dioxide
RHA	Rice husk ash
SS	Sodium silicate
SH	Sodium Hydroxide
PCM	Phase change material
C-A-S-H	Calcium Alumino Silicate Hydrates
N-A-S-H	Sodium Alumino Silicate Hydrates
MP	Marble Powder
MPa	Megapascal
mm	Milimeter
SEM	Scanning electron microscope
%	Percentage
µm	Micro-meter
M	Molarity
Kg/m^3	Unit of density
W/G’s	Water to Geopolymer binder ratio
AA/B	Alkali activator solution to binder ratio
Kg/m^3	Kilogram per meter cubic
m^2/Kg	Meter square per Kilogram
sec	Seconds
SP	Superplasticizer
SCC	Self compacting concrete

N/mm^2	Newton per millimeter square
XRD	X-Ray Diffraction
OPC	Ordinary Portland Cement
SiO_2	Silica
Al_2O_3	Alumina
$CaCO_3$	Calcium carbonate
$MgCO_3$	Magnesium carbonate
Fe_2O_3	Ferrous- oxide

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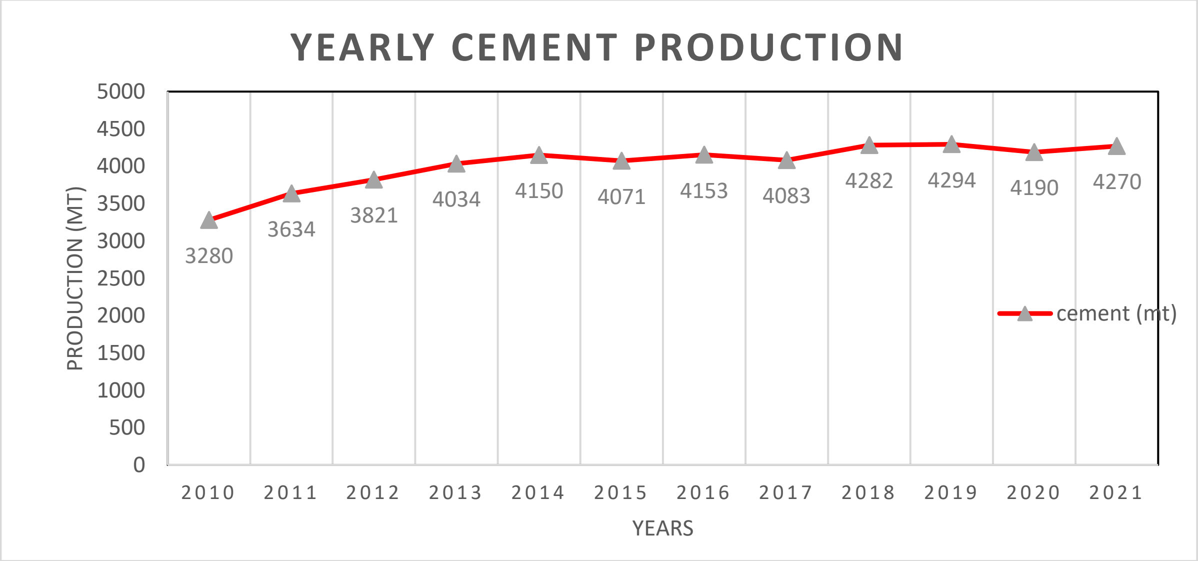
CHAPTER 1 INTRODUCTION

1.1 General

The demand for concrete as a construction material has steadily increased because of its flexibility in situ, usability, durability, fire resistance, and high strength. However, cement, the binder of aggregates, is costly and pollutes the environment during production. Cement manufacturing releases a substantial quantity of CO_2 into the environment. Roughly 7% of yearly greenhouse gas emissions are attributed to the manufacture of cement. Another estimate says that each tonne of cement produced emits around 900 kilos of carbon dioxide. Both chemical processes and the incineration of hydrocarbon deposit contribute to the release of carbon dioxide in the cement industry. Deforestation, pollution from electricity production, and other factors contribute to the irreparable loss of the ozone layer. Limestone, the basic material for cement production, has been used irresponsibly, causing landscape depletion and other consequences. Appropriate controls must be used to limit the amount of cement used in the manufacturing of concrete. Methods to reduce or eliminate the consumption of cement include economical mix design, the substitution of binder with thermal plant waste or similar waste from other industries as binders, for concrete in the form of geopolymer concrete.

Cement production leads to the emission of large quantities of carbon dioxide into the environment. Each tonne of cement emits upto 0.75 tonnes of CO_2. The



Reference: *https://www.iea.org/data-and-statistics/charts/global-cement-production-in-the-net-zero-scenario-2010-2030-4537*

Figure 1.1:Global cement production graph

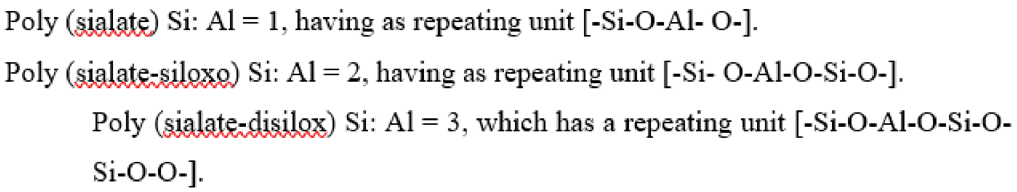
construction industry contributes over 40 percent of worldwide emissions, with the range of building activities growing each year. It has been quoted by (Verma et al. 2021) that, “in globe two-fifth need of the infrastructure is already available three-tenth needs to be created. “. As a result of the many industries, harmful landfill is generated. Industrial wastes and by-products, such as ground-granulated blast-furnace slag, slag, fly ash, silica fume, etc., have chemical and physical features of cement. Utilizing industrial by-products and waste materials containing silicate could be an efficient alternative to binder, since it reduces binder use. Due to their pozzolanic characteristics, the frequent wastes from industries such as “Flyash”, “GGBFS”, and agricultural wastes such as rice husk ash are employed as cement substitutes.

In (Davidovits 1988) was the first person to use the word geopolymer to refer to a family of mineral binders. These mineral binders have an amorphous microstructure and a chemical composition similar to that of zeolites. Geo-polymerization is a polycondensation process that takes place under very alkaline circumstances. This reaction takes place between aluminosilicate substances and SiO_3 of Na, and it assures the polymerization "Si-O-Al-O-links," that leads to “GPC”. In contrast to regular Portland cement, geopolymers get their structural strength from the process of polycondensation rather than the creation of a gel composed of calcium silicate and hydrate. According to Davidovits, the production of geopolymers results in "approximately 0.184 tonnes of CO_2 per tonne of precursor (binder)" being released into the atmosphere (Ye et al. 2019). In comparison to OPC, geopolymers demonstrate a decrease in CO_2 emission of around 80 percent.

1.2 Geopolymerization

Polymers are a type of material formed from complex molecules that are made up of many repeating units (monomers). The properties of a material are controlled by how the small molecules that render up the big molecules are put together. The non-crystalline or amorphous state is the one when there is no defined order of atoms being packed together. Glass is the type of amorphous solid that most people know. The formation of binders via a polymerization process is an essential part of the mechanism behind geopolymers. The fact that water is simply necessary to permit proper workability throughout the geopolymerization process is the most important aspect of this reaction. Water does not alter the polymerization mechanism in any way. Instead, it emerges from the reaction as a by-product during the curing process. In contrast, the interaction of alkalis with water results in the formation of hydration products in the case of typical concrete. These products, which include calcium silicate and calcium hydroxide, are examples. The calcium hydroxide slowly evaporates over time, which leads to the creation of spaces inside the matrix. These voids may be seen as pores. These gaps make it possible for potentially damaging ions from the environment to permeate the material, which leads to degradation. In contrast, the process of polymerization in the case of geopolymers results in the formation of relatively fewer voids, which has a positive influence on the mechanical properties and also makes it more immune to heat, water ingress, alkali-aggregate reactivity, and other forms of the chemical attack.

The polymerization reaction of silica and alumina in the presence of an alkali-activating solution results in the formation of an alumino-silicate gel. This gel is able to keep the loose aggregates together and produces three-dimensional structures that range from crystalline to amorphous polymers and have strong Si-O-Al connections. The mechanism is sensitive to the specific types of silica and alumina-containing source materials as well as the alkaline activators. Various research has suggested a variety of various methodologies for the process of geopolymer creation. As per (Davidovits 1988) “There are three distinct forms of three-dimensional amorphous to crystalline alumina-silicate geopolymer structures”. Those structures are determined by the ratio of silica to alumina.



Poly (sialate) Si: Al = 1, having as repeating unit [-Si-O-Al- O-].

Poly (sialate-siloxo) Si: Al = 2, having as repeating unit [-Si- O-Al-O-Si-O-].

Poly (sialate-disilox) Si: Al = 3, which has a repeating unit [-Si-O-Al-O-Si-O-Si-O-O-].

However, to this day, the setting process of “GPC” is not completely understood till date. In the investigation of the most important steps in the production of geopolymers, the primary chemical reactions may be broken down into the following sequential or phased activities:

Atoms of silicon and aluminium are dissolved as a result of the action of hydroxide ions originating from the source material.

The movement or configuration of the precursor ions, as well as their condensation into monomers.

The formation of polymeric structures by the polymerization of monomers or the polycondensation of monomers.

Structures composed of polymers that result from the polymerization of monomers.

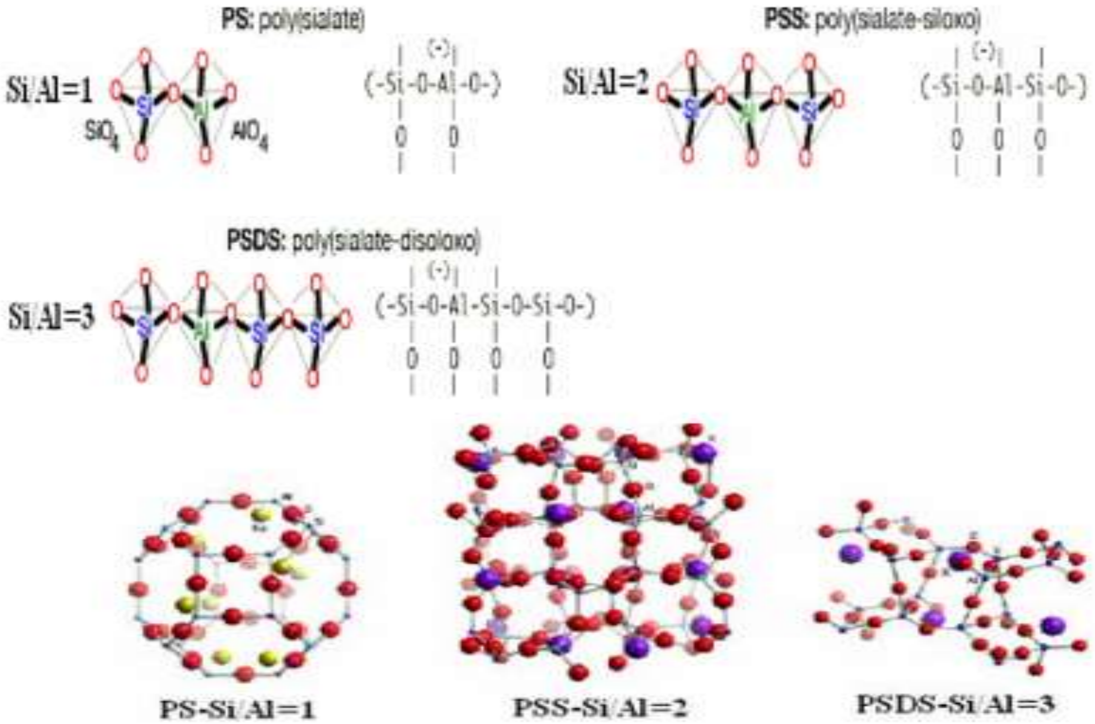


Figure 1.2: Three Fundamental Geopolymer Forms

1.3 “Self-Compacting Geopolymer Concrete “

“GPC” has high viscosity that makes it vulnerable to cracking, hence “SCGPC” has been thought about. It is an improved concrete that does not need vibration for placing and compaction. Even in the presence of substantial reinforcement, it is capable of flowing under its own weight, completely filling forms, and achieving full compaction. Sustainable “SCGPC” results in environmentally friendly concrete with a smaller carbon footprint than ordinary concrete. “SCGPC”, as its name suggests, is composed of geopolymer cement and has a self-compacting capability. Self-compaction and the usage of geopolymer cement are coupled with this form of concrete to provide its benefits. With an alkaline solution and superplasticizer, the binder (fly ash, “GGBFS”, RHA, or metakaolin) participates in the binding process and aids in the production and development of strength. The matrix phase in “SCGPC” binds coarse aggregates, fine aggregates, and other unblended ingredients to create the desired workability. Reduction of CO_2 emissions, exclusion of Portland cement manufacturing, suspension of the use of vibrators, and major minimization of noise pollution surrounding building sites, etc., may also be accomplished by “SCGPC” in order to make amazing health and safety advancements.

The ratio of water to geopolymer solids in “SCGPC” has to be carefully selected since it is a key control parameter for both the workability and the “Compressive strength” of the concrete. In addition, the fine aggregates have a substantially greater impact on the fresh characteristics of the “SCGPC” than the coarse aggregate does. It is the job of the superplasticizer in “SCGPC” to adsorb onto the binder grains, which gives them a negative charge and causes them to repel one other, which is then followed by deflocculation and dispersion. Therefore, greater workability and performance may be accomplished by strengthening the plastic and hardened characteristics of the material, which leads to a higher “Compressive strength” and improves the microstructure.

On “SCGPC“, the elements that are primarily researched are selection of the optimal Sodium Hydroxide molarity concentration, superplasticizer content, curing conditions, and curing length. In an effort to attain more sustainable building practices, “SCGPC” is experimenting with the use of supplemental cementitious materials such as Fly ash, “GGBFS”, Metakaolin and rice husk ash among other things as binder individually or in combination. On the other hand, the incorporation of additional alterations with fine and coarse aggregates were not attempted simultaneously for “SCGPC”. Further sustainability is tried on replacement of fine aggregates with waste “MD” and coarse aggregates with “RCA”. Development of “SCGPC” and study of its fresh and hardened properties along with durability aspect has been achieved in the present research. The cost analysis of the developed self-compacting concrete has also been explored as per cost incurred in development of “Self-Compacting Geopolymer Concrete “.

1.4 Scope of the study

The majority of research on “SCGPC“ so far has focused on comparing its hardened characteristics to those of conventional concrete. They are discovered to have superior strength and durability compared to conventional concrete. Nevertheless, the demand for high-temperature curing does not inspire confidence among engineers. Various precast uses of geopolymer concrete have been documented, but no significant work on cast-in-place construction applications has been recorded. The current need is to create a method that eliminates the need for oven curing or hot steam curing. This may be accomplished by combining the source materials with binding substances (“GGBFS” and “fly ash”) that increase the rate of polymerization in geopolymer concrete at room temperature. The incorporation of these binding elements into the geopolymer system may fulfil the intended objective, but their influence on critical features like as workability, strength, and durability must be examined before to pointing straight to the self-curing characteristics. Few research has documented the favourable benefits of adding “GGBFS” and “fly ash” on the strength qualities of “SCGPC “, but there have been no substantial consequences. Additionally, an attempt has been tried on partial replacement of fine aggre,gates with “MD” and partial replacement of coarse aggregates with “RCA”. “MD” is an industrial waste obtained from the cutting process of marble. A large quantity of marble waste is produced. As a result, nearly 25% of the marble by weight is reduced and converted to form waste “MD”. This causes a negative impact on the environment and humans. “MD” is primarily composed of oxides of calcium, magnesium, aluminium, silicon and iron. ”MD” can be a promising material for replacement of fine aggregate as per research available. Replacement of coarse aggregate with “RCA” or construction waste has been studied earlier and replacement percentage varies corresponding to various controlling parameters. Therefore, it is tried in present research to investigate the impact of “GGBFS” substitute with fly ash blended with “MD” and “RCA” on the fresh and hardened properties of concrete with durability behaviour of “SCGPC “.

1.5 Objectives of the study

Not only does “SCGPC” prove to be an effective alternative to conventional concrete, but it also helps to alleviate the disposal issues that are associated with industrial by-products such as “fly ash”, ”GGBFS”, Metakaolin, and “RHA”. This is accomplished by utilising these materials as a binder for concrete, whereas they would otherwise be disposed of as waste. In the similar manner, “MD” which is a by-product of marble cutting process and recycled coarse aggregate are used in the development of “SCGPC“. The following is a list of the set of objectives that the research aims to achieve:

- To develop “Self-Compacting Geopolymer Concrete“ at optimized dose of alkali activator and superplasticizers.
- To study the strength characteristics of the developed “Self-Compacting Geopolymer Concrete” blended with “MD” and “RCA”.
- To study the durability behaviour of the optimized self com “Self-Compacting Geopolymer Concrete “.
- To perform the cost analysis of optimized “Self-Compacting Geopolymer Concrete “with conventional self-compacting concrete.

1.6 Chapter Outline

This thesis comprises of 8 (Eight) Chapters, each has been written to fulfil the major objectives of research and their discussions. The chapter contents are summarized in the paragraphs given below:

Chapter 2 consist a detailed study on the researches been done on the two main constituents type of binders in GPC, Marble dust, RCA and type of alkaline activator with varying molarities of NaOH. The research has been listed in chronological order taking the latest findings first and a detailed summary has been prepared after analyzing the trends which are majorly visible.

Chapter 3 emphasises on the experimental program which includes the materials and equipment used for relevant tests to be performed on them as per Codal recommendations.

Chapter 4 includes Methodology to be adopted for achieving the research objectives and details of various test to be performed on “SCGPC”. Alkaline activator solution preparation has also been discussed.

Chapter 5 Comprises of all the experimental results in tabular and graphical form with their discussion.

Chapter 6 includes cost analysis of optimum mix and comparison with control mix.

Chapter 7 comprises of conclusions drawn from observed results of experimental work.

Chapter 8 discusses the scope of further studies to refine the research area.

CHAPTER 2 REVIEW OF LITERATURE

2.1 General

An extensive study has been carried out to identify the various parameters and materials involved in the development of "SCGPC". Types of binder, Molarity of NaOH, SS/SH ratio, dosage of admixture, marble dust and RCA are the various parameters in the present study. Industrial waste and agricultural waste having appreciable amount of silica and alumina are of prime focus as binders, 8M to 16M NaOH solution has been studied, SS/SH ratio from 1 to 3 has been observed and dosage of admixture depends upon the type of admixture and workability requirements. Marble dust can be used as a filler to replace fine aggregate in concrete and mortar. RCA can be used to replace coarse aggregates by an appropriate percentage depending on type and age of demolished waste.

2.2 Literature review on binder to be used in GPC

Binder to be used in GPC should have an appreciable amount of silica and alumni as these are prime components responsible for geopolymerization. Various industrial and agricultural waste has been found to be suitable to be used as a binder such as GGBFS, FA, MK, RHA and silica fume etc. The extent of geopolymerization depends upon active silica and alumina found in the binders. In this literature review the behaviour of various binders are being reviewed to find the best possible option in terms of workability, strength and cost. Detailed literature review is shown below in chronological order.

(Memon, Nuruddin, and Shafiq 2013) In this study, the effects of additional water and superplasticizer on the strength and workability of "SCGPC" were explored by comparing the results of several trial mixes. The research was carried out by comparing the outcomes of four distinct trial mixtures. The following conclusions have been reached based on the experimental findings that were provided in this research. The observations showed that upto 10% replacement of "Flyash" with silicafume is giving satisfactory workability as well as strength.

(Hwang and Huynh 2015a) In this study, a variety of samples are formed by adjusting the amount of RHA present from 0 to 40, and 50 percent and by adjusting the molarity of the NaOH from 8 to 10, 12 to 14, respectively. There are many different mechanical characteristics that are described, as well as how the alkali activator and RHA content affect the geopolymer that is based on fly ash and rice husk ash. The materials that were utilised and the specifications were: An earlier version of the Class F FA+ RHA, Activator: (NaOH) combined with (Na_2SiO_3) Molarity ranging from 8 to 14M, curing conditions are 35 degrees Celsius with a relative humidity of 50 percent, with an A/B ratio of 0.36, 0.40, 0.44, and 0.48. The “Compressive strength” of the material improves in proportion to the length of time it is allowed to cure. The mixture that contains RHA at a concentration of 35% and NaOH at a concentration of 10M yields the maximum “Compressive strength” possible. Even when examined with a SEM, the sample containing 35% rice husk ash and 10M sodium hydroxide was shown to have a dense microstructure. It comes to the conclusion that the preparation of geopolymers based on fly ash and RHA is very acceptable and helpful, and it demonstrates that RHA and fly ash may be safely deposited.

(Hwang and Huynh 2015b) It has been reported by researcher that silica and alumina to metal-oxide ratio in “GPC” has great impact on strength improvement. The study was conducted on locally available “Flyash” at varying metal oxide ratios. Tested “Flyash” gave satisfactory workability and strength in “GPC”

(Mathew and Joseph 2018) When the curing temperature is increased over 100 degrees Celsius, the “Compressive strength” of geopolymer concrete begins to decline. This limit is reached when the curing temperature reaches 100 degrees Celsius. It is possible to speed up the growth of geopolymer concrete's strength by making careful decisions about the temperature and duration of curing. If the curing process is done for 24 hours at 100 degrees Celsius, it is possible to reach 96.4% of the 28th day cube “Compressive strength” in just 7 days. With careful consideration of the proportion of fine aggregate to total aggregate content and the total aggregate content, it is possible to increase the modulus of elasticity and Poisson's ratio of geopolymer concrete to levels that are comparable to or higher than those of ordinary Portland cement. By choosing the proper ratio of fine aggregate to total aggregate content and total aggregate content, this can be achieved. In comparison to ordinary cement concrete, geopolymer concrete achieved a 19.2% rise in Poisson's ratio and a 14.4% increase in modulus of elasticity in the current study. This resulted in success. To achieve a commensurate increase in the material's “Split tensile strength”, the percentage of aggregate in geopolymer concrete should be raised. According to the current study, split and flexural “Split tensile strength” increased by 45.5% and 30.6%, respectively, when the total aggregate content was raised from 60% to 75% (keeping the percentage of fine aggregate to total aggregate constant at 0.35).

(Patel and Shah 2018) The research is designed to assess the impact that rice husk ash has on “SCGPC” incorporated by “GGBFS” in terms of both its mechanical and fresh characteristics. Materials that were employed and their associated characteristics are as follows: the precursor was “GGBFS”+ “RHA”, the activator was Na_2SiO_3 and NaOH, the molarity was 12M, and the curing conditions were room temperature for twenty-four hours. The workability of a concrete mixture intentionally diminishes as the % of “RHA” in the “GPC” changes from 5% - 25% (slump flow value decreased from 690mm to 650mm). Following the addition of RHA in amounts up to 5%, the concrete mixture achieved high “Compressive strength”s of 35.33MPa, 38.27MPa, and 42.6MPa after being tested at 3, 7, and 28 days, respectively. The “Split tensile strength” of concrete mixture containing 5% RHA is determined to be 2.3, 2.66, and 2.85MPa after 3, 7, and 28 days respectively, and the “Flexural strength” of the mixture is determined to be 2.94, 3.11, and 3.46MPa after 3, 7, and 28 days respectively. These are very impressive results. With an increase in the RHA level, the sorptivity values begin to climb, going from 0.069 to 0.112 mm/(min)0.5 (this is for 5%, 10%, and 25% RHA content in the concrete mixture). However, a low sorptivity score suggests that concrete will operate well in an abrasive environment, and this suggests that concrete is very long-lasting. According to the results of the SEM investigation, the microstructure of the concrete mixture containing 5% RHA is found to be rather thick.

(Kaur, Singh, and Kaur 2018) In this study, we analyse how the molarity of the NaOH, and the Na_2SiO_3 would influence “RHA” based “GPC”. The ratio of AA/B may range from 0.5 to 0.6, and even up to 0.7. There is a range of molarities available for the alkaline activator, including 12M, 14M, and 16M. The materials that were utilised and the specifications were: Precursor: RHA, Activator: sodium hydroxide, The molarities are 12, 14, and 16M. Curing conditions include an oven cure at 80 degrees Celsius for twenty-four hours. It may be deduced from an increase in the ratio of alkali activator to binder that there has been an improvement in the “Compressive strength”. When the ratio of alkali activator to binder is anywhere from 0.5 to 0.7, the compressive test outcomes are improved by 68.33%, 65.81%, 44.66%, and 28.51% accordingly after ambient curing at 3, 7, 14, and 28 days. After curing for 28 days, the material has a “Compressive strength” of 39.95 N/mm^2 when the ratio of AA/B is 0.7, and the molarity of NaOH is 14 M. This combination yields the greatest “Compressive strength” possible. Increases in molarity and the activator-to-binder ratio indicate a denser microstructure and a more homogeneous matrix in the sample mixture.

(Ramineni, Boppana, and Ramineni 2018) It was observed that using “GGBFS” as a substitute for fly ash at a ratio of 50 percent “enhanced both the fresh and hardened qualities of the concrete”, proving its usage of sustainable ingredients. At the end of seven days, the “Compressive strength” of concrete cubes has increased by 40.26 percent, and after 28 days, it has increased by 33.97 percent. Because the combination of fly ash and “GGBFS” has substantially decreased the setting time and has improved the mechanical qualities of the concrete, it has allowed for the removal of heat curing in the case of geopolymer, which was previously required. Using the assistance of this solution, the “SCGPC” that was created with “fly ash” and “GGBFS” combination may be used in precast structures as well as cast in situ constructions under ambient circumstances. Because “SCGPC” also has self-compatibility, it paves the way for the use of concrete in the construction of high-rise buildings and boosts the durability criteria.

(Mehta and Siddique 2018) The research focused on exploring the qualities of “GGBFS”-based “GPC” with partly replaced “RHA” at varying percentages 0-30% at interval of 5. The materials that were utilised and the specifications were: “GGBFS”+ RHA is the precursor, while Na2SiO3 and NaOH are the activators. 10M for the molarity, the curing conditions are 80 degrees Celsius for a whole day. In “GGBFS” “SCGPC” concrete mix, the substitution of up to 15% RHA shows a greater increment in the “Compressive strength”, which is 69MPa after 90 days of testing; however, when the RHA content is increased to more than 15%, the concrete mixes show a drop in “Compressive strength”. The concrete mix with 15% RHA replacement was found to have the highest “Split tensile strength”, which was measured to be 7.33 MPa after 90 days of curing. When the concrete mixture is substituted with 15% RHA, the values for chloride permeability and sorptivity decrease; however, if this threshold is exceeded, the values for chloride permeability and sorptivity rise. According to the findings of SEM and XRD, the microstructure of the concrete mix containing 10% RHA is denser than that of other concrete mixes including RHA.

(Al-Rawi and Tayşi 2018) The “GGBFS” replacement amount has a significant bearing on the fresh characteristics of the “SCGPC”. The fresh properties suffered as a direct result of increased “GGBFS” levels in the blends. However, research conducted by “EFNARC-2005” has shown that the addition of Silica Fume has a significant impact on the fresh qualities of “SCGPC” while still falling within the parameters of what is considered acceptable. The FA-based “SCGPC” needed to be removed from the moulds two or three days after they were cast because they did not reach the desired level of hardness after one day. This was necessary because “Flyash” contains a low quantity of CaO, which is the most important factor that determines how long it takes concrete to set for the first time. However, this challenge may be conquered by incorporating “GGBFS” into geopolymer concrete that is based on “Flyash”. The “FA”-based “SCGPC” has a low “Compressive strength” because to the low calcium content and the weak activity of “FA”. In addition, the incorporation of “GGBFS” into “SCGPC” mixtures resulted in a significant boost to the material's “Compressive strength”, with the degree of enhancement reaching more than 200% for (S100SF0) specimens. According to the findings of this investigation, “GGBFS” had a significant impact on the values of

“Compressive strength” shown by “SCGPC”s mixtures. As was said before, the incorporation of SF into OPC concrete had a marginal impact on the values of the material's “Compressive strength”. On the other hand, the incorporation of silica fume (SF) into “SCGPC” had no appreciable effect on the material's “Compressive strength”.

(Hadi, Zhang, and Parkinson, 2019) It has been concluded by researcher that, “40% GGBFS+FA at AA/B ratio of 0.5 and SS/SH ratio of 2 gave best results in workability and “compressive strength”. GPC performed better than routine concrete using OPC.”

(Parthiban et al. 2020) In this study, we explore what happens when rice husk ash is partly replaced with fly ash at various percentages (0 percent, 10 percent, 20 percent, 30 percent, 40 percent, and 50 percent). As per study, “the strength characteristics of geopolymer concrete” and traditional concrete are contrasted and analysed head-to-head. The strength qualities of the GPC significantly deteriorate with increasing % of RHA in the mix beyond 10% in case of ambient curing.

(Rahman and Al-Ameri 2021) According to the findings of this research, it is indisputable that “GPC” is an effective alternative for OPC. On the other hand, the parameters for the creation of “SCGPC” are to be expanded. The purpose of this research is to evaluate the fresh and hardened properties with minute features of a developed “SCGPC” at ambient curing. This “GPC” contains “fly ash”, “GGBFS”, and micro fly ash as binder components. After varying % of “FA+GGBFS” with AA/B ratio, the successful mix of “SCGPC” was obtained. This assisted in validating the function that the composition of fly ash and slag played, as well as the influence that water had on the binder materials. The tested mix have had their water-to-solids ratios altered between 10% -20%, and the water-to-solids ratio varied from 0.4-0.5. According to the findings, an industry-ready “GPC” has been developed. This “GPC” has the ability to self-compact and can be cured at room temperature. This innovation is applicable for use in applications involving in-situ concrete; however, additional research is required to determine how well it will function in the presence of thick reinforcements. According to the findings “FA” and “GGBFS” of 60/40 and had a water/solids percentage of 0.45 has highest performed.

(Almutairi et al. 2021) According to the findings of this research, when phase changing materials (PCM) is in a solid state, the “Compressive strength” of geopolymer concrete (GPC) microcapsules enclosing PCM is larger than when PCM is in a liquid form. This difference in “Compressive strength” may be because of an increase in the internal stress of the microcapsules that occurs when the temperature is increased. A reduction in chloride permeability in Geopolymers compared to regular concrete experimental via reduces in pore size and porosity and growth in deformation, which are generally due to the compact structure of the gel (C, N)-A-S-H and its coexistence. This was accomplished by decreasing the pore size and porosity of the Geopolymers. In order to preserve the concrete structures that are exposed to the maritime environment, an innovative geopolymer coating material has been offered as a potential solution. Extensive testing in both the field and the laboratory has shown that the coating has an adequate setting time, outstanding anti-corrosion capabilities, and a high bonding strength. Because of its chemical stability in marine environments, it is possible to offer concrete buildings with protection that is long-lasting.

(**Muhammad faheem Mohd Tahir et. al. 2022)** The results show that the optimum value of sodium hydroxide concentration, the ratio of sodium silicate to sodium hydroxide, and the ratio of solid-to-liquid for fly ash based geopolymer are 10 M, 2.0, and 2.5, respectively, with a maximum compressive strength of 47 MPa. The durability of “fly ash” based GPC is higher than that of OPC concrete.

(Mansi et al. 2022) It has been quoted by the author that **“**Geopolymer concrete is an environmentally friendly concrete as it relies on minor treated natural materials or industrial wastes like (Fly ash, “GGBFS” and silica fumes etc) which are having high alumina and silica content, to significantly reduce the carbon footprints.”

(Karthik and Mohan 2021) The researcher stated that, “A B4 binder that was made up of 45% “FA”, 45% “GGBFS”, and 10% SF, a dose of superplasticizer that was 1.5%, a Na_2SiO_3/NaOH ratio that was equal to 1.5, and a molar content of 12 showed the most effective “Compressive strength”.” It has been determined that the Taguchi method of mix design, which aims to attain a target strength 25 Newton/mm^2, is appropriate for use in urban building projects in developing nations like India. The L9 orthogonal array of the Taguchi method was discovered to be effective and accurate for estimating the quantities of optimized mix that can provide the target strength. As a result, preparation of a large number of trial-mixes was reduced as a result of this discovery. Despite this, it has been shown via further studies that the strength of the GPC mixes may be improved by including a number of elements that have varied degrees of significance. As a result of the research, it was discovered that the components that make up the optimization strategy—such as binder mixes, Na_2SiO_3/NaOH fractions, proportion of superplasticizer, and the molarity of Na-OH in the mix—are extremely important in order to achieve the desired level of strength in accordance with the standard design steps. Future research can, on the basis of the optimal GPC combination, investigate the resistance of GPC to impact and abrasion, the performance of GPC in structural applications, its durability, and any other relevant mechanical qualities.

(Kumar Das et al. 2022) The purpose of this study is to investigate the hypothesis that the chemical and mineralogical composition of rice hush ash (RHA) varies depending on the source material and the manufacturing procedure. Nevertheless, RHA typically consists of 85–90% amorphous silica, which enables it to function as a viable secondary raw material for "SCGPC". Before "RHA" may be used as a binder precursor for "SCGPC", it must first undergo the appropriate processing in order to get a higher level of pozzolanic performance. The crystallinity of RHA may be reduced, and its reactivity increased by controlled burning, particularly for 700-800 degrees Celsius. Milling "RHA" has been suggested as a method for achieving highly reactive RHA, which would include a reduction in particle size as well as an increase in specific surface area. Because "RHA" is an excellent source of reactive silicate, the final qualities of the products that are synthesised are influenced by its specific surface area, particle size, and solubility.

2.3 Literature review on SS/SH ratio

SS/SH ratio is having a great impact on geopolymerization process. It has been found that the ratio of SS/SH is being used by various researchers varying between 1 to 3 and intermediate fractions. In this literature review the impact of SS/SH ratio is being reviewed to find the optimized ratio in terms of workability, strength and cost. Relevant literature has been discussed in chronological order below:

(Younis et al. 2021) The purpose of this study is to investigate the effects that an alkali activation solution, comprised of "sodium hydroxide- (SH) and sodium silicate (SS)", has on the fundamental fresh and hardened features of "Self-Compacting Geopolymer Concrete ". In light of the following findings, the optimal SS/SH ratio was determined to be 2.5, and the optimum SH concentration was determined to be 12. The rise in SH content also resulted in a reduction in the flowability of the substance. Ratio of SS/SH (2.5) was the best possible options as per "EFNARC-2005", notably for the segregation resistance and flowability tests. While increasing the blend's plastic viscosity, an increase in SH concentration and SS/SH ratio results in a drop in the blend's slump flow value and L-Box ratio. As the ratio of SH concertation raised, the impedance to bleeding and segregation increased, as did the cohesiveness and viscosity of mixtures that contained a greater concentration of SH and an elevated SS/SH ratio. The flow-ability and fluidity of "SCGPC" mixtures decreased as the ratio of SH concertation raised.

(Pham et al. 2022) According to this study, the author quoted that "the optimal mix for achieving a favourable chemical reaction inside the "GPC", as well as increased "compressive strength" and "Split tensile strength", is a AA/binder ratio of 0.7 or 0.8, with "Fly ash 20%+GGBFS80%" as binder. "The distribution of steel fibre contributes to the significant enhancement of the in "Compressive strength", "Split tensile strength", and "Flexural strength", and in impact energy absorption.. Because the impact resistance of concrete was strengthened by fibres both against the commencement of the primary crack and the ultimate fracture, this indicated that the energy absorption capacity of fibre geopolymer concrete was increased. The experimental observations are well mapped with results of Ansys software with a little and acceptable deviation about 10%. The agreement was found in the behaviour of geopolymer concrete. When crack appearance in impact testing is compared to crack appearance in simulation studies, both are in sync to complement each other. This was determined by comparing the two types of analyses. As a consequence, it would seem that the numerical technique is capable of making rather accurate predictions of test outcomes.

(Rautaray, Bera, and Rath 2023) In this work of study, the following issues have been investigated, and their findings are reported as follows:

"While the strength of "SCGPC" decreases with increasing NaOH concentration, it increases in other ways. An increase in the matrix's ratio of Na_2SiO_3 to NaOH makes concrete more workable, but the strength of the concrete suffers as a result. It was discovered that a concentration of 12 M for NaOH is optimal, and that a proportion of super plasticizer equal to 7% by weight of fly ash is the ideal amount."

In an ideal situation, the ratio of alkaline solution to fly ash would be 0.5, the ratio of water to geo-polymer solid would be 0.33, the ratio of liquid to fly ash would be 0.69, and the ratio of NS to NH would be 2.5.

Both the workability and the strength of "SCGPC" are improved when "GGBFS" (up to 30 percent) and SF (up to 10 percent) are added.

2.4 Literature review on MD and RCA

Marble dust is a by-product of construction industry which is otherwise dumped at bare lands leading to depletion in the soil fertility and hence its usage as a construction material is beneficial for the environment. Demolished waste is increasing day by day due to urbanization and increment in population index. The three R's (Reduce, Reuse, Recycle) of sustainability are to be implemented to improve the global scenario of waste management. In this literature review the optimum use of MD and RCA has been identified and listed in chronological order below:

(Sundaramurthy et al. 2013) In this work, sand is partially replaced by marble powder (MP), which is sourced from adjacent cutting and polishing marble enterprises. “Flyash”is obtained from a local dealer, and utilised as a partial substitute for cement. Five percent increments of MP were added as follows: 5%, 10%, 15%, 20%, and 25% of the sand's weight. The findings show that the ideal replacement ratios for cement and sand were 20% FS and 10% MP, respectively. The production of sustainable concrete that solves an environmental issue could be impacted by the significant outcomes of the study.

(Ismail and Ramli 2013) The research focused on treatment of acid solvent and age of “RCA” before using in concrete. The researcher quoted that, “the use of different acid molarities to remove or minimise loose mortar particles attached on the surfaces of “RCA” can significantly improves its physical and mechanical properties. In addition, the reduction of loose mortar that covers “RCA” particles can significantly improves surface contact between the new cement paste and the aggregate which subsequently resulted in a significant improvement in the strength of concrete mechanical. However, the effectiveness of these treatment methods remains dependent on several factors that require further consideration.”

(Uygunoglu, Topçu, and Çelik 2014) This study uses marble powder (MP), which is acquired from local marble cutting and polishing enterprises, to partially substitute sand. The fly ash, which is utilised as a partial cement substitute, is obtained from a local dealer. Five percent increments of MP were added as follows: 5%, 10%, 15%, 20%, and 25% by weight of sand. The best replacement percentages for sand and cement, according to the data, were 10% MP and 20% “Flyash” respectively.

(Arel 2016) This review reports on the replacement of cement with waste marble and the use of waste marble as aggregate in concrete production. On the basis of the reviewed studies, it was observed that as the amount of marble powder used in place of fine aggregate increases, its workability decreases; however, this powder contributes to the “Compressive strength” of concrete because of $CaCO_3$ and SiO_2 present in the chemical structure of marble, while marble pieces used in place of coarse aggregate contribute to the workability and mechanical properties of concrete. When natural standard sand is replaced with “MD” at a ratio of 15–75%, the “Compressive strength” increases by 20–26% while the “Split Tensile strength” increases by 10–15%.

(Singh et al. 2016) In this work, sand is partially replaced by marble powder (MP), which is sourced from adjacent cutting and polishing marble enterprises. “Fly ash” is obtained locally , and utilised as a partial substitute for cement. Five percent increments of MP were added as follows: 5%, 10%, 15%, 20%, and 25% of the sand's weight. The findings show that the ideal replacement ratios for cement and sand were 20% “FA” and 10% MP, respectively. The production of sustainable concrete that solves an environmental issue could be impacted by the significant outcomes of the study.

(Aliabdo, Abd Elmoaty, and Salem 2016) In this study, “MD” was added by 0-15%, replacement ratios by weight of cement and sand. Both mortar and concrete modified with “MD” are enhanced due to the use of marble dust. Concrete made of ‘MD” as filler showed better performance compared to binder alternative. Marble dust prove to be a better replacement for fine aggregates.

(Djerbi 2018) In this work, researcher examined the effect of “RCA” on the microstructure of the concrete for 25,35 and 45MPa. The “RCA” effect on porosity was studied using “SEM” images for behaviour of “RCA” with fresh paste.

(Kore, Vyas, and Syed 2020) It has been quoted by the researcher that, “use of marble powder as a 10% replacement of cement does not have any adverse impact on the properties of concrete or mortars. It is more beneficial when marble waste is combined with fly ash and then is used as a binder rather than just as a replacement of ordinary Portland Cement. On the other hand, replacement of fine and coarse aggregate by marble waste can be done between the range of 50% and 75%..”

(Mhamal and Savoikar 2023) In the present study replacement of “MD” and granite dust with sand were observed and it was observed that under varying conditions marble and granite waste shows permissible replacement at 20%.

2.5 Summary of Literature Review

As per the detailed literature review on various parameters it has been summarised regarding binder that presence of silica and alumina is important for geopolymerization process. “FA” and GGBFS both are having good amount of both constituents and hence these are promising binders in GPC. Class F “FA” perform better in GPC than Class C.

SS/SH ratio has been used by many researchers between 1 to 3 but the SS/SH ratio prove to be better between 2 to 3 rather than at extremes.

MD was used as a filler for concrete as well as mortar in replacement of fine aggregates. It is found to be varying between 15% to 50% alone or in combination with other replacements.

RCA being weak in strength and higher in water absorption has limited use as replacement of coarse aggregates and its varying from 25 to 40% depending upon the age and properties of RCA.

It was discovered that a superplasticizer dose of up to 5 -7 percent can be adjusted for enough flowability and strength.

2.6 Research Gap

Several author have worked on developing “GPC”/ “SCGPC” with different binders such as “FA”, GGBFS, MK, Silica fume and combinations of these at varying percentage. It has been concluded from the literature study that “self-compacting geopolymer concrete “has yet not been developed with replacement being tried on both fine and coarse aggregates with “GGBFS” as sole binder.

2.7 Hypothesis of research

In the present study, Optimization of “NaOH” molarity and “Sodium-silicate to sodium hydroxide” ratio has been achieved with “FA” and then “FA+GGBFS” has been tested for the optimized parameters at ambient curing conditions. Further optimized binder has been tested for partial replacement of fine and coarse aggregates “MD” and “RCA” locally available with optimized parameters at ambient curing conditions. Durability test of RCPT and water permeability and cost analysis of optimized mix has been performed.

CHAPTER 3 EXPERIMENTAL PROGRAM

3.1 General

Materials to be used in the present experimental work has been studied for their physical and chemical characteristics. Properties of binders, “FA” and “GGBFS” have been included in the following chapter. Fine and coarse aggregates properties have been studied as per relevant IS codal recommendations. SEM images of binders and Marble dust have been discussed. Properties of admixture and alkali activator solution have been discussed.

3.2 Equipment

The equipment that has been used in this research are listed below:

Table 3:1: List of equipment’s

Equipment	**Description**
Le-Chatelier’s Flask	It is used to calculate the specific gravity of “GGBFS” and fly ash. The flask holds 500 millilitres.
IS sieve set	Using a sieve, it is used to investigate aggregates of all sizes. Using an IS sieve set with ranges of 20 millimetres to 4.74 millimetres and 4.75 millimetres to 75 microns, respectively, is utilized for the sieve examination of fine aggregate and coarse aggregate.
Pycnometer	It is used to calculate the specific gravity of fine aggregate. The pycnometer flask has a 1-liter volume capacity.
Density bucket	Using this equipment, the specific gravity and bulk density of coarse aggregate are determined. Three Liters can be stored in the bucket.
Weighing balance	A weighing balance is a tool that is used to determine the mass of samples. Based on the required level of accuracy, it does this calculation using a variety of alternative approaches.
Slump cone	A device with a 200 mm base, a 100-millimeter top, and a 300-millimeter height is used to gauge how well freshly mixed concrete will operate. The device has a cylindrical structure.
Flow table	The surface used to allow freshly mixed concrete to flow is a plate with dimensions of 700 millimeters by 700 millimeters. It is used to assess how easily concrete mix can flow.
J-Ring	To create a ring with a diameter of 300 mm, a rectangular portion measuring 30 mm by 25 mm is positioned vertically. Each rectangular

	portion is placed next to each other with a gap between them. The gap between each portion is typically 48 ± 2 mm, meaning it can vary between 46 mm and 50 mm.
V-Funnel Apparatus	The purpose of utilizing it is to measure the flow rate of freshly mixed self-compacting concrete. This test involves a stainless-steel funnel that is positioned vertically on a supportive pedestal. The funnel is equipped with a cover, which includes a small opening that can be temporarily opened.
L-Box Apparatus	It is constructed of a rectangular section box with a "L" shape. It is divided into a vertical segment and a horizontal section by a movable gate. In front of the gate, the vertically reinforcing bars are put.
U-Box Apparatus	The device includes a container that is divided into two halves by a wall in the middle of the container; there is a gap in the device that is fitted with a gate that can slide open and shut.

3.3 Materials

3.3.1 Fly ash

The by-product fly ash is created when coal is burned in thermal power plants. Fuel ash is called fly ash. Precursors can be replaced with better results by adding fly ash to concrete mixtures. A fly ash sample (class F) was obtained for the current inquiry from the Rajpura Thermal Plant in Punjab and used as a predecessor. Using the codes IS 1727-1968 and IS 4031 (Part 1)-1988, the specific gravity was calculated, and the result was 2.21. The following Table 3:***2*** provides information on the fly ash's various physical properties:

Table 3:2: Physical Properties of Fly Ash

MATERIAL PROPERTIES	Specific Gravity	Colour	Particle Size	Surface Area	Fineness Modulus	Bulk Density
VALUES	2.21	Grey	1µm-150µm	300-500 m^2 /kg	2.73	540-860 kg/m^3

Depending on the characteristics of the coal it was burned in the power plants, the chemical composition of fly ash varies. Since the coal burned in the power plant arrives in such a variety of forms, there is a wide range of potential fly ash compositions. Silica, alumina, and iron oxide make up the majority of ash's chemical makeup, with minor amounts of calcium, magnesium, and sulphur (SO_3). The engineering properties of fly ash are influenced by its constituents' silica, free lime, iron, and carbon. Fly ash can have a pH that ranges from 8 to 12. The breakdown of the chemicals that make up fly ash is provided in Table 3:***3***.

Table 3:3: Chemical composition of Fly Ash

Chemical component	SiO_2	Al_2O_3	FeO	MgO	TiO_2	SO_3	CaO	Loss of ignition
Percentage	58	30.43	7.06	1.91	1.56	1.8	3.6	2

Class F fly ash $SiO_2 + Al_2O_3 + Fe_2O_3 \geq 70\%$

3.3.2 Ground granulated blast-furnace slag (“GGBFS”)

Blast-furnace with Ground Granules Slag, also referred to as “GGBFS”, is a cementitious substance used primarily in the creation of concrete. It is a by-product from the furnaces used to make iron. Blast furnace input materials are mixed in a specific ratio and heated to temperatures of about 1,500 degrees Celsius while the furnace is in operation. The remaining elements are used to create the slag, which floats on top of the iron after iron is removed from the iron ore. This liquid molten slag is periodically tapped out, and if it is to be employed in the creation of “GGBFS”, it must be quickly quenched in a sizable amount of water. The quenching procedure results in the generation of granules that are similar to coarse sand and enhances the cementitious properties. After being dried off, this "granulated" slag is next crushed into a fine powder. Table 3**:4** shows the chemical composition of ground granulated blast furnace slag while Table 3***:5*** depicts its physical characteristics .

Table 3:4: Chemical composition of “GGBFS”

Chemical compound	**Percentage**
Silicon-oxide	33.89
Al-oxide	16.990
Ca-oxide	36.971
Fe-oxide	0.708
Mg-oxide	7.791
S-trioxide	0.499
Mn-oxide	0.199
L. ignition	0.498

Table 3:5: Physical properties of “GGBFS”

Material Properties	“Specific Gravity”	“Fineness Modulus”	Colour	“Bulk Density”	Surface area	Particle Size
Values	2.85	3.75	Light grey	1200 kg/m^3	450 m^2 /kg	Avg. 45micron

3.3.3 SEM images of “FLYASH” AND “GGBFS”

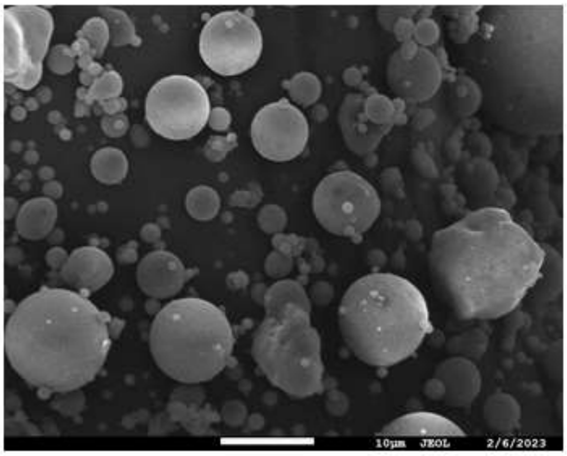


Figure 3.1: SEM image of “Flyash”

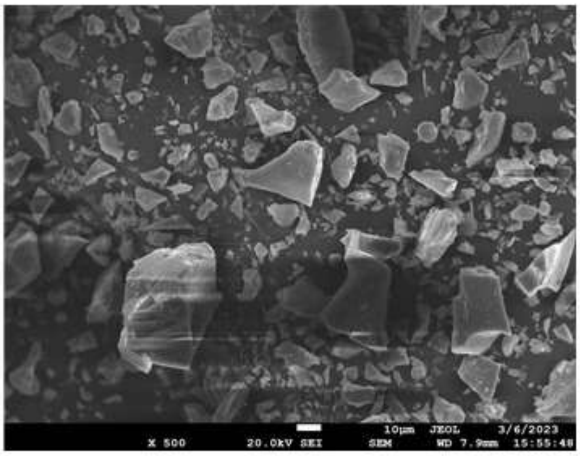


Figure 3.2: SEM image of “GGBFS”

As per Figure 3.1 SEM image of “Flyash” indicates spherical shape and crystalline structure of the particles, whereas and Figure 3.2 indicates that “GGBFS” has angular shape of particles and amorphous structure

3.3.4 Fine aggregate

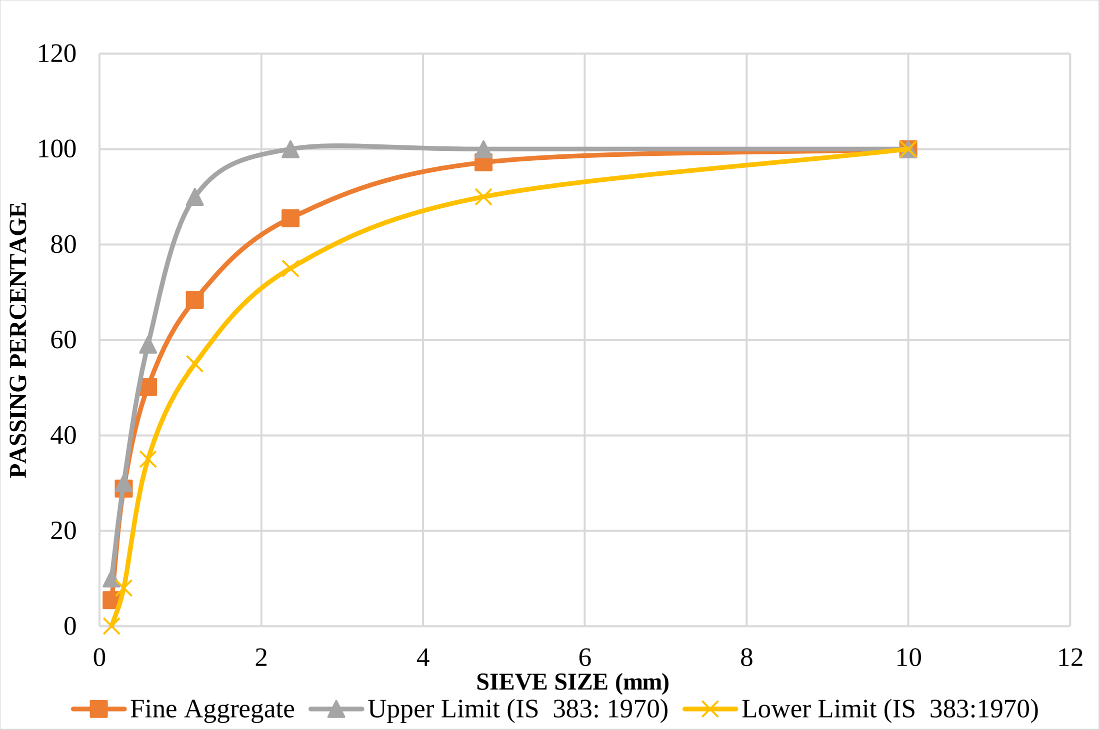
In this investigation, Natural River sand was obtained from a nearby river source which is used as the fine aggregate . The fine aggregate was determined to comply with the Zone-II requirements of the IS 383-2016 standards after the test for sieve analysis was carried out by the IS 383-2016 specifications. The bulk density, specific gravity, and fineness modulus have been listed in Table 3***:6*** and Table 3***:7*** shows the sieve analysis of fine aggregates. These tests were conducted in compliance with IS 2386 (Part-III)-2002 criteria. Graph 3.1 shows a plot of the total percent passing about the fine aggregate sieve size.

Table 3:6: Physical Properties of Fine Aggregate

“Material Properties”	“Specific Gravity”	“Fineness Modulus”	“Bulk Density”	zone	Grade	Water absorption
Values	2.65	2.644	1668 kg /m^3	II	Medium sand	0.81%

Table 3:7: Sieve Analysis of Fine Aggregate

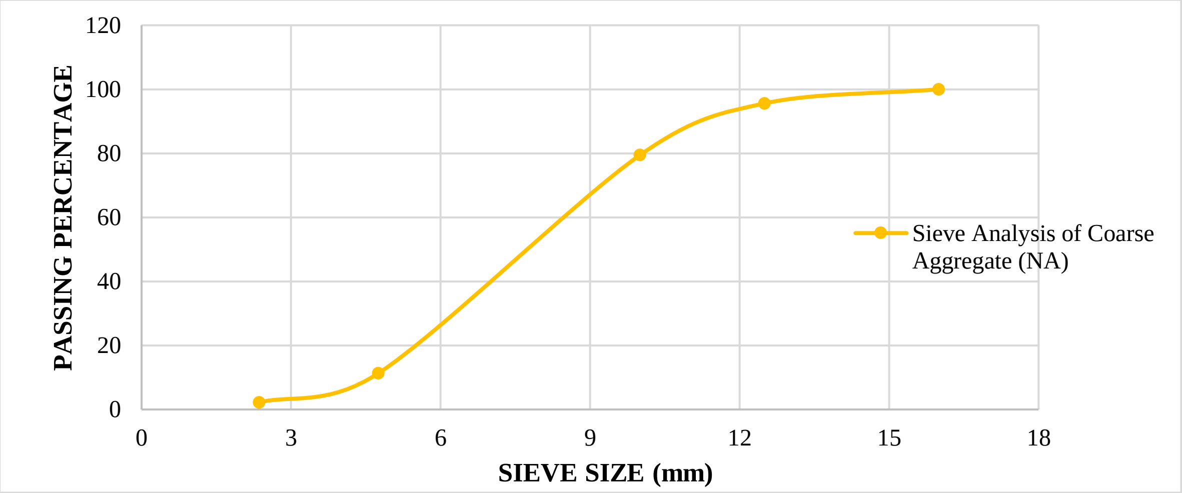
S. No	Sieve size	Weight retained (grams)	% weight retained	Cumulative percentage weight retained	Cumulative percent passing	
					Fine aggregate	IS 383 (2016) – Zone II requirement
01	10mm	0	0	0	100	100
02	4.75mm	56	2.8	2.8	97.2	90-100
03	2.36mm	234	11.7	14.5	85.5	75-100
04	1.18mm	342	17.1	31.6	68.4	55-90
05	600µm	364	18.2	49.8	50.2	35-59
06	300µm	427	21.35	71.15	28.85	8-30
07	150µm	468	23.4	94.55	5.45	0-10
08	pan	109	5.45	-	-	-



Graph 3.1: Grading curve of fine aggregate

3.3.5 Coarse aggregate

We employed crushed stones measuring 12.5 millimetres in diameter. According to the Indian standard code, we conducted experiments to determine the water absorption and specific gravity of the coarse aggregate with a size of 12.5mm. The obtained values were found to be precise, with 0.596% as water absorption and a "specific gravity" of 2.671. To analyse the gradation of the coarse aggregate by the Indian standard code, we utilized sieve analysis and recorded the results in Graph 3.2 (referring to the quantity of five kg tested) displays the coarse aggregate grading curves as specified by the Indian standard code.



Graph 3.2: Grading curve of coarse aggregate

Table 3:8: Sieve analysis of Coarse Aggregate

S. No	Sieve size	Weight retained (grams)	Percentage weight retained	Cumulative percentage weight retained	Cumulative percent passing	
					Coarse aggregate	IS 383 (2016)
01	16mm	0	0	0	100	100
02	12.5mm	406	8.12	8.12	91.88	90-100
03	10mm	354	7.08	15.2	84.8	40-85
04	4.75mm	3884	77.68	92.88	7.12	0-10
05	2.36mm	280	5.6	98.48	1.52	-
06	pan	76	1.52	-	-	-

Table 3:9: Characteristics of Coarse Aggregate

Material Properties	“Specific Gravity”	“Fineness Modulus”	“Bulk Density”	Type	Grade	Water absorption
Values	2.671	6.146	1568 kg /m^3	Crushed stones	12.5mm	0.596%

3.3.6 Waste “MD”

In this present research, waste “MD” was obtained from local marble dealer in Jalandhar. The properties of “MD” has been tested in the laboratory and has been listed in the Table 3:***10***.

Table 3:10: Chemical composition of waste “MD”

Chemical	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	$CaCO_3$	$MgCO_3$	Al_2O_3	**S**	LOI*
WMD	3	0.14	52.28	0.39	0.50	93.3	1.04	0.14	0.03	0.05

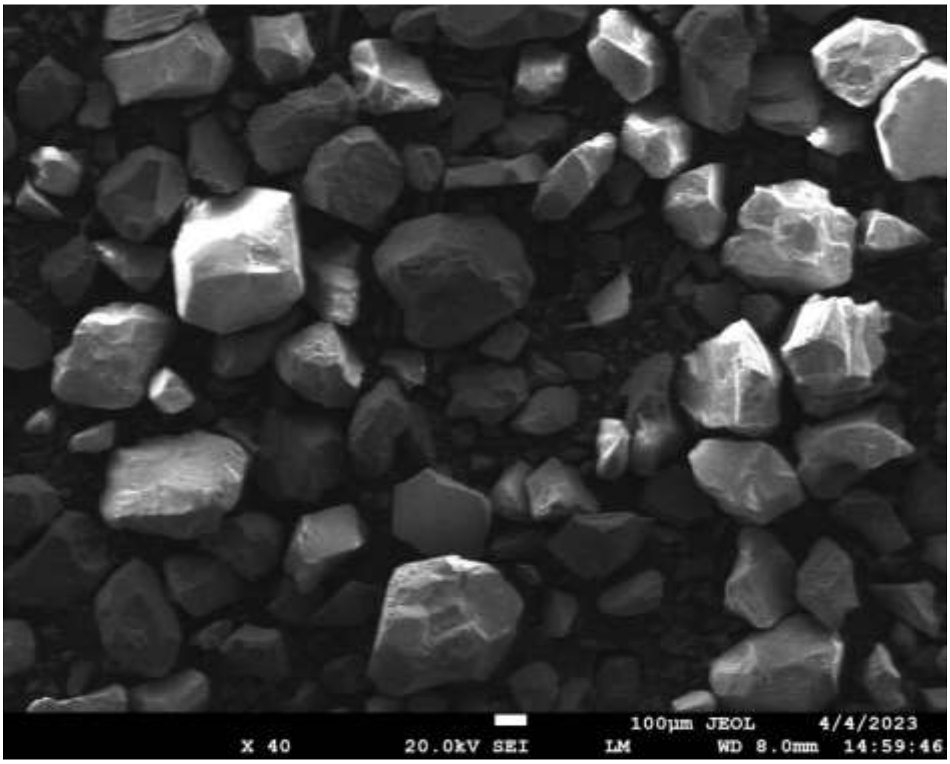


Figure 3.3: SEM image of waste “MD”

The Scanning electron microscope (SEM) is used to analyze the morphology, particle size, and shape of the materials. The waste “MD” has an irregular particle structure and a rough texture (Singh et al., 2017). Similar observations are there for the waste “MD” as shown in Figure 3.3.

3.3.7 Recycled Coarse Aggregate

Recycled aggregate concrete is used from available demolished concrete. Attached mortar has been removed before being used in concrete. Recycled aggregates have been tested for specific gravity, bulk density and water absorption before being used in concrete. The various tests conducted on “RCA” have been shown in **Table *3:11***.

Table 3:11: Characteristics of “RCA”

Material Properties	Specific Gravity	Fineness Modulus	Bulk Density	Type	Grade	Water absorption
Values	2.672	6.146	1382 kg /m^3	Crushed stones	12.5mm	2.31%

Figure 3.4: Coarse aggregates from demolished concrete for “RCA”

3.3.8 Alkali activator solution

For the purpose of this investigation, an alkaline solution was comprised of a combination of sodium hydroxide and sodium silicate. Both of these compounds are now readily available on the market for various commercial applications. The decision was made to employ sodium-based solutions rather of potassium-based ones due to the sodium-based solutions' lower cost. Sodium silicate contributes to the easier dissolution of the components of the binder. Both of the alkalis had industrial grades, and they were obtained from vendors in the immediate area. In the aqueous solution of Na-silicate, the ratio of silicate-oxide to sodium-oxide is 2.

Table 3:12: Physical and chemical properties of Sodium Silicate

Chemical Formula	Na_2O	SiO_2	H2O	Appearance	Molecular Weight	Boiling Point	Specific Gravity	Colour
Na_2SiO_3	14.73 %	29.75 %	55.52 %	Liquid (Gel)	184.04	102°C	1.39	colour-less

To achieve the desired concentration, pellets of sodium hydroxide need to be dispersed in water before the solution is produced. The molar concentration of the sodium hydroxide solution can vary. A solution with a molarity of 10 would contain 10 times 40, means 400 grams of NaOH solids per litre of water when considering the sodium hydroxide solution's concentration. NaOH has a molecular weight of 40, making one mole weigh 40 grams. As a result, there would be 400 grams of NaOH per litre of water in a 10 M (molar) NaOH solution. There are roughly 314 grams of solid sodium hydroxide in every kilogram of sodium hydroxide solution. This suggests that roughly 314 grams of a 1-kilogram solution of NaOH would be made up of NaOH solids as shown in Figure 3.5 and Figure 3.6. The prepared sodium hydroxide solution is processed for a full day before it is combined with another solution containing sodium silicate .

Figure 3.5: Sodium Hydroxide Flakes

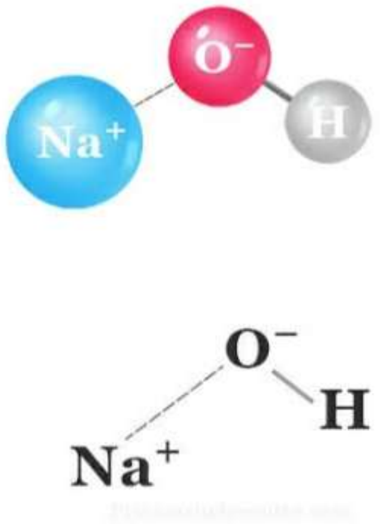


Figure 3.6: NaOH 3D Structure

An alkaline solution is produced by mixing the “SH” and “SS” solutions at room temperature. It is advised to wait 20 minutes before utilizing the mixture since the polymerization process starts interacting with one another as soon as the two components are combined and because of this reaction produces an excessive amount of heat. The researchers discovered that the weight ratio of “SS/SH” solution varied between 2.1 and 2.7 over the duration.

Figure 3.7: Sodium Silicate Solution

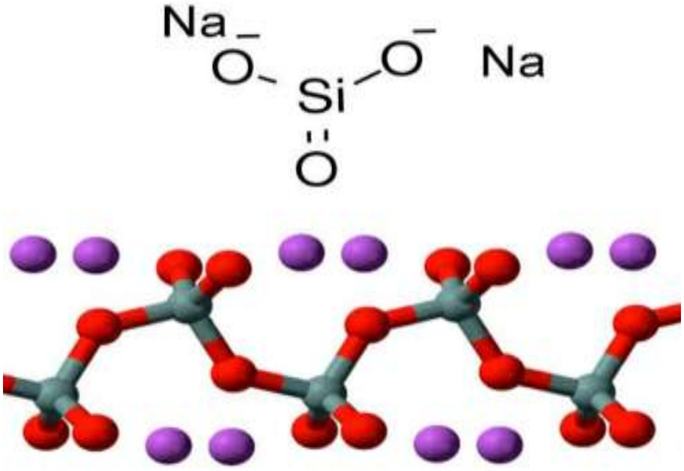


Figure 3.8: 3D Sodium Silicate Structure

3.3.9 Water

In the course of the experiment, potable water was utilized to create an alkaline solution. The workability of “Self-Compacting Geopolymer Concrete “have been also improved by adding more water. Geopolymer is a solid that was taken at 20% of its weight.

3.3.10 Superplasticizer

Superplasticizers based on “Poly carboxylic ether” is represented by procreate SCC. The product was created with high-performance concrete applications in mind, which demand the best performance and durability. It also has no chloride and very little alkali. It can be used with any type of cement.

Figure 3.9: Superplasticizer

Figure 3.10: Polycarboxylate Ether

CHAPTER 4 RESEARCH METHODOLOGY

4.1 General

The methodology adopted for the experimental study has been discussed along with preparation of alkali activator solution. Procedures and images of various test being performed on developed “SCGPC” has been done performed. Workability tests on “SCGPC” such as Slump flow, Slump flow T50, L-Box, V-Funnel and J-ring tests have been conducted and images of the same have been included in the chapter below.

4.2 Methodology

Self-compacting in the realm of building, a cutting-edge substance known as geopolymer concrete is becoming more popular. There is currently no provision in the statutes or regulations governing the design of the mix or the optimization of the material components for “SCGPC”. In the current investigation, the Taguchi method is being used to the task of developing a mix design for “SCGPC“in accordance with the standards established by IS 10262-2019 and “EFNARC- 2005”. The first thing that has to be done in this investigation is to determine the Na_2SiO_3/NaOH, as well as the molarity of sodium hydroxide solution, taking into account both its fresh and its hardened states. And the next stage is to identify optimum partial substitution of “Flyash” with “GGBFS” in order to attain permissible workability behaviour and strength behaviour. Further, replacement of sand with MD and coarse aggregate with “RCA” is studied for workability and strength behaviour.

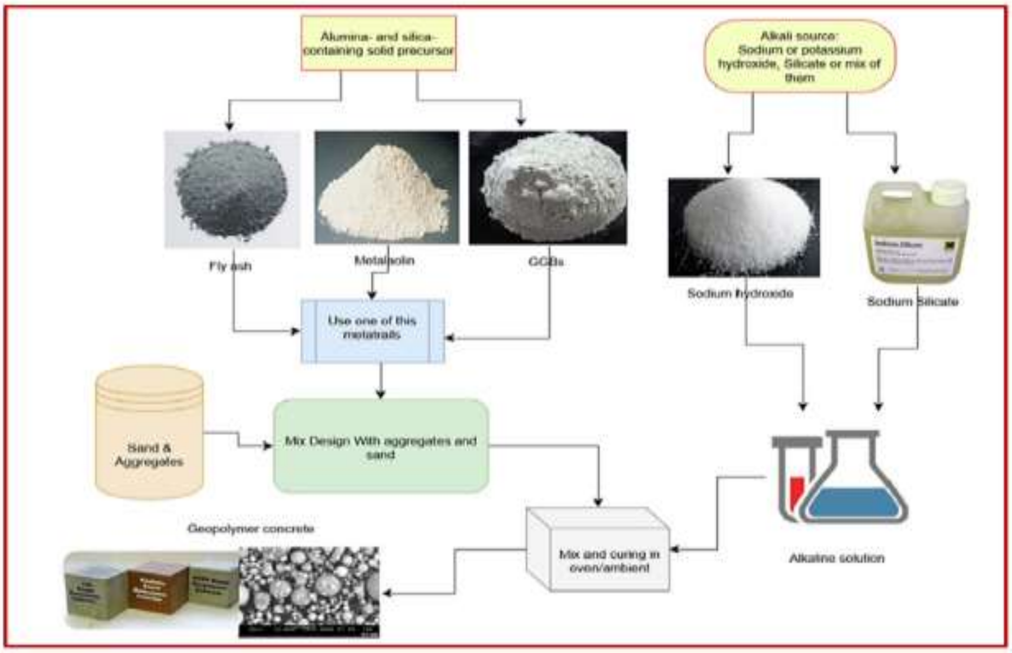


Figure 4.1: Pictorial Representation of Methodology

Based on strength behaviour, durability behaviour has been studied for optimized mix. The very last thing that has to be done is to compare the prices of producing conventional concrete and “Self-Compacting Geopolymer Concrete “.

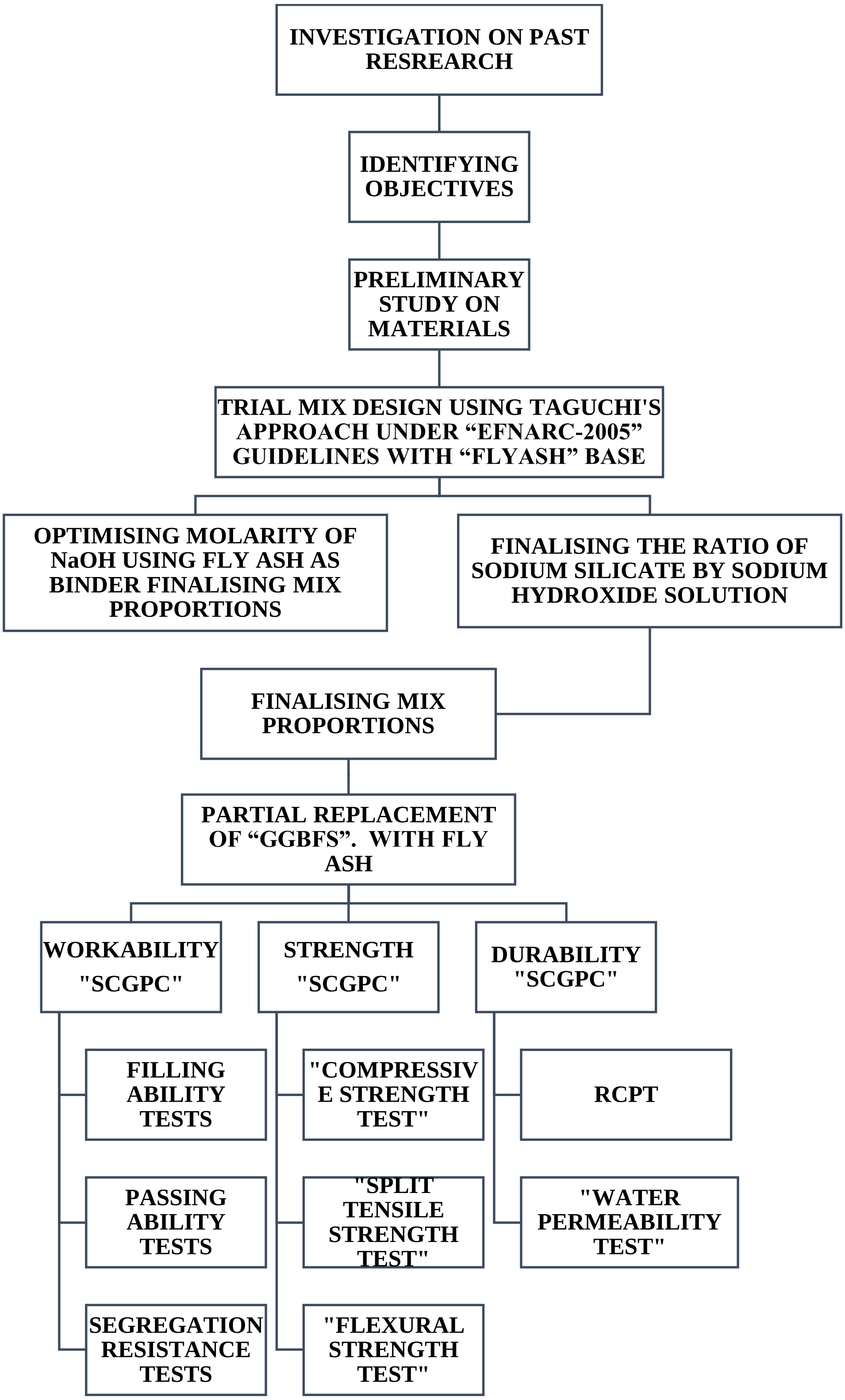


Figure 4.2: Graphical Representation of Methodology

4.3 Trials for “SCGPC” development

There are no set guidelines till now for development of geopolymer concrete. Hence trials have been prepared corresponding to selected binders and alkali activators with “EFNARC-2005” guidelines of SCC. The following specifications are used in development of “SCGPC”. Water to geopolymer solids (W/G’s) ratio by mass for all the mixes was maintained at 0.23 binder content was fixed at 440 kg/m^3. An extra H_2O of 20% and Polycarboxylate ether of 5% by binder mass was utilised for workability 0.45 ratio of AAS/B was kept constant. As per above discussions, twelve different mix proportions have been prepared under four different groups. In first group, “Flyash” Class F was taken as sole binder, but the concentration of NaOH was taken from 10M, 12M and 14M respectively with Na_2SiO_3/NaOH variation from 2.1 to 2.5. Once the sodium hydroxide concentration and ratio were optimised, “GGBFS”, a different binder, was attempted both wholly and partially at different molarities of NaOH as shown in Table 5.1. Chapter 5 goes into great detail about the percentages of the “SCGPC” mix and the ingredients.

4.4 Preparation, casting and curing of specimen

The mixing process was split into two stages. Initially, fine aggregate, coarse aggregate in saturated surface dry condition (SSD) and binder (“GGBFS” and “FA”) were mixed in concrete mixer for 2.5 minutes. After dry mixing, premixed liquid mixture, containing alkaline solution, superplasticizer and extra water was added in the concrete mix, and wet mixing continued for 3 minutes. To ensure uniformity in the mix, fresh “SCGPC” was mixed further 2 to 3 minutes.. As per “EFNARC-2005” guidelines, tests on workability were carried out to check the fresh properties of “SCGPC”. Casting of specimens is performed after completing the fresh properties test of “SCGPC”. For 7-day, 14-day and 28-day mechanical strength properties, cubes of 150 mm x 150 mm x 150 mm , . cylinders of 150 mm diameter and 300 mm height and prisms of 150 mm x 150 mm x 700 mm were cast for each mix proportion. The specimens after 24 hrs and placed at room temperature till testing.

4.5 Alkaline activator solution preparation

The polymerization of aluminosilicates depends on the alkaline activators. The quantity of sodium hydroxide in the alkaline solution depends on its concentration .

For 1M (one molar solution):

Quantity of NaOH pellets required = 1 x 40 = 40 g where 40 is the molecular weight of NaOH

Quantity of water required =1000ml

Thus 40 grams of NaOH pellets and 1000ml of water make 1 molar concentration of NaOH solution.

For 1 kg 12molar sodium hydroxide solution:

Quantity of NaOH pellets required = 12 x 40 = 480 g

Quantity of water required = 675.67ml

Therefore, an alkaline activator solution is prepared by mixing both NaOH and Na_2SiO_3 solutions. The NaOH solution is added constantly and slowly by thorough mixing so that a homogeneous solution mix is formed. A large amount of heat is evolved during the preparation of sodium hydroxide. Sodium hydroxide solution is prepared one day before casting the specimens.

4.6 Fresh properties of the “SCGPC” concrete

The evaluation of the fresh attributes of “SCGPC” mixes was based on the following three primary features of SCC:

Ability to fill : The ability to flow by itself into confined areas without outside assistance. Because of its own weight, SSC moves on its own.

Ability to pass: Ability to pass through congested space between reinforcing bars.

Resistance to segregation: The potential of SCC to resist or remain stable in the face of segregation is one of its most essential properties. In essence, to keep its consistency and uniformity throughout the mixing, transporting, and placing processes.

The experiments were carried out using the equipment that was readily accessible in the research facility. The next part provides an overview of the tests that have been discussed below.

4.7 T_{50}cm Slump Flow

This is the test that is the least complicated and the one that is used the most often for determining the SCC's capacity for flow and filling. The conventional slump test is used as the primary piece of testing apparatus in order to carry out the test. The Slump cone was put down on a levelled surface that was hard, non-absorbent, and firm. After the concrete has been mixed, it is poured into the cone without being tamped and then elevated vertically so that it may flow freely out. The amount of time, in seconds, that elapses between the lifting of the cone and the point at which the flow spread reaches a circle with a diameter of 500 mm is measured. This flow time is referred to as T_{50}cm. A quicker time suggests an increased capacity for flow. It is important to point out that.

In comparison to mixtures with shorter T_{50}cm durations, excessively viscous mixtures will have T_{50}cm timings that are less relevant and maybe more unpredictable.

Figure 4.3: Slump Flow Test

Figure 4.4: Slump Flow Table

4.8 Slump Flow Test

The same slump cone is used for both the measurement and the flow testing of the slump. This is a typical and straightforward test that may be used to evaluate the filling capacity of SCC. At the time of carrying out the slump T_{50}cm test, the concrete is allowed to flow freely and the diameter of the concrete in two directions that are perpendicular to one another is measured when flow has come to a complete halt. The dimensions that were measured twice each had their averages recorded. SCC should have flowability as per guidelines of "EFNARC-2005".

4.9 J-Ring Test

The capacity of "SCGPC" concrete to pass the J-ring test was evaluated using this particular test. It is appropriate for use in the laboratory for evaluating the ability of various concrete mixes to pass, and it is also appropriate for use in the field as a quality control test.

Figure 4.5: Slump Flow measurement

Figure 4.6: J Ring Test

4.10 V- Funnel Test

It is used most often to check the filling ability (flow ability) of SCC, and the segregation resistance of the material. A funnel in the form of a V was used as the instrumentation for this test. In order to carry out this test, you will require around 12 litres of concrete, and the funnel will need to be entirely stuffed with the material before it is tapped or compacted. After the funnel has been filled with concrete, the trap door at the bottom is opened, and the concrete is permitted to pour out under the force of gravity. The time consumed for the concrete to flow out through the opening in its entirety is what is referred to as the V-funnel flow time. In most cases, a funnel flow time that falls between 6 and 12 seconds is desirable for SCC.

Figure 4.7: V-Funnel Test

4.11 L-Box Test

The potential of SCC to fill and pass the L-box was evaluated with the help of this test. This is a very common test that may be performed in a lab or on site. It's versatile like that. The L-box is made up of a box with a rectangular portion that is shaped like an L. This box has a vertical part and a horizontal segment that are divided by a moveable gate. In front of this gate, vertical reinforcing bars are attached. Before beginning the test, the L-box was positioned on ground that was levelled and hard, and the inside surfaces of the box were sprayed with water. After that, the concrete was poured into the vertical chamber of the box, and then the gate that was isolating the vertical and horizontal segments was lifted. This allowed the concrete to move through the densely packed reinforcing bars at the bottom of the box and into the horizontal chamber. After the flow of concrete has been halted, the level of the concrete that has reached the end of the horizontal part is indicated as a percentage of that which is still present in the vertical section.

Figure 4.8: L-Box Test Apparatus

4.12 Tests for Hardened properties of developed concrete

In order to examine the fluctuation of strength parameters, a number of hardened characteristics were tested. These includes “Compressive strength”, “Split tensile strength”, and beam “Flexural strength”. Cube specimens with dimensions of 150 by 150 by 150 millimetres, cylinders with dimensions of 100 by 200 millimetres, and prism beams with dimensions of 100 by 100 by 500 millimetres were each created for the purpose of testing the material's “Compressive strength”, “Split tensile strength”, and “Flexural strength”, respectively. The initial strength of specimens was tested after seven days, fourteen days, and twenty-eight days in order to determine the variance in how the strength developed initially. For the purpose of illustrating the hardened qualities of compression, flexure, and tension, the phrases “Compressive strength”, beam flexure, and “Split tensile strength” were used, respectively. IS 516-1959 requirements were used for compression and flexural testing, whereas IS 5816-1999 specifications were used for split tensile testing. Specimen preparation and testing were carried out in accordance with these standards.

Figure 4.9: Testing Samples

Figure 4.10: 100% “GGBFS” Samples

4.13 Compression test

The compression test is a standard test that is performed on hardened concrete in order to get an understanding of how the most desired characteristic features of concrete are qualitatively connected to the material's “Compressive strength”. The compression test was performed on cubes of dimension 100 millimetres by 100 millimetres by 100 millimetres utilising a 3000 kilonewton compression testing equipment at a constant rate of loading 140 kilogrammes per square centimetre per minute until failure. The configuration of the test may be seen in Figure 4.11. Experiments were performed on triplet specimens for each possible combination, and the formula for calculating the average stress was as follows:

“Compressive strength” (MPa) = Maximum load / Cross section area of the cube.

Figure 4.11: Compression Testing Machine

Figure 4.12: Fractured samples after compression

4.14 “Split tensile strength” test.

A cylinder of 100 millimetres in diameter and 200 millimetres in depth was used for the test. The average “Split tensile strength” values of each mix were determined after three specimens were manufactured for each mix. The cracking that was detected was in the form of a tension failure.

“Split tensile strength” in MPa = $2P/\pi DL$

Where, P = compressive load (N)

L = length of specimen (mm)

D = Diameter of specimen (mm)

Figure 4.13: Split Tensile Test

Figure 4.14: Tested cylinder

4.15 Flexural test

The test specimen is a prism with dimensions of 500mm by 100mm by 100mm, and the setup for the test is shown in Figure 16, the two-point loading mechanism is applied to the top of the specimen. Triplet specimens were created for each possible combination, and the method for calculating the average “Flexural strength” is as follows:

“Flexural strength” in MPa = PL/2bd

Where, P = Load in N

L = Length in mm, b = breadth in mm, d = Depth in mm

Figure 4.15: Flexural test

Figure 4.16: Prism Specimens

4.16 Tests for Durability behaviour of concrete

4.16.1 Rapid Chloride Penetration Test RCPT:

Rapid Chloride Penetration Test (RCPT) Chloride Penetration of optimum mix of concrete is checked using Rapid Chloride Penetration Test which is performed in accordance to standard (ASTMC1202, n.d.). The specimens of G100, G100M15, G100M30 and G100M15R15 are prepared as cylinders of 100 mm diameter and 200 mm depth which are further spliced in samples of depth 50 mm. The obtained samples are then placed in vacuum saturator and the air voids are replaced with water particles as shown in Figure 4.17. The vacuum saturated samples are placed in mould of RCPT apparatus and sealed with silicone sealant as shown in Figure 3.18. The moulds are filled with NAOH solution of 0.3 molarity strength provided in positive diode, NACL solution with 3% strength provided in negative diode and tested by passing a current of 60 V DC. The current passed in sample is obtained in milli-amperes and the current passed is noted after 30 minutes duration till 6 hours. The result is tabulated in Table 5**:*17*** and average charge passed is calculated in Coulombs. The results obtained are compared with the standards of ASTM C1202.

Figure 4.17: Specimen set for RCPT

4.16.2 Water Permeability test

Water permeability test on 28 days cured concrete samples is conducted as per BS EN 12390-8 and DIN 1048 Part 5. A constant hydrostatic pressure is applied for 72 hours. After three days, the samples are removed from the testing apparatus, cracked in half vertically and maximum depth of water penetration measured.

Figure 4.18: Specimen set for water permeability test

Figure 4.19: Specimen checked for water permeability test

CHAPTER 5 OBSERVATIONS AND DISCUSSION

5.1 General

The observed results of the experimental work have been discussed. Effect of various parameters have been discussed on workability and strength behaviour of various mixes developed for “SCGPC” have been included in the chapter below. The key findings are -

Concrete mix G100M30 is the most reliable choice for applications requiring long-term strength since it consistently displays the highest “Compressive strength” at all testing periods (7-day, 14-day, and 28-day) with conditions just fulfilled to satisfy the self-compacting behaviour, compromising for durability behaviour.

“Flyash” based “SCGPC” for optimizing Molarity of NaOH and ratio of sodium silicate to sodium hydroxide

“SCGPC” mix with a particular binder show varying behaviour at different molarities of NaOH and varying ratio of silicate of sodium to NaOH. Hence, to optimize the molarity of NaOH “SCGPC” is developed using “Flyash” as binder. Table 5.1 shows the designation of mix prepared and selected composition of the constituents of developed “SCGPC”. Ratio of Sodium silicate to sodium hydroxide is varied as 2.1, 2.3, 2.5 and 2.7 with Molarity of NaOH as 10, 12 and 14 for each variation at constant dose of superplasticizer as 3%.

Table 5.1: Mix proportion of “Flyash” based SCGPC for varying sodium silicate by sodium hydroxide solution ratio in Kg/m^3

Mix code	Flyash	Fine aggregate	Coarse aggregate	AA/B ratio	NaOH sol.	Na_2SiO_3	Molarity	SP %
2.1F10	450	910	835	0.45	65.32	140.18	10	3
2.1F12	450	910	835	0.45	65.32	140.18	12	3
2.1F14	450	910	835	0.45	65.32	140.18	14	3
2.3F10	450	910	835	0.45	61.36	141.14	10	3
2.3F12	450	910	835	0.45	61.36	141.14	12	3
2.3F14	450	910	835	0.45	61.36	141.14	14	3
2.5F10	450	910	835	0.45	57.85	144.65	10	3
2.5F12	450	910	835	0.45	57.85	144.65	12	3
2.5F14	450	910	835	0.45	57.85	144.65	14	3

2.7F10	450	910	835	0.45	54.73	147.77	10	3
2.7F12	450	910	835	0.45	54.73	147.77	12	3
2.7F14	450	910	835	0.45	54.73	147.77	14	3

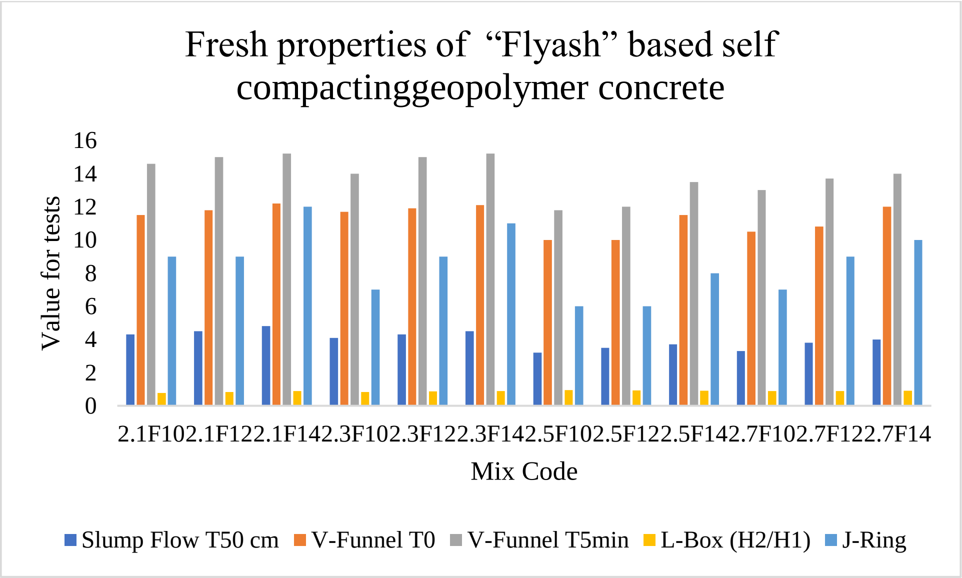
Note: Mix code to be read as ratio of Na_2SiO_3/NaOH -binder base- Molarity of NaOH, e.g. 2.1F10 shows ratio of sodium silicate to sodium hydroxide as 2.1 with binder as “FA”and 10 Molarity of NaOH

Workability and strength behaviour of prepared “SCGPC” has been tested. For checking the flowability and passingability and segregation resistance of the prepared “SCGPC”, Slump flow, slum flow T_{50}cm, V-funnel, V-funnel T5min, As per Table 5.2 Mix code 2.5F10 and 2.5F12 show equally good behaviour for workability of “SCGPC” whereas as listed in Table 5.3, strength behaviour of 2.5F12 is better than 2.5F10. Graph 5.1 and Graph 5.2 shows the Workability and strength behaviour of “SCGPC”. As per the observation of Table 5.2, As the Molarity of NaOH is increasing from 10 to 14, workability tends to decrease. Similar trend has been seen for increasing ratio of Na_2SiO_3/NaOH. Strength behaviour for Mix 2.5F12 is best with reference to other mix hence, 2.5 Na_2SiO_3/NaOH and 12 molarity of NaOH is selected for further testing of “SCGPC”.

Table 5.2: Workability behaviour of various mix codes based on Flyash

Mix code	Slump Flow (micrometers) (550-850)	Slump Flow T_{50} cm (sec.) (2 to 5)	V-Funnel T_0 (sec.) (8-12)	V-Funnel T_{5min} (sec.) (+3)	L-Box (H2/H1) (ratio) (0.8-1)	J-Ring (mm) (0-10)
2.1F10	0.691	4.3	11.5	14.6	0.78	9
2.1F12	0.678	4.5	11.8	15	0.82	9
2.1F14	0.665	4.8	12.2	15.2	0.88	12
2.3F10	0.695	4.1	11.7	14	0.83	7
2.3F12	0.685	4.3	11.9	15	0.86	9

2.3F14	0.672	4.5	12.1	15.2	0.88	11
2.5F10	0.71	3.2	10	11.8	0.94	6
2.5F12	0.710	3.5	10	12	0.92	6
2.5F14	0.692	3.7	11.5	13.5	0.9	8
2.7F10	0.705	3.3	10.5	13	0.88	7
2.7F12	0.692	3.8	10.8	13.7	0.88	9
2.7F14	0.685	4	12	14	0.9	10

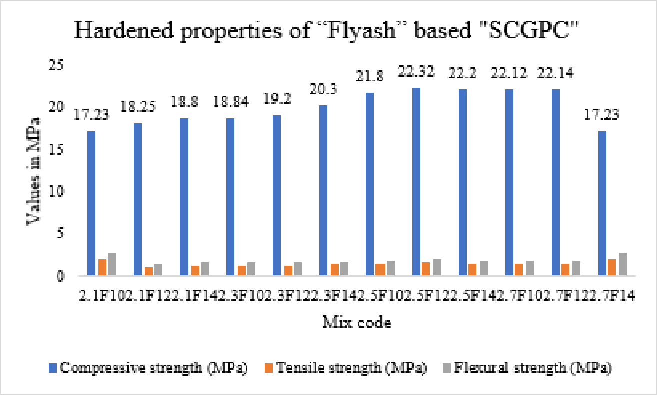


Graph 5.1: Result for workability behaviour of various mix codes

Table 5.3: 28- day Strength behaviour of “SCGPC” based on “Flyash” in MPa

Mix code	**“Compressive strength”**	**“Split tensile strength”**	**“Flexural strength”**
2.1F10	17.23	2.06	2.75
2.1F12	18.25	1.05	1.53
2.1F14	18.8	1.21	1.58

2.3F10	18.84	1.28	1.6
2.3F12	19.2	1.37	1.64
2.3F14	20.3	1.4	1.75
2.5F10	21.8	1.53	1.82
2.5F12	22.32	1.6	2
2.5F14	22.2	1.5	1.94
2.7F10	22.12	1.46	1.87
2.7F12	22.14	1.49	1.93
2.7FG4	17.23	2.06	2.75



Graph 5.2: Result for hardened properties of “Flyash” based “SCGPC “

5.2 Trials for “GGBFS” based “SCGPC” blended with “Flyash”

After optimizing the molarity of NaOH as 12 and ratio of Na_2SiO_3/NaOH as 2.5 further trials have been performed on “GGBFS” as single binder at varying molarities (8, 10,12,14) and blended binder with “Flyash”. It has been observed that “GGBFS” as only binder, the workability in the manner of slump flow and L- box retards as the mix become firm. The fast rate of setting and accelerated geopolymeric reaction due to “GGBFS” being more reactive being in amorphous state in “SCGPC”. Also, the workability tends to lower due to irregular shaped “GGBFS” particles. The observations of “SCGPC” are shown in Table 5.5. It was observed, a rise in the concentration of NaOH in alkaline solution results reduction of flowability and passing ability of “SCGPC” mixes. By using fly ash as a secondary binder, workability improves due to its round shape particles and less reactive as compared to “GGBFS”. The workability results were impacted due to “GGBFS” as a binding material. Though as per Table 5.5 all the mix id except 14G100 is showing satisfactory behaviour in workability as per “EFNARC-2005”. Mix 14G100 fails to pass V-funnel test as the observed value is 13 seconds where permissible limits are 8-12 seconds. Flowability, passingability and segregation resistance are found to be within the permissible limits for rest of Mixes.

Table 5.4: Mix proportions of “GGBFS” and “Flyash” based “SCGPC” in Kg/m^3

Mix ID	Molarity (M)	“GGBFS”	“Fly Ash”	Fine Aggregate	Coarse aggregate	“SH”	“SS”	Super plasticizer(%)
8G100	8	440	-	920	840	56.57	141.43	5
10G100	10	440	-	920	840	56.57	141.43	5
12G100	12	440	-	920	840	56.57	141.43	5
14G100	14	440	-	920	840	56.57	141.43	5
12G75F25	12	330	110	920	840	56.57	141.43	5
12G50F50	12	220	220	920	840	56.57	141.43	5
12G25F75	12	110	330	920	840	56.57	141.43	5
12G0F100	12	-	440	920	840	56.57	141.43	5

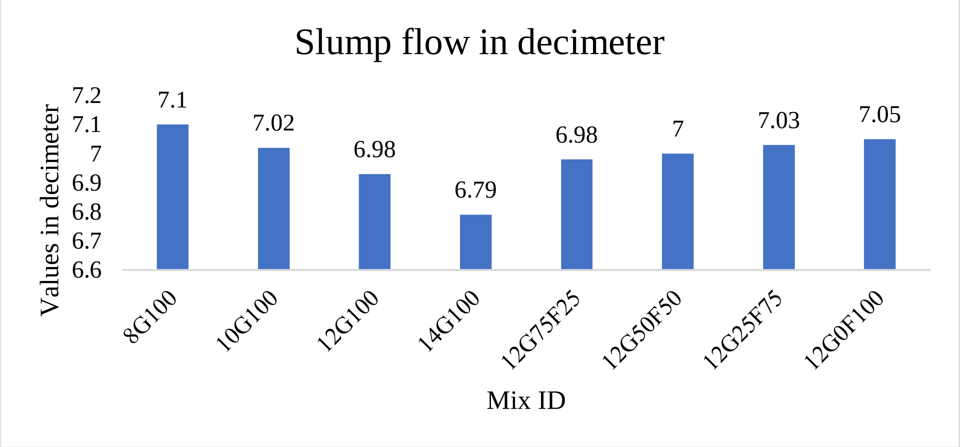
Note: Mix Id to be read as Molarity-binder-percentage of binder, e.g. 12G7525 represents 75% “GGBFS” 25% “Flyash” and 12 M NaOH solution for “SCGPC”

Table 5.5: Fresh properties of “GGBFS” and “Flyash” based “SCGPC “

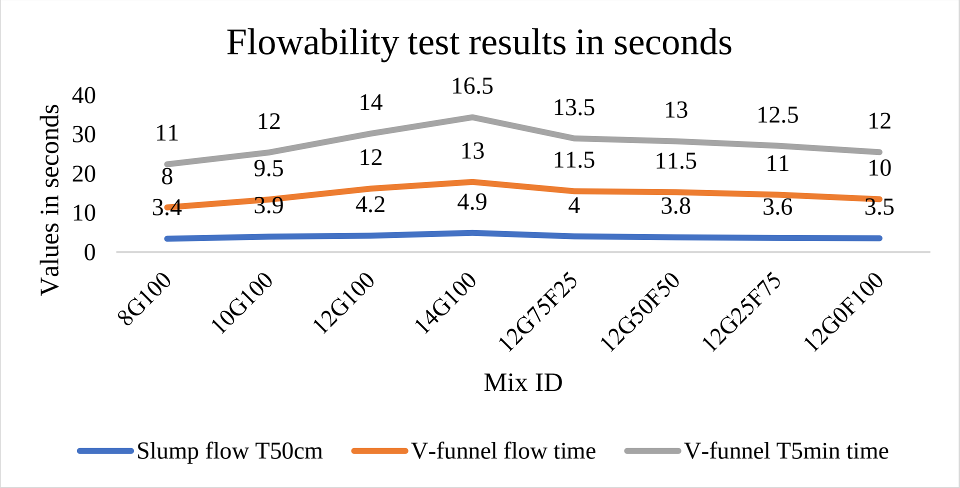
Mix ID	“Slump-flow” (dm)	T”$_{50}$cm Slump flow”(sec)	“V-funnel flow time” (sec)	V-funnel T_{5min} time (sec)	L-box (H_2/H_1)	J-Ring 0test (mm)
8G100	7.10	3.4	8	11	0.95	3
10G100	7.02	3.9	9.5	12	0.92	5
12G100	6.98	4.2	12	14	0.93	5
14G100	6.79	4.9	13	16.5	0.86	7
12G75F25	6.98	4	11.5	13.5	0.91	6
12G50F50	7.00	3.8	11.5	13	0.92	6
12G25F75	7.03	3.6	11	12.5	0.92	5
12G0F100	7.10	3.5	10	12	0.93	4

5.3 “Slump Flow and T_{50}cm Slump Flow Test Results”

Table 5.5 and Graph 5.3 depicts the workability of various “SCGPC” mixes. As per “EFNARC-2005” guidelines, concrete having superior filling ability if the slump flow value lies between 650 mm to 800 mm. A 710 mm slump flow value was noted for the control mix 8G100F0. Lowest slump 679 mm was noted for the mix proportion 14G100F0 at 14M molarity. “SCGPC” mix viscosity increase as NaOH molarity increases from 8 to 14 molar, lowering flowability and finally leading to slump flow value. The test results of the T_{50}cm slump flow test for different “SCGPC” mixes are presented in Table 5.5. Time was also monitored for the concrete mix to reach up to a 500mm slump flow during the slump flow test. A lesser flow time of “SCGPC” mix shows the good flowability as per “EFNARC-2005” guidelines. Range for T_{50}cm slump flow test lies between 2 to 5 seconds. A minimum T_{50}cm slump flow time of 3.4 sec was noted for 8G100F0. While as longest time of 4.9 sec was recorded for 14G100F0 to reach 500mm diameter.



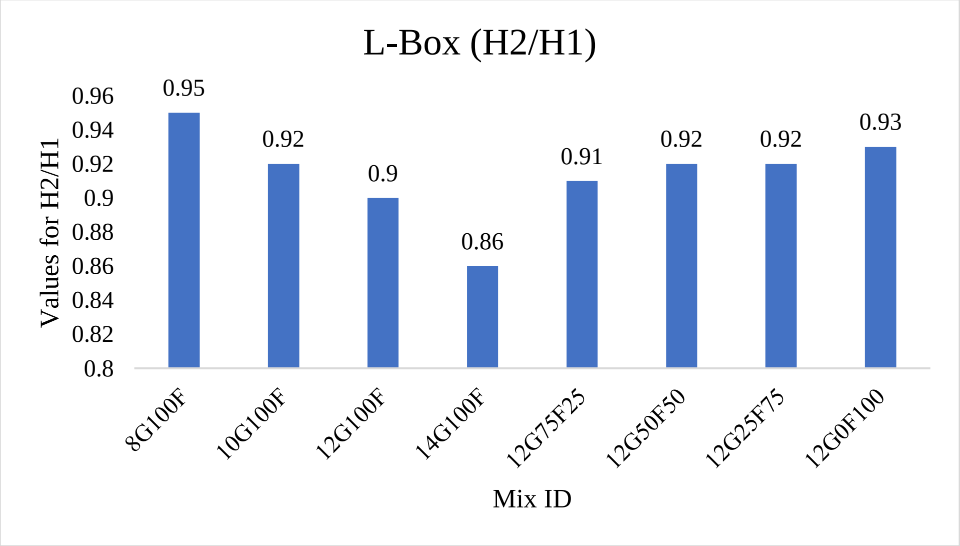
Graph 5.2: Slump Flow Graph



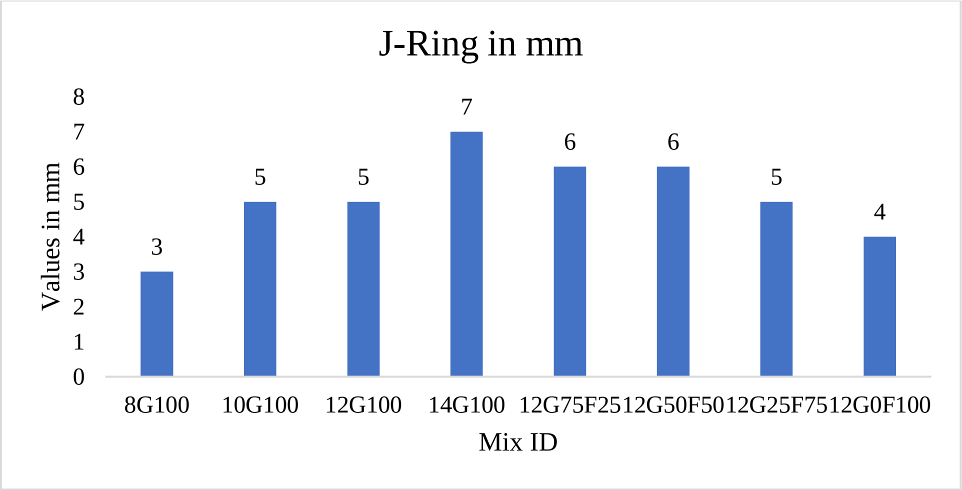
Graph 5.3: Slump flow T_{50}cm, V-funnel and V-funnel T5 min

5.3.1 V-Funnel Flow and V-Funnel T_{5MIN} test results

The flowability and stability of “SCGPC” mixes were evaluated with the help of V-funnel flow and V-funnel T_{5min} tests. The outcome of the V-funnel flow test and the flow time for the V-funnel T_5min are presented in Graph 5.3 and Table 5.5. The standard range of V-funnel flow values is 6–12 sec, according to “EFNARC-2005” guidelines. The V-funnel test is used to assess whether concrete mixes can be filled, while the V-funnel T_5min test is used to check segregation resistance of flowable concrete. For the 8G100 mix has least flow time of 8 secs. For mix 14G100 has flow duration of 13 secs. As the % of sodium hydroxide rose, the “SCGPC” concrete mix's flowability and fluidity dropped resulting in an increase in flow time. However, as the fly ash content increases, the flowability gets better. Additionally, the V-funnel T5min test showed that the least value for 8G100 of 11 seconds. In contrast has highest flow duration of 16.49 secs for 14G100.



Graph 5.4: L-Box Test (H2/H1)



Graph 5.5: J-Ring test

5.3.2 "L-Box and J-ring Test "

The filling and passing of "SCGPC" mixes were accessed with the help of L-box and J-ring tests. The outcomes of the L-box test and J-ring depicted in Table 5.5, Graph 5.4 and Graph 5.5. A concrete mix is counted as good mix in terms of filling and passing ability if the L-box ratio lies between 0.8 and 1.0 as per "EFNARC-2005" guidelines. It was noted, L-box decreases with increase in concentration of sodium hydroxide from 8M to 14M. But it increases with increase in the percentage of fly ash content. The highest L-box ratio of 0.95 for mix 8G100 of 8M sodium hydroxide concentration and lowest 0.86 for mix 14G100 of 14M NaOH concentration was recorded. Also, the standard range of J-Ring test is 0-10 mm as per "EFNARC-2005" guidelines. The J-Ring value of all the "SCGPC" mixes were within the standard limits of "EFNARC-2005". The lowest value of 3 mm was documented for mix 8G100F0 and highest value of 7 mm for mix 14G100. As the concentration of sodium hydroxide rises from 8M to 14M, passing ability of "SCGPC" concrete mix retards and hence upsurge in the J-Ring value was recorded.

5.4 Hardened properties of "SCGPC"

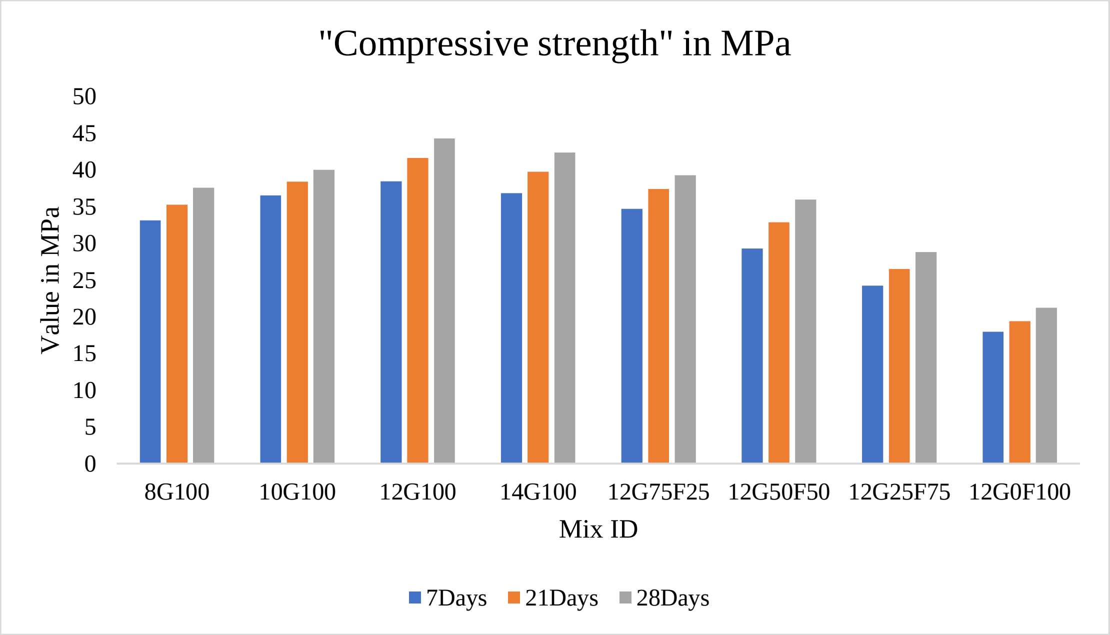
To evaluate the hardened properties of "SCGPC", tests like "Compressive strength" test, "Split tensile strength" test and "Flexural strength" test were performed. The code used for testing the "SCGPC" specimens was IS 516-1959. The outcomes of hardened properties of "SCGPC" are shown in Table 5:***6***. 12G100 mix of 12M concentration of sodium hydroxide with “GGBFS” as sole binder shows the best result in terms of hardened properties than other mix proportion

Table 5:6: Hardened properties of “Self-Compacting Geopolymer Concrete “

Mix	“Compressive strength” (MPa)			“Split tensile strength” (MPa)			“Flexural strength” (MPa)		
	7Days	14Days	28Days	7Days	14Days	28Days	7Days	14Days	28Days
8G100	33.12	35.25	37.57	2.30	2.43	2.58	2.73	2.84	2.90
10G100	36.54	38.43	40.04	2.43	2.72	2.81	2.86	2.94	3.03
12G100	38.45	41.63	44.28	2.71	2.94	3.09	2.95	3.05	3.28
14G100	36.83	39.75	42.36	2.54	2.79	2.95	2.91	3.01	3.12
12G75F25	34.69	37.42	39.27	2.37	2.62	2.77	2.82	2.89	3.00
12G50F50	29.32	32.88	35.95	2.30	2.38	2.45	2.54	2.67	2.80
12G25F75	24.25	26.52	28.81	2.06	2.19	2.27	2.28	2.41	2.52
12G0F100	17.95	19.39	22.32	1.52	1.57	1.6	1.85	1.92	2.00

5.5 “Compressive Strength”

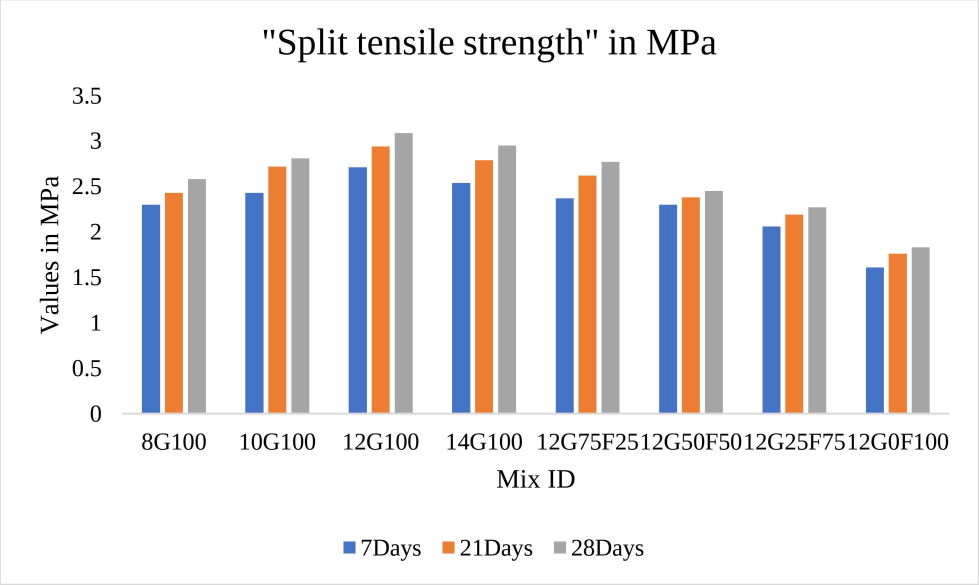
NaOH is important to stimulate the alumino-silicate based mineral to create geopolymer concrete. It plays a crucial role in dissolution part and in binding of solid particles. The rise in concentration of NaOH improves the solubility of alumino-silicate constituents. With increasing the concentration of Sodium Hydroxide, bond process increases which further upsurges the “Compressive strength” of “SCGPC”. This is due to the quicker dissolving of alumina and silica from the precursor into the solution, which aids in the creation of higher volumes of alumino-silicate polymeric gel, which speeds up the geopolymerisation process. The “Compressive strength” of “SCGPC” specimen increased with increasing NaOH molarity from 8 M to 12 M and reduced with increasing NaOH molarity beyond 12M. Graph 5.6 depicts the “Compressive strength” of all the “SCGPC” mixes. 12G100 mix of 12M molarity of NaOH attained utmost "Compressive strength" 12G100 that there was an upsurge in "Compressive strength" from 8M to 12M of sodium hydroxide but retarded from 14M molarity of sodium hydroxide for all days of testing. It was 10.32%, 16.09%, and 11.2% increase in strength in compression of 10G100, 12G100 and 14G100 mixes with compared to compression behaviour of 8G100F0 at 7 days. Similarly for 28 days, it was 6.567%, 17.849%, and 12.266% raise in "Compressive strength" of 10G100F0, 12G100F0 and 14G100F0 mixes with compared to "Compressive strength" of 8G100F0. While in case of blending "GGBFS" with fly ash, strength tends to reduce in compression as "FA" increases. It was 39.267MPa, 35.905MPa, 28.809 MPa and 21.23MPa "Compressive strength" of mixes 12G75F25, 12G50F50 and 12G25F75 and 12G0F100 respectively at 28 days. It is due to lower alumina content and insufficient polymerization.



Graph 5.6: "Compressive strength" graph

5.6 "Split tensile strength"

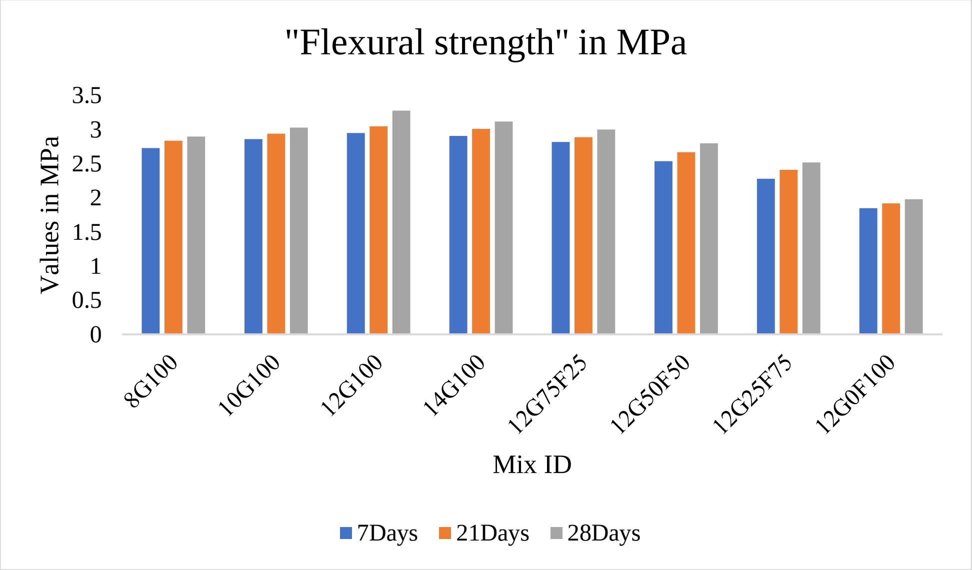
The "Split tensile strength" outcomes of "SCGPC" mixes are depicted in Figure 32. It improves with the age of "SCGPC" in all mixes. After 28 days of ambient curing, the "SCGPC" mix 12G100 attained highest "Split tensile strength" of 3.09MPa. At 7, 21, and 28 days, respectively, the "Split tensile strength"of control mix 8G100F was observed at 2.3, 2.43, and 2.58 in 0 MPa. For mix 12G100F0, the percentage increase in strength was 14.01% from 7 to 28 days at ambient curing; while, for reference mix 8G100, the percentage increase in "Flexural strength" was 12.17%. In contrast to the controlled mix 8G100F0, Graph 5.7 explains the percentage rise of “Split tensile strength” at 28 days for “SCGPC” mixes 10G100, 12G100, and 14G100, those are 8.91%, 19.76%, and 14.34%. “Split tensile strength” was shown to decrease as fly ash percentage rises in the case of a combined binder (fly ash and “GGBFS”). The “Compressive strength” of mixes 12G75F25, 12G50F50, 12G25F75, and 12G0F100 after 28 days of ambient curing. The geopolymerization causes a quick rise in “Split tensile strength” during the first 7-days, owing to high heat of hydration of the calcium hydroxide content of “GGBFS”, causes a quick percentage rise in “Split tensile strength” during the first 7-days. It shows that early C-S-H and geo-polymeric gel precipitation allowed for the majority of the strength in the fly ash and “GGBFS” based “SCGPC” to be attained in 7 days.



Graph 5.7: “Split tensile strength” graph

5.7 “Flexural Strength”

Graph 5.8 displays the behaviour in flexure of “SCGPC” mixtures with varying percentages of fly ash and NaOH concentrations. Increases in sodium hydroxide concentration from 8 to 12 molar improved the “Flexural strength” of “SCGPC”, but at 14 molar, the strength tends to decrease in compression. As excess hydroxide ions retard geo-polymerization at high sodium hydroxide concentrations (14M), the increase in geo-polymerization rate is the cause. Fly ash is used to reduce “Flexural strength” since it contains less Al_2SiO_3, but it generally makes the “SCGPC” mix more workable. The trend shows reduction in “Flexural strength” with rise in “FA” content. Whereas with age it tends to rise. 12G100F0 mix gains highest “Flexural strength” of 3.28 MPa in 28-days and the lowest was noted in the 12G0F100 mix of 1.98 MPa. The “Flexural strength” of 8G100F0 of 2.73, 2.84 and 2.90 MPa was observed at 7, 21 and 28 days respectively. The percentage increase of 11.18% was observed from 7-days to 28-days of ambient curing for mix 12G100F0. It was examined that the “Flexural strength” tends to reduce with “FA” rise from 25% to 75%. It might be due to differential solubility of “GGBFS” and “FA” tending to poor geopolymerization or due to rise in SiO_2/ Al_2O_3.



Graph 5.8: “Flexural strength” graph

5.8 Blending of “GGBFS” based “SCGPC” with “MD”

After observing the strength behaviour of trials on “GGBFS” and Fly ash at 12M NaOH solution and 2.5 ratio of Na_2SiO_3 to NaOH, compatible workability is achieved with appreciable strength for 12G100F0. Based on the observation 12G100F0 is used as a base to test partial replacement of “MD” with fine aggregate (15%, 30%, 45%, 60%) at optimized 12M NaOH with ratio of Na_2SiO_3 to NaOH as 2.5. The workability and strength behaviour of mix proportions mentioned in Table 5:*7* are listed in Table 5:*8* and Table 5:*9* and graphical presentation is given in Graph 5.9 to Graph 5.15.

Table 5:7: Mix proportions of “GGBFS” based “SCGPC” blended with “MD” at 12M of NaOH

Mix ID	**Fly - ash (Kg/m^3)**	**“MD” (Kg/m^3)**	**Fine Aggt. (Kg/m^3)**	**Coarse Aggt. (Kg/m^3)**	**NaOH (Kg/m^3)**	**Sodium Silicate (Kg/m^3)**	**Super plasticizer (%)**
G100	440	-	920	840	56.57	141.43	6
G100M15	440	138	782	840	56.57	141.43	6
G100M30	440	276	644	840	56.57	141.43	6
G100M45	440	414	506	840	56.57	141.43	6

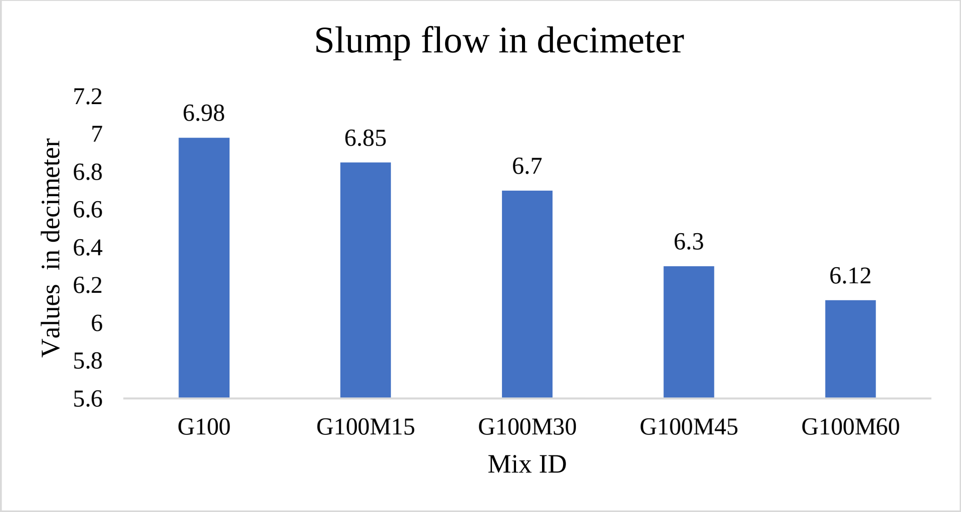
G100M60	440	552	368	840	56.57	141.43	6

Note: Mix ID to be read as binder percentage-MD percentage replacement with fine aggregates e.g. G100M15 indicates "SCGPC" developed using "GGBFS" as sole binder and natural fine aggregates replaced by 15% "MD".

Table 5:8: Fresh Properties of "GGBFS" based "SCGPC" blended with "MD" at 12M of NaOH

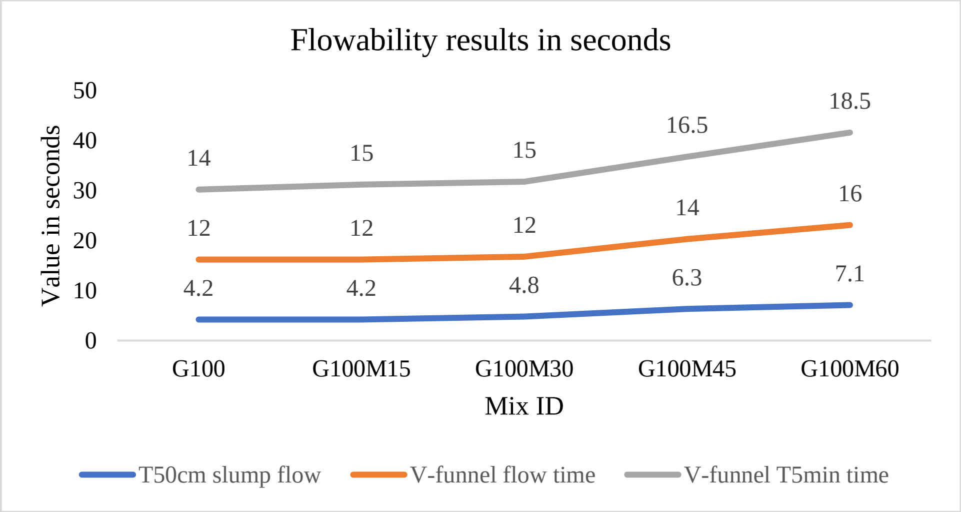
Mix ID	Slump flow (mm)	T_{50}cm Slump flow (sec)	V-funnel flow time (sec)	V-funnel T_{5min} time (sec)	L-box ratio (H_2/H_1)	J-Ring test (mm)
G100	698	4.2	12	14	0.93	5
G100M15	685	4.2	12	15	0.90	7
G100M30	670	4.8	12	15	0.84	10
G100M45	630	6.3	14	16.5	0.75	12
G100M60	612	7.1	16	18.5	0.68	13

As per Table 5:*8*, It has been observed that workability tends to decrease as the content of "MD" is increasing. This is due to higher water absorption capacity of "MD" and finer size as compared to natural fine aggregates



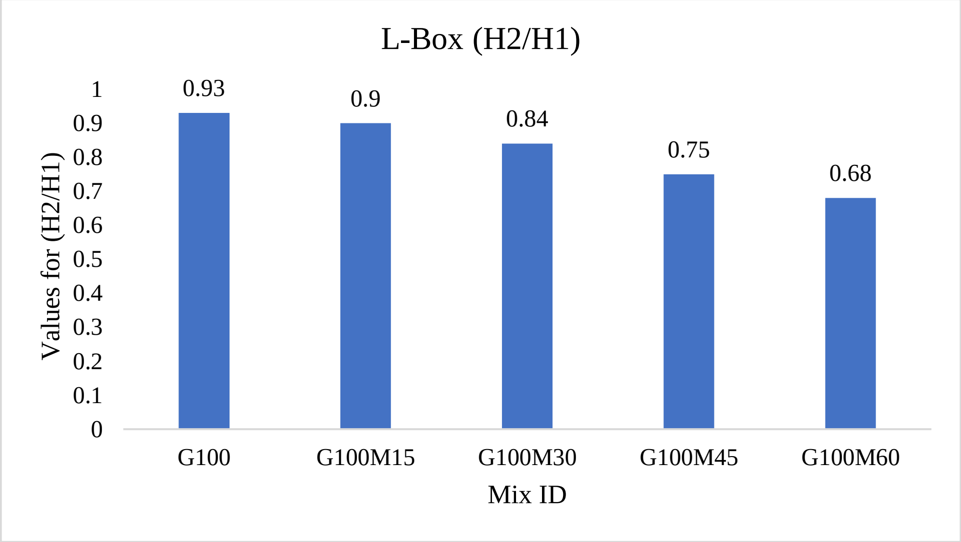
Graph 5.9: Slump flow for "GGBFS" based "SCGPC"' blended with "MD" at 12M of NaOH

As per Graph 5.9 Slump flow decreases by 1.86%, 4%, 9.74% and 12.32% for Mix G100M15, G100M30, G100M45, G100M60 as compared to control mix G100. G100M45 and G100M60 fails to reach the permissible slump flow value (650-850) as per "EFNARC-2005".



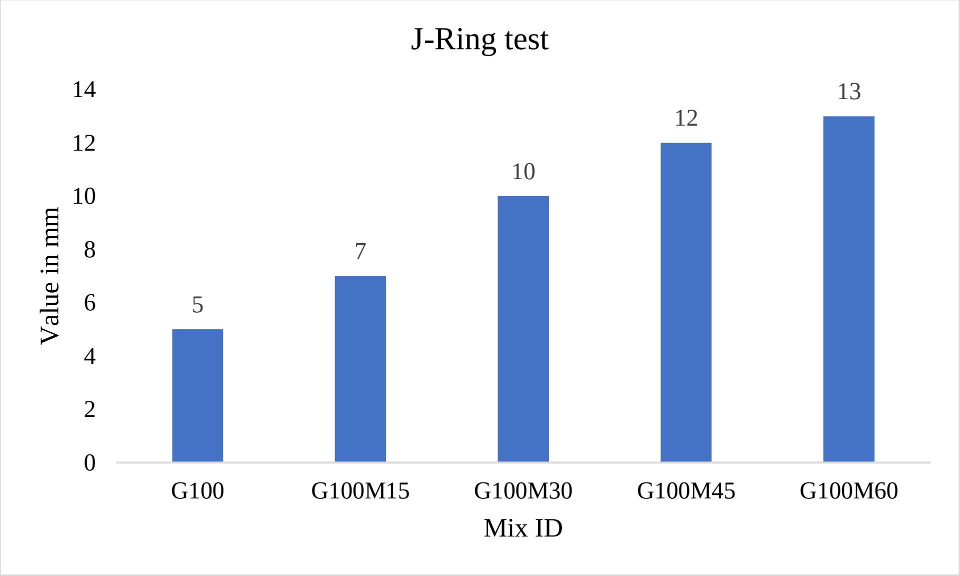
Graph 5.10: Workability test for "GGBFS" based "SCGPC" blended with "MD" at 12M of NaOH

As per Graph 5.10 T_{50} cm slump flow increases by 0%, 7.14%, 50% and 69% for Mix G100M15, G100M30, G100M45, G100M60 as compared to control mix G100. G100M45 and G100M60 fails to reach the permissible T_{50} cm slump flow value (2-5 seconds) as per "EFNARC-2005".



Graph 5.11: L Box result for "GGBFS" based "SCGPC" blended with "MD" at 12M of NaOH

As per Graph 5.11 L-Box results are not satisfactory for mix G100M60. There is a decrease by 3.22%, 9.67%, 13.97% and 26.88% for Mix G100M15, G100M30, G100M45, G100M60 as compared to control mix G100. G100M60 fails to satisfy the permissible L-Box value (0.8-1) as per "EFNARC-2005".



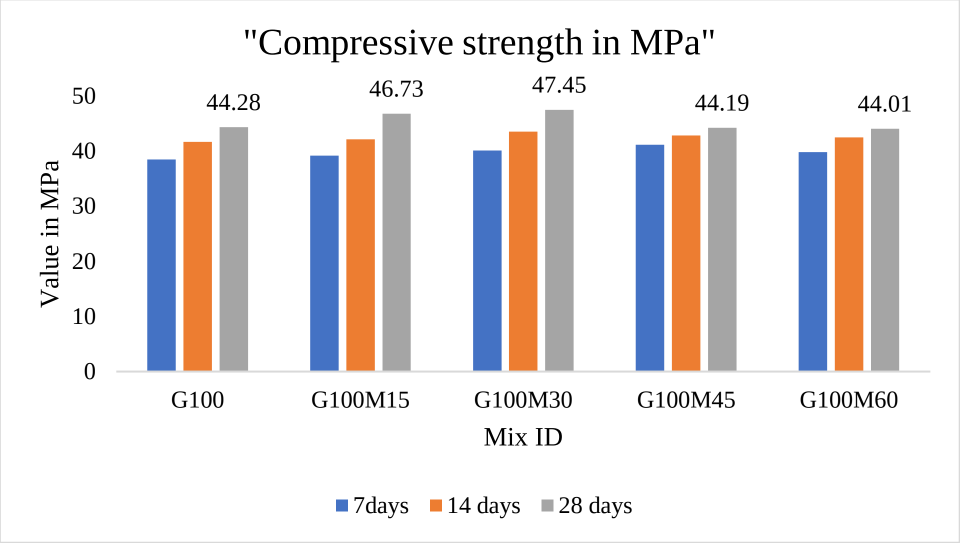
Graph 5.12: J-ring result for "GGBFS" based "SCGPC"' blended with "MD" at 12M of NaOH

As per Graph 5.12 J-ring results are not satisfactory for mix G100M60. G100M60 fails to satisfy the permissible J-ring value (0-10) as per "EFNARC-2005". Hence, "MD" addition beyond 30% is not recommended as per workability behavior observations for "SCGPC".

Table 5:9: Strength behaviour of "GGBFS" based "SCGPC" with "MD" at 12M of NaOH

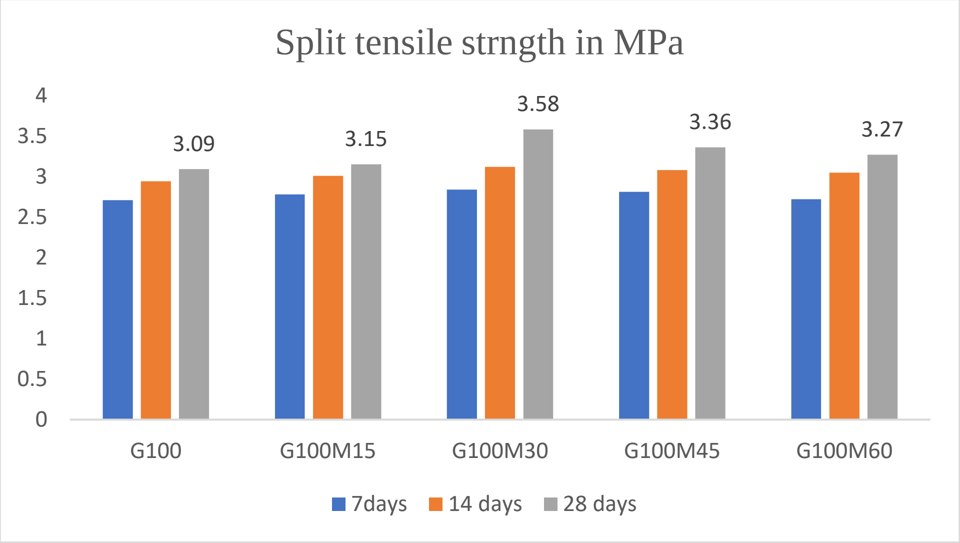
Mix ID	"Compressive strength" (MPa)			"Split tensile strength" (MPa)			"Flexural strength" (MPa)		
	7-days	14-days	28-days	7-days	14-days	28-days	7-days	14-days	28-days
G100	38.45	41.63	44.28	2.71	2.94	3.09	2.95	3.05	3.28
G100M15	39.12	42.07	46.73	2.78	3.01	3.15	3.02	3.11	3.32
G100M30	40.08	43.50	47.45	2.84	3.12	3.58	3.24	3.35	3.48
G100M45	41.12	42.78	44.19	2.81	3.08	3.36	3.18	3.27	3.32
G100M60	39.80	42.45	44.01	2.72	3.05	3.27	3.12	3.21	3.29

As per Table 5:*9*, Hardened properties tends to increase by 5.5% and 6.68% G100M15 and G100M30 with respect to control mix G100. Further rise, tends to show no appreciable rise in strength hence, observations do not recommend the replacement of fine aggregate with "MD" beyond 30%.

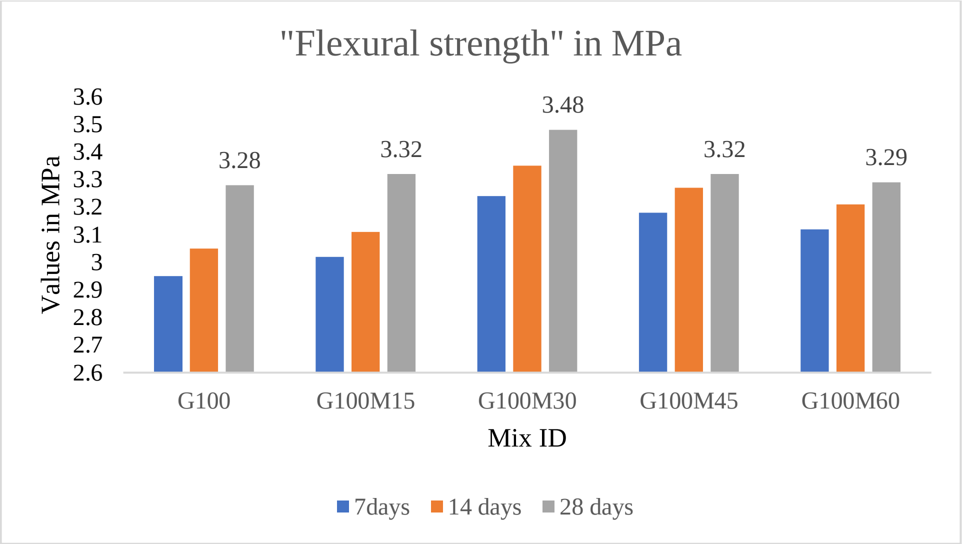


Graph 5.13: "Compressive strength" for "GGBFS" based "SCGPC" blended with "MD" at 12M of NaOH"

As per Graph 5.13 "Compressive strength" results are optimum for Mix G100M30. This may be due to the effect of "MD" that tends to reduce the void content in concrete, making it dense and hence "Compressive strength" increases. Similar effect is visible as per Graph 5.14 and Graph 5.15 for strength against tension and flexure.



Graph 5.14: "Split tensile strength" for "GGBFS" based "SCGPC"' blended with "MD" at 12M of NaOH"



Graph 5.15: "Flexural strength" for "GGBFS" based "SCGPC"' blended with "MD" at 12M of NaOH

5.9 Blending of "GGBFS" based "SCGPC" with "MD" and "RCA"

As per observations of Table 5**:*8*** and Table 5**:*9*** it was concluded that workability behaviour is better with G100M15 and strength behaviour is better in case of G100M30. Hence, replacement of coarse aggregate with "RCA" (15%, 30%, 45%) has been tested for "MD" 15% and "MD" 30% replaced with fine aggregates. Mix proportion of the tested mix are listed in Table 5.10. Workability and strength properties of the G100M15 with replacement of coarse aggregates with "RCA" (15%, 30% and 45%) have been compiled in Table 5.11 and Table 5**:*12*** and graphical representation has been shown in Graph 5.16 to Graph 5.22 Workability and strength properties of the "SCGPC" prepared with G100M30 and coarse aggregate being replaced with "RCA" (15%, 30% and 45%) have been compiled in Table 5**:*13*** and Table 5**:*14***and graphical representation has been shown in Graph 5.23 to Graph 5.29.

Table 5.10: Mix proportions of "GGBFS" based "SCGPC"' blended with "MD" and "RCA" at 12M of NaOH with 6% Superplasticizer

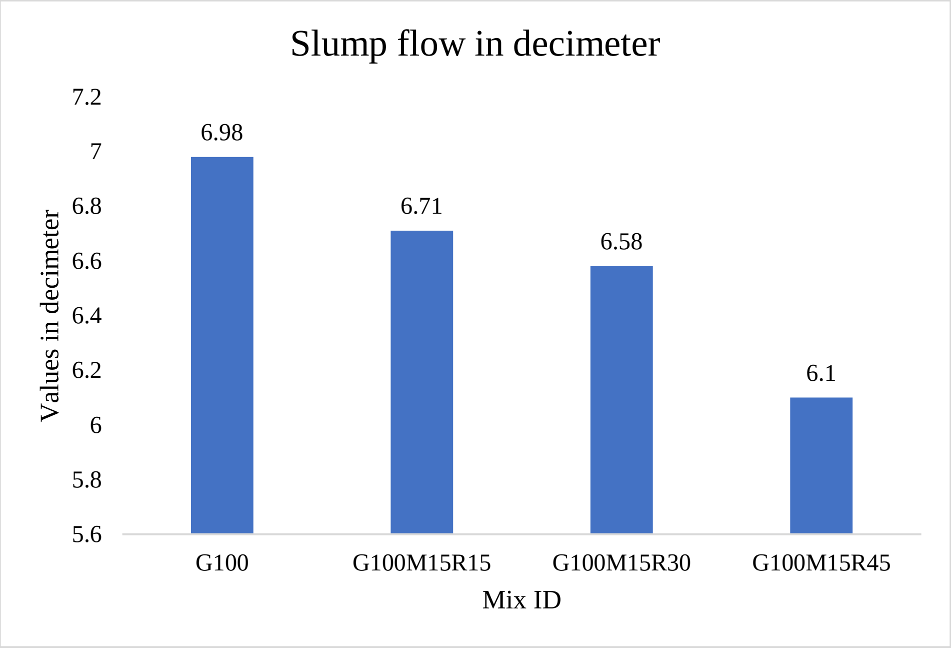
Mix ID	"GGBFS" (Kg/m^3)	**Fine Aggregate (Kg/m^3)**	"MD" (Kg/m^3)	**Coarse Aggregate (Kg/m^3)**	"RCA" (Kg/m^3)	**Sodium Hydroxide (Kg/m^3)**	**Sodium Silicate (Kg/m^3)**
G100	440	920	-	840	-	56.57	141.43
G100M15R15	440	782	138	714	126	56.57	141.43
G100M15R30	440	782	138	588	252	56.57	141.43

G100M15R45	440	782	138	462	378	56.57	141.43
G100M30R15	440	644	276	714	126	56.57	141.43
G100M30R30	440	644	276	588	252	56.57	141.43
G100M30R45	440	644	276	462	378	56.57	141.43

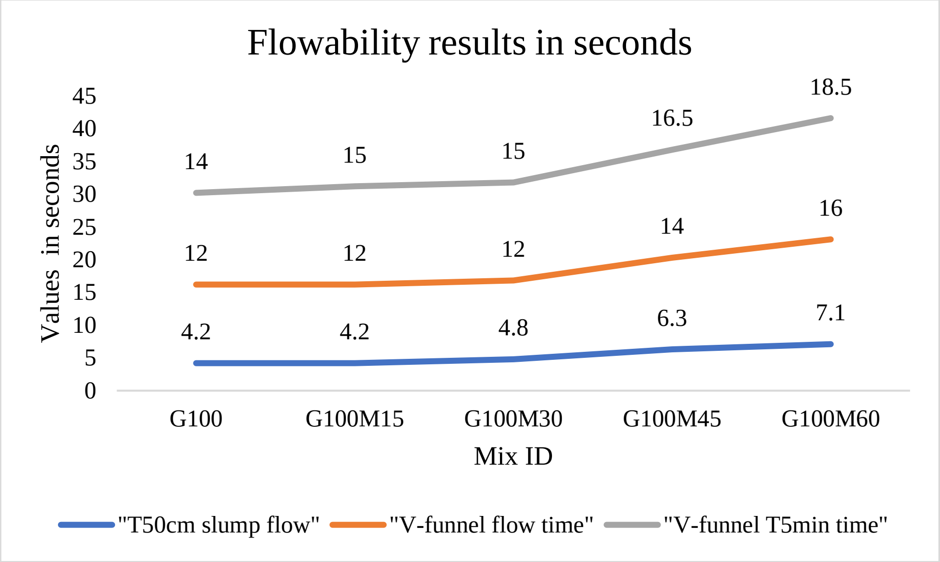
Table 5.11:Fresh Properties of SCGC blended with “MD” and “RCA”

Mix ID	**Slump flow (mm)**	**T$_{50}$cm Slump flow (sec)**	**V-funnel flow time (sec)**	**V-funnel T$_{5min}$ time (sec)**	**L-box ratio (H_2/H_1)**	**J-Ring test (mm)**
G100	698	4.2	12	14	0.93	5
G100M15R15	671	4.8	12	15	0.79	9
G100M15R30	658	5.3	14	18	0.78	11
G100M15R45	610	6.4	16	18	0.71	14

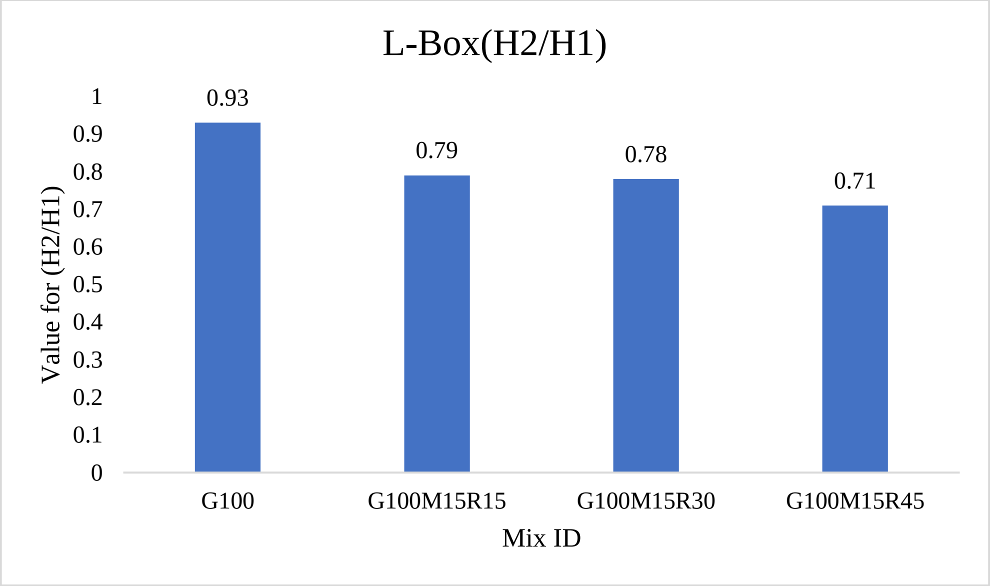
As per Table 5.11 Mix G100M15R15 shows satisfactory behaviour in workability whereas G100M15R30 and G100M15R45 does not satisfy the recommended values for various tests to check flowability and passing ability and segregation resistance for developed “SCGPC”.



Graph 5.16: Slump flow for “GGBFS” based “SCGPC”’ blended with “MD” (15%) and “RCA” at 12M of NaOH

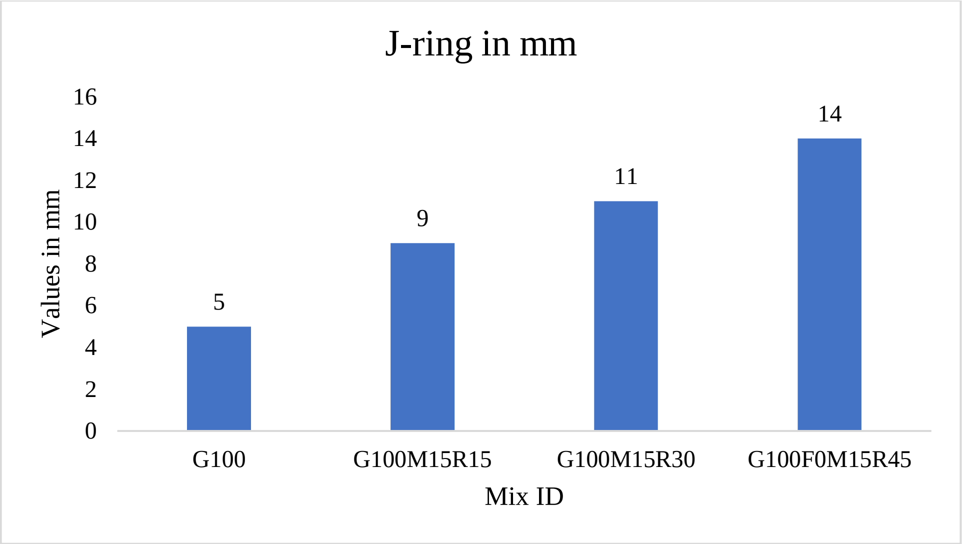


Graph 5.17: Flowability results for “GGBFS” based “SCGPC” blended with “MD” (15%) and “RCA” at 12M of NaOH



Graph 5.18: L-box ratio for “GGBFS” based “SCGPC” blended with “MD”(15%) and “RCA” at 12M of NaOH

As per Graph 5.17 and Graph 5.18 “SCGPC” developed with “GGBFS” binder and 15% “MD” to replace fine aggregate show decrease in workability with increasing percentage of coarse aggregate with “RCA”.



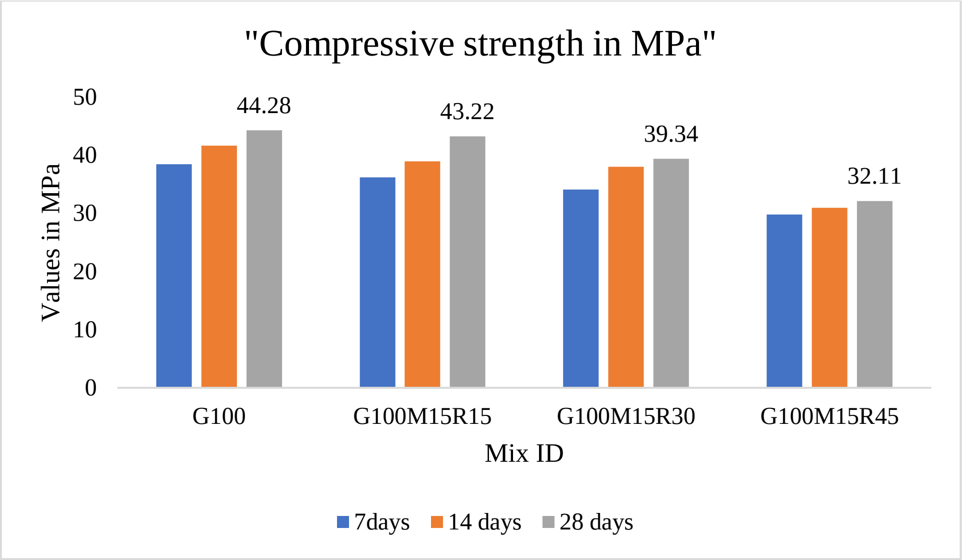
Graph 5.19: J-ring for “GGBFS” based “SCGPC”’ blended with “MD” (15%) and “RCA” at 12M of NaOH

As per Graph 5.19, “GGBFS” based “SCGPC” blended with “MD” 15% and “RCA” 15% for replacement of fine and coarse aggregate respectively shows satisfactory behavior whereas G100M15R30 and G100M15R45 does not satisfy the workability conditions for developed “SCGPC”.

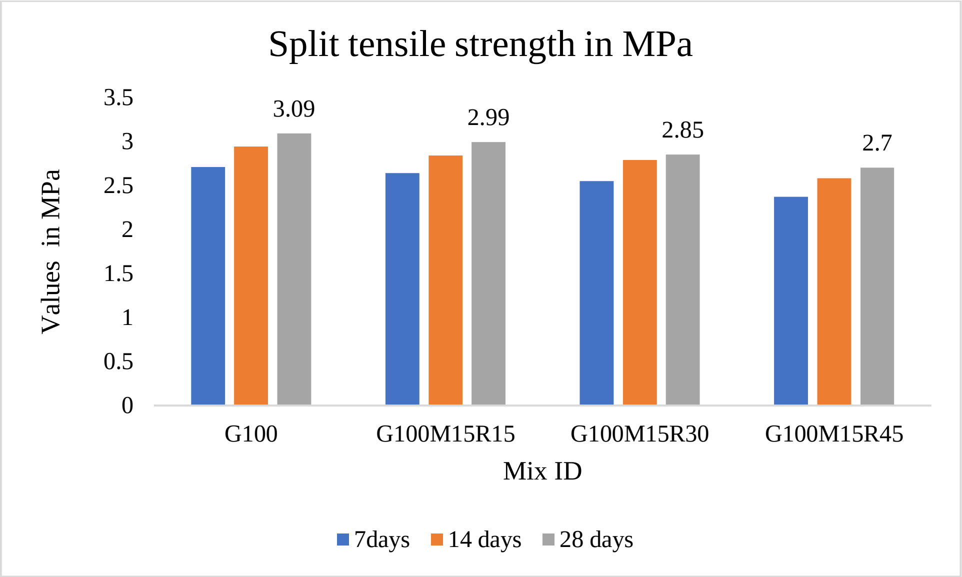
Table 5:12:Mechanical strength of “SCGPC” blended with “MD”(15%) and “RCA”

Mix ID	“Compressive strength” (MPa)			“Split tensile strength” (MPa)			“Flexural strength” (MPa)		
	7-days	14-days	28-days	7-days	14-days	28-days	7-days	14-days	28-days
G100	38.45	41.63	44.28	2.71	2.94	3.09	2.95	3.05	3.28
G100M15R15	36.18	38.92	43.22	2.64	2.84	2.99	2.86	2.95	3.12
G100M15R30	34.09	37.97	39.34	2.55	2.79	2.85	2.76	2.84	2.95
G100M15R45	29.79	30.95	32.11	2.37	2.58	2.70	2.54	2.61	2.65

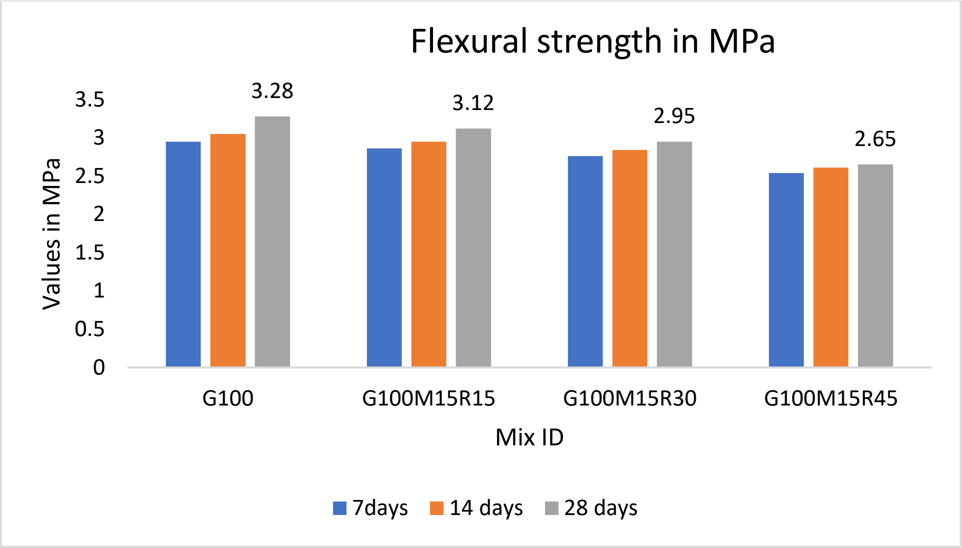
As per Table 5:***12*** and Graph 5.20 to Graph 5.22, the “Compressive strength” behavior is just satisfactory G100M15R15. With further increase in replacement of “RCA” with coarse aggregate decreases the strength with reference to G100. Similar trend is observed for strength in tension as well as in flexural. Hence, G100M15R15 justify the development of “SCGPC” with “GGBFS” base blended with “MD” and “RCA”.



Graph 5.20: Strength in compression for “GGBFS” based “SCGPC” blended with “MD” (15%) at 12M of NaOH



Graph 5.21: “Split tensile strength” for “GGBFS” based “SCGPC” blended with “MD” (15%) at 12M of NaOH

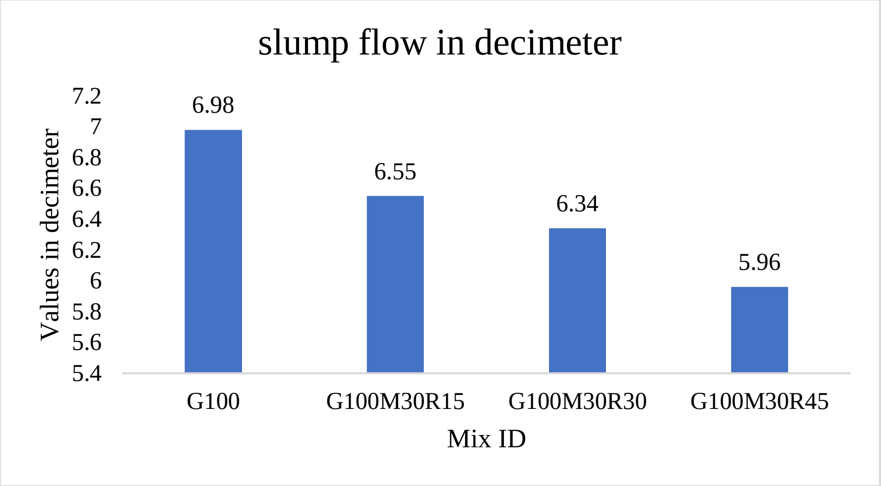


Graph 5.22: Strength in flexure for “GGBFS” based “SCGPC”’ blended with “MD” (15%) at 12M of NaOH

Table 5:13: Fresh Properties of “SCGPC” blended with “MD” (30%) and “RCA”

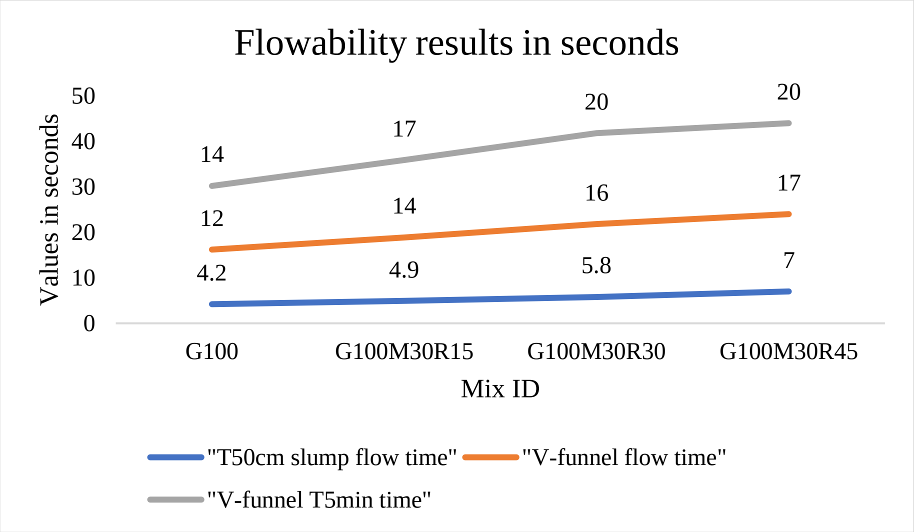
Mix ID	Slump flow (mm) (650-850)mm	T_{50}cm Slump flow (sec) (2-5) sec	V-funnel flow time (sec) (8-12) sec	V-funnel T_{5min} time (sec) +/-3 sec	L-box ratio (H_2/H_1) (0.8-1.0)	J-Ring test (mm) (0-10)
G100	698	4.2	12	14	0.93	5
G100M30R15	655	4.9	14	17	0.78	10
G100M30R30	634	5.8	16	20	0.74	12
G100M30R45	596	7	17	20	0.68	15

As per Table 5:***13*** blending of Mable dust (30%) and “RCA” (15%, 30%, 45%) does not support workability requirement as per “EFNARC-2005” for developing “SCGPC”. For Mix G100M30R15 V-funnel T5min and J-ring test does not satisfy the recommended values. G100M30R30 and G100M30R45 fails to satisfy the requirements of workability behaviour of developed “SCGPC”. This behaviour of developed “SCGPC” owe to the higher content of “MD” and higher water absorption of “RCA”. Graphical representation of workability behaviour is depicted through Graph 5.23 to Graph 5.26.



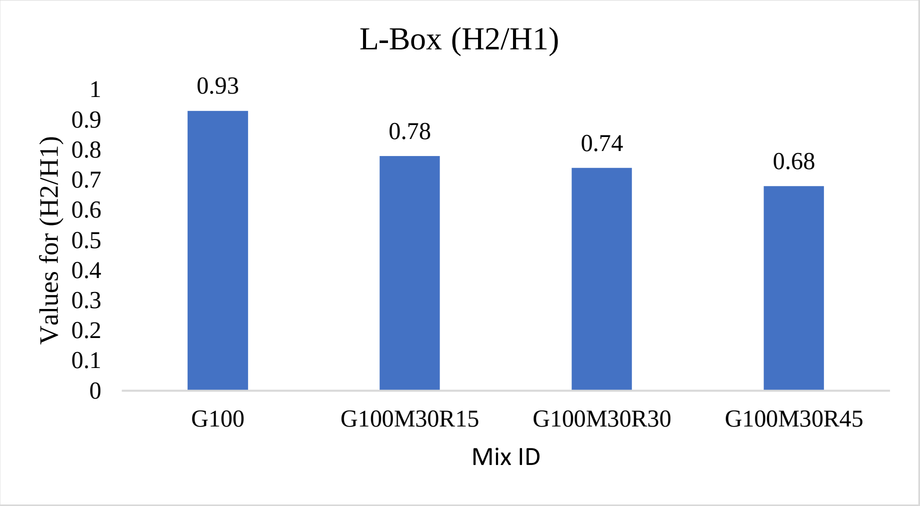
Graph 5.23: Slump flow for "GGBFS" based "SCGPC" blended with "MD" (30%) and "RCA" at 12M of NaOH

G100M30R30 mix and G100M30R45 fail to satisfy the slump flow requirement as per "EFNARC-2005". The permissible range for slump flow is 650-850mm (6.5 to 8.5 in decimeter.)



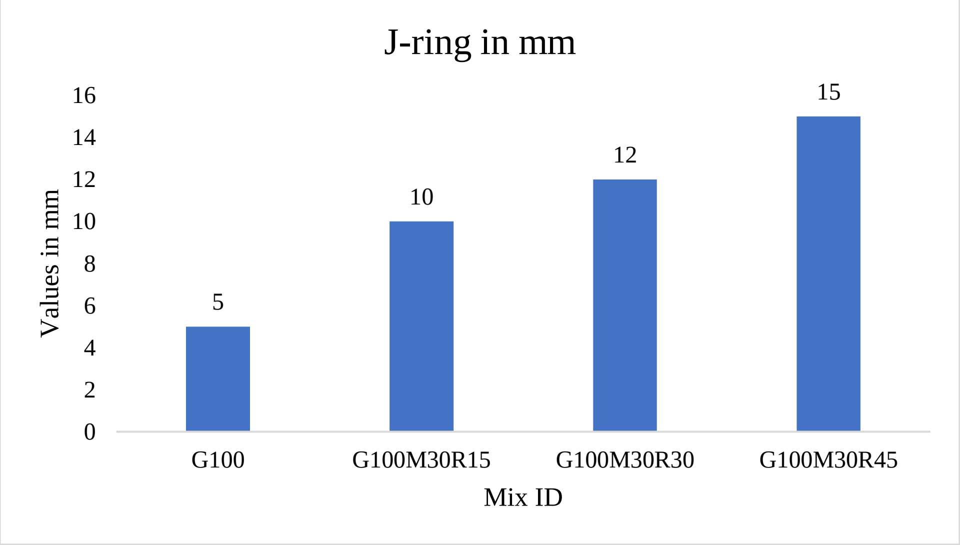
Graph 5.24: Flowability results for "GGBFS" based "SCGPC" blended with "MD" (30%) and "RCA" at 12M of NaOH

G100M30R15 just passed the T_{50} slump flow time but fails in V-funnel flow time and V-funnel T5 min test. G100M30R30 mix and G100M30R45 fail to satisfy the T_{50} cm slump flow time requirement and V-funnel and V-funnel T5 min test as per "EFNARC-2005". The permissible range for T_{50} cm slump flow time is 2-5 seconds. For V-funnel test its 8-12 seconds and V-funnel T5 min its +/-3 seconds



Graph 5.25: L-Box ratio for "GGBFS" based "SCGPC" blended with "MD" (30%) and "RCA" at 12M of NaOH

As per Graph 5.25, G100M30R15 tends to decrease passing ability of "GGBFS" based "SCGPC" blended with "MD" (30%) at 12M of NaOH. L-Box test results G100M30R15, satisfy the passing ability test at the brim whereas, G100M30R30 and G100M30R45 fails to do so. J-ring test is not showing satisfactory result for G100M30R30 and G100M30R45.

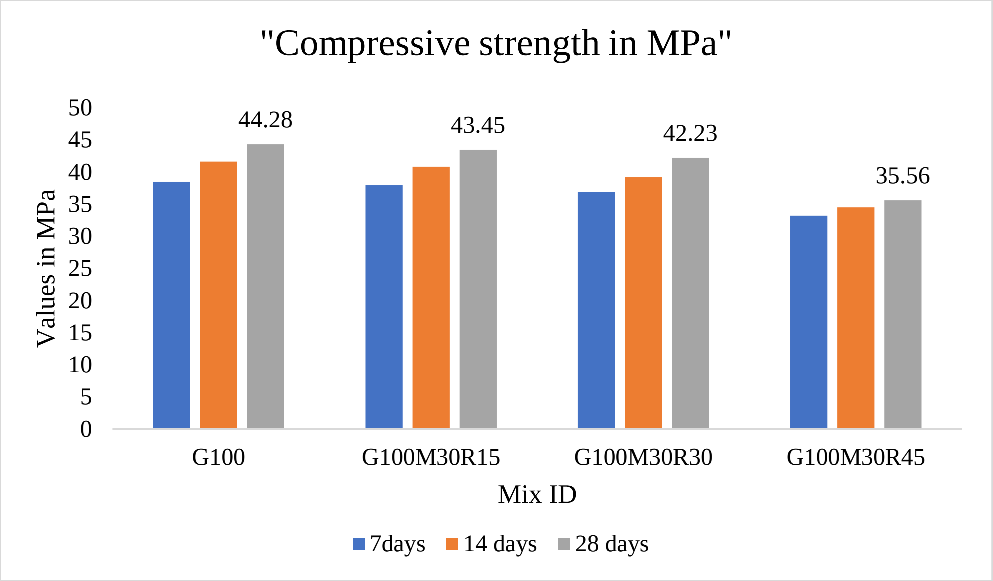


Graph 5.26: J-ring for "GGBFS" based "SCGPC" blended with "MD" (30%) and "RCA" at 12M of NaOH

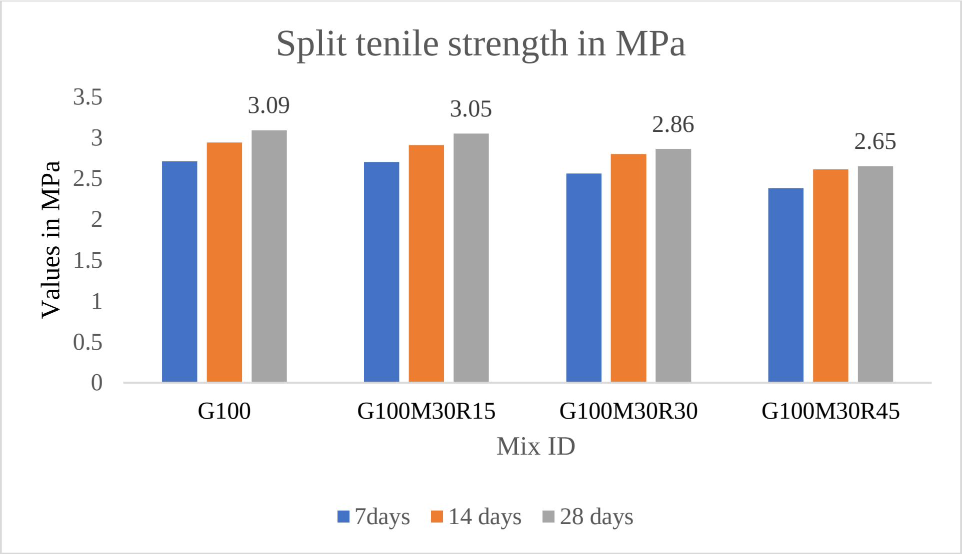
Table 5:14: Hardened Properties of “SCGPC” with “MD”(30%) and “RCA”

Mix ID	“Compressive strength” (MPa)			“Split tensile strength” (MPa)			“Flexural strength” (MPa)		
	7-days	14-days	28-days	7-days	14-days	28-days	7-days	14-days	28-days
G100	38.45	41.63	44.28	2.71	2.94	3.09	2.95	3.05	3.28
G100M30R15	37.94	40.8	43.45	2.7	2.91	3.05	2.88	2.92	3.08
G100M30R30	36.87	39.15	42.23	2.56	2.8	2.86	2.75	2.84	2.95
G100M30R45	33.18	34.47	35.56	2.38	2.61	2.65	2.54	2.61	2.81

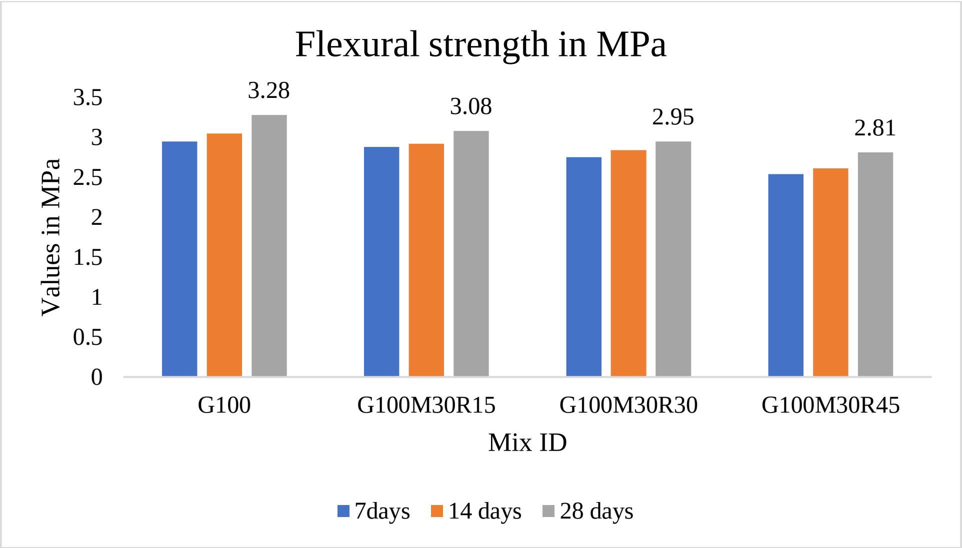
As per Table 5:***14*** and Graph 5.27, Graph 5.28 and Graph 5.29 strength is compatible for Mix G100M30R15 as compared to G100 but self-compacting characteristics are not maintained. Hence , “SCGPC” prepared with “GGBFS” base, using 30% replacement of fine aggregate with “MD” does not motivates the replacement of natural coarse aggregate with “RCA”.



Graph 5.27: Strength in compression for “GGBFS” based “SCGPC” blended with “MD” (30%) at 12M of NaOH



Graph 5.28: Strength in Tension for “GGBFS” based “SCGPC”’ blended with “MD” (30%) at 12M of NaOH



Graph 5.29: “Flexural strength” for “GGBFS” based “SCGPC”’ blended with “MD” (30%) at 12M of NaOH

5.10 Optimized mix based on “Compressive strength”

As per observations based on workability and “Compressive strength” after 7 -14-28 days, mix are listed in Table 5:*15*. All these mixes are satisfying the conditions of a workable self-compacting concrete as per “EFNARC-2005”. It is observed that highest strength is achieved for mix G100M30 whereas best workability behavior is witnessed for mix G100.

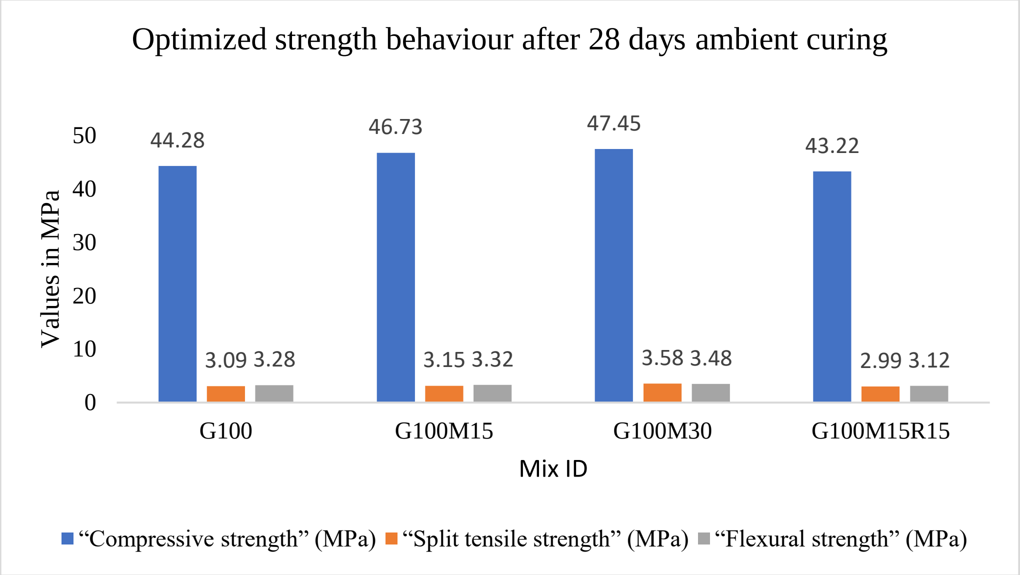
Table 5:15: Optimized workability behaviour

Mix ID	**“Slump-flow (mm)”**	**“T_{50}cm Slump flow (sec)”**	**“V-funnel flow time (sec)”**	**“V-funnel T_{5min} time (sec)”**	**“L-box ratio (H_2/H_1)”**	**“J-Ring test (mm)”**
G100	698	4.2	12	14	0.93	5
G100M15	685	4.2	12	15	0.90	7
G100M30	670	4.8	12	15	0.84	10
G100M15R15	671	4.8	12	15	0.79	9

Table 5:16: Optimized strength behaviour after 28 days ambient curing

Mix ID	“Compressive strength” (MPa)	“Split tensile strength” (MPa)	“Flexural strength” (MPa)
G100	44.28	3.09	3.28
G100M15	46.73	3.15	3.32
G100M30	47.45	3.58	3.48
G100M15R15	43.22	2.99	3.12

As per Table 5***:15***, workability tends to fall with addition of “MD”. 15% replacement of fine aggregate with “MD” is better than 30% replacement whereas strength behaviour is better at 30% replacement of “MD” as per table 5.16. Mix G100M30 shows the best strength behaviour in “Compressive strength”, “Split tensile strength” and “Flexural strength”.



Graph 5.30: Optimized mix selection for “GGBFS” based Self Compacting at 12M NaOH

5.11 Durability Behaviour

Durability behaviour of selected mix has been studied using RCPT test and Water permeability test. Table 5.17 lists the current values during RCPT test . Table 5.19 shows the depth of water penetration.

Table 5:17: Rapid Chloride Penetration Test Results

Designation	Time	G100	G100M15	G100M30	G100M15R15
I_o	10:20 AM	57	69	74	85
I_{30}	10:50 AM	94	87	90	100
I_{60}	11:20 AM	115	126	115	120
I_{90}	11:50 AM	122	135	138	144
I_{120}	12:20 PM	130	143	142	148
I_{150}	12:50 PM	118	158	153	162
I_{180}	01:20 PM	114	179	182	192
I_{210}	01:50 PM	169	198	189	199
I_{240}	02:20 PM	183	215	221	240
I_{270}	02:50 PM	205	234	238	256
I_{300}	03:30 PM	215	246	257	270
I_{330}	03:50 PM	205	235	267	289
I_{360}	04:20 PM	183	261	280	299
$I_{Cumulative}$ (mA)		3580	4242	4338	4624

$I_{Average}$ (Coulombs)	3222	3817.8	3904.2	4161.6

$I_{Cummulative} = I_0 + I_{360} + (2x\,(I_{30} + I_{60} + I_{90} + I_{120} + I_{150} + I_{180} + I_{210} + I_{240} + I_{270} + I_{300} + I_{330}))$

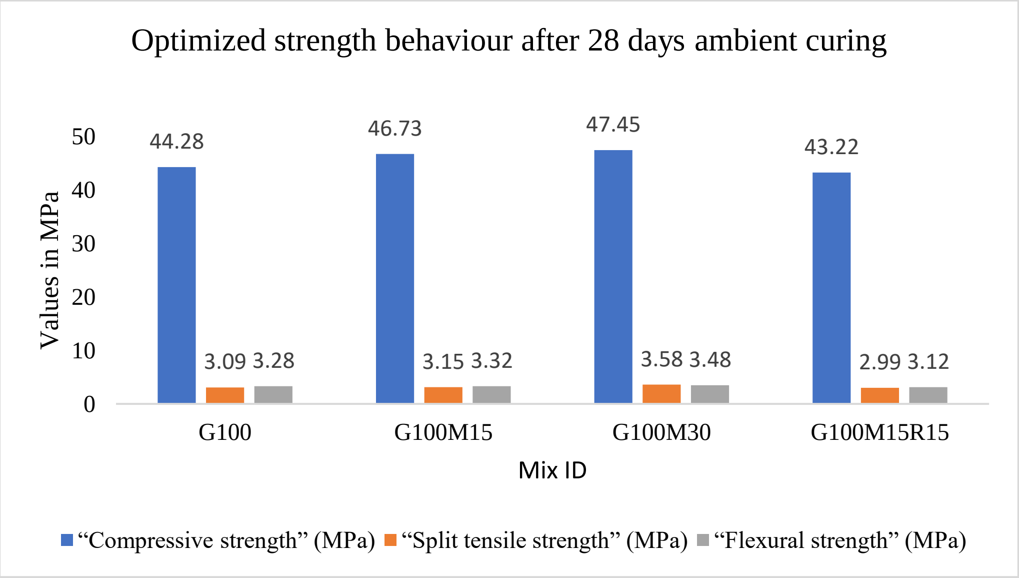
$I_{Average} = I_{Cummulative} * 900/1000$

Table 5:18: Rapid Chloride Penetration Test of Optimum mix and Control Mix

Mix ID	$I_{average}$
G100	3222
G100M15	3817.8
G100M30	3904.2
G100M15R15	4161.6

Table 5:19: Water Permeability test

Mix ID	Depth of permeability
G100	15mm
G100M15	18mm
G100M30	20mm
G100M15R15	32mm



According Table 5:***16*** and Graph ***5.30***, concrete mix G100M30 is the most reliable choice for applications requiring long-term strength since it consistently displays the highest "Compressive strength" at all testing periods (7-day, 14-day, and 28-day) with conditions just fulfilled to satisfy the self-compacting behaviour, compromising for durability behaviour. G100M15 is next higher strength, as compared to G100 and G100M15R15 and also fulfilling the durability aspect. As per the control mix G100, there is 5.53% rise in strength for G100M15. However, there is 7.16% rise in compressive strength, 15.86% rise in tensile strength and 6.1% rise in flexural strength with G100M30. As compared to control mix G100 mix G100M15R15 shows decrease of 2.39%, 3.34% and 4.87% in compressive strength, split tensile strength and flexural strength respectively. Durability behaviour as per RCPT shows medium conductivity (4000 coulombs) and water permeability is found to be satisfactory (<25mm) for G100, G100M15 and G100M30. G100M15R15 can be the choice ignoring durability aspect.

CHAPTER 6 COST ANALYSIS

6.1 General

The cost analysis of the selected mix for optimization purpose has been performed as expressed in Table 6**:*1*** to Table 6**:*4***. Cost of various materials and amenities have been considered as per Schedule of Rates 2023-2024. mixes G100, G100m15, G100M30 , G100M15R15 and conventional SCC of grade M35. It has been observed from Graph 6.1 there is increase in cost for G100, G100M15, G100M30 and G100M15R15 by 21.4%, 21.3%, 20.8% and 19.7% as compared to conventional SCC with compatible strength.

Table 6:1: Cost of mix G100

Description	Quantity	Market Rate	Rate per 10 cubic meter	Total Amount 10 CUM	Total Amount 1 cum
"GGBFS"	*4400*	Rs 8 / Kg	*35200*	*35200*	*3520*
Sand	*9200*	Rs 1.2 / Kg	*11040*	*11040*	*1104*
Coarse Aggregates	*8400*	Rs 1.4 / Kg	*11760*	*11760*	*1176*
Admixture	*264*	Rs 90 / Kg	*23760*	*23760*	*2376*
"MD"	*0*	Rs 1 / Kg	*0*	*0*	*0*
"RCA"	*0*		*0*	*0*	*0*
Sodium Silicate	*271.5*	Rs 15/ Kg	*4072.5*	*4072.5*	*407.25*
Sodium Hydroxide	*622.3*	Rs 25 / Kg	*15557.5*	*15557.5*	*1555.75*
Mason	*3 Nos.*	Rs 500 / person	*Rs 150*	*1500*	*150*
Labour	*12 Nos.*	Rs. 400 / person	*Rs 480*	*4800*	*480*
Sundries	*Lump Sum*	-	*Rs 45*	*450/-*	*450/-*
Total of Materials and Labour				*107690*	*10769*
Add 1.5% water charges				*1615.35*	*161.535*
Total cost for 10 cubic meter concrete				*109305*	*10930.5*

Table 6:2: Cost of mix G100M15

Description	Quantity	Market Rate	Rate per 10 cubic meter	Total Amount 10 CUM	Total Amount 1 cum
"GGBFS"	*4400*	Rs 8 / Kg	*35200*	*35200*	*3520*
Sand	*7820*	Rs 1.2 / Kg	*9384*	*9384*	*938.4*
Coarse Aggregates	*8400*	Rs 1.4 / Kg	*11760*	*11760*	*1176*
Admixture	*264*	Rs 90 / Kg	*23760*	*23760*	*2376*
"MD"	*1380*	Rs 1 / Kg	*1380*	*1380*	*138*

“RCA”	0		0	0	0
Sodium Silicate	271.5	Rs 15/ Kg	4072.5	4072.5	407.25
Sodium Hydroxide	622.3	Rs 25 / Kg	15557.5	15557.5	1555.75
Mason	3 Nos.	Rs 500 / person	Rs 150	1500	150
Labour	12 Nos.	Rs. 400 / person	Rs 480	4800	480
Sundries	Lump Sum	-	Rs 45	450/-	450/-
Total of Materials and Labour				107414	10741.4
Add 1.5% water charges				1611.21	161.121
Total cost for 10 cubic meter concrete				109025	10902.5

Table 6:3: Cost of mix G100M30

Description	Quantity	Market Rate	Rate per 10 cubic meter	Total Amount 10 CUM	Total Amount 1 cum
“GGBFS”	4400	Rs 8 / Kg	35200	35200	3520
Sand	**6440**	Rs 1.2 / Kg	**7728**	**7728**	**772.8**
Coarse Aggregates	7140	Rs 1.4 / Kg	9996	9996	999.6
Admixture	264	Rs 90 / Kg	23760	23760	2376
“MD”	2760	Rs 1 / Kg	**2760**	**2760**	**276**
“RCA”			0	0	0
Sodium Silicate	271.5	Rs 15/ Kg	4072.5	4072.5	407.25
Sodium Hydroxide	622.3	Rs 25 / Kg	15557.5	15557.5	1555.75
Mason	3 Nos.	Rs 500 / person	Rs 150	1500	150
Labour	12 Nos.	Rs. 400 / person	Rs 480	4800	480
Sundries	Lump Sum	-	Rs 45	450/-	450/-
Total of Materials and Labour				107138	10713.8
Add 1.5% water charges				1607.07	160.707
Total cost for 10 cubic meter concrete				108745	10874.5

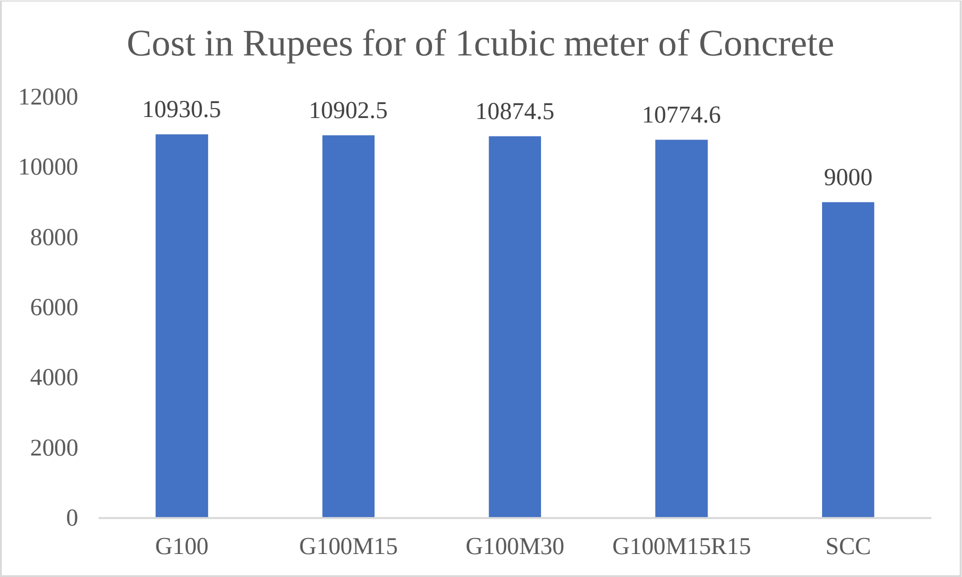
Table 6:4: Cost of mix G100M15R15

Description	Quantity	Market Rate	Rate per 10 cubic meter	Total Amount 10 CUM	Total Amount 1 cum
“GGBFS”	4400	Rs 8 / Kg	35200	35200	3520
Sand	7820	Rs 1.2 / Kg	9384	9384	938.4

Coarse Aggregates	7140	Rs 1.4 / Kg	9996	9996	999.6
Admixture	264	Rs 90 / Kg	23760	23760	2376
“MD”	1380	Rs 1 / Kg	1380	1380	138
“RCA”	1260	Rs 0.4/ Kg	504	504	50.4
Sodium Silicate	271.5	Rs 15/ Kg	4072.5	4072.5	407.25
Sodium Hydroxide	622.3	Rs 25 / Kg	15557.5	15557.5	1555.75
Mason	3 Nos.	Rs 500 / person	Rs 150	1500	150
Labour	12 Nos.	Rs. 400 / person	Rs 480	4800	480
Sundries	Lump Sum	-	Rs 45	450/-	450/-
Total of Materials and Labour				106154	10615.4
Add 1.5% water charges				1592.31	159.221
Total cost for 10 cubic meter concrete				107746	10774.6

Table 6:5 Cost of conventional SCC

Description	Quantity	Market Rate	Rate per 10 cubic meter	Total Amount 10 CUM	Total Amount 1 cum
Cement	*4400*	Rs 7.5/ Kg	***33000***	***33000***	***3300***
Sand	*7820*	Rs 1.2 / Kg	*9384*	*9384*	*938.4*
Coarse Aggregates	*8400*	Rs 1.4 / Kg	*11760*	*11760*	*1176*
Admixture	*264*	Rs 90 / Kg	*23760*	*23760*	*2376*
“MD”	*0*		*0*	*0*	*0*
“RCA”	*0*		*0*	*0*	*0*
Sodium Silicate	*0*		*0*	*0*	*0*
Sodium Hydroxide	*0*		*0*	*0*	*0*
Mason	*3 Nos.*	Rs 500 / person	*Rs 150*	*1500*	*150*
Labour	*12 Nos.*	Rs. 400 / person	*Rs 480*	*4800*	*480*
Sundries	*Lump Sum*	-	*Rs 45*	*450/-*	*450/-*
Total of Materials and Labour				*88704*	*8870.4*
Add 1.5% water charges				*1330.5*	*133.05*
Total cost for 10 cubic meter concrete				*90000*	*9000*



Graph 6.1: Cost analysis for the selected mix for optimization

Today the cost production of OPC concrete for similar grade normal SCC mix with similar range “Compressive strength” is around Rs 9000 respectively as per Schedule of Rates 2023-2024. So, considering the Schedule of Rates 2023-2024 cost analysis of selected mix has been performed. Table 6.1 to Table 6.5 shows the cost analysis prepared for selected mixes G100, G100m15, G100M30 , G100M15R15 and conventional SCC of grade M35. It has been observed from Graph 6.1 there is increase in cost for G100, G100M15, G100M30 and G100M15R15 by 21.4%, 21.3%, 20.8% and 19.7% as compared to conventional SCC with compatible strength. These rates may vary from region to region and country to country, depending upon the quantity and quality of available industrial waste. So, taking environmental impacts into consideration i.e., the CO_2 emission during the production of OPC and load on landfills for dumping industrial waste, one can easily implement “GGBFS” based SCGPC with compromise in the cost.

CHAPTER 7 CONCLUSION

7.1 General

The experimental study conducted in the present research leads to many important aspects of development of "SCGPC" and the material constituents. Use of industrial waste as binder, MD as filler and RCA as replacement of coarse aggregates in optimum quantity has been achieved in the present work.

7.2 Following conclusions can be drawn from the research and are listed below:

- The "SCGPC" with a binder content ("GGBFS") of 440 kg/ m^3, AA/B ratio of 0.45, SS/SH ratio of 2.5, and NaOH concentration of 12 M achieved the highest 28-days compressive strength (44.28 MPa) at ambient curing conditions.
- At ambient curing, "SCGPC" formed with 100% fly ash as binder satified the workability behaviour as SCC but showed low strength for 2.5F12 (22.32 MPa) at 28 days due to incomplete geo-polymerisation without heat.
- Workability of "GGBFS" based self-compacting geo-polymer concrete decreased with increase in molarity of NaOH solution from 8M to 14M. Also, it improves with increase in fly ash percentage as partial replacement of "GGBFS".
- Rise in replacement percentage of marble dust beyond 15% tends to decrease the workability. Fresh properties of "SCGPC" for mix G100M15 is better as compared to G100 and G100M30 and G100M15R15.
- "Compressive strength" of developed "SCGPC" tends to increase with rise in replacement of fine aggregates with marble dust up to 30%. G100M30 has compressive strength of 47.45MPa after 28 days at ambient curing which is 7.16% higher than G100.
- Similar trend has been seen in "Split tensile strength" and "flexural strength." G100M30 has "Split tensile strength" 15.8% higher and "flexural strength" 6.1% higher than G100.
- G100M15R15 shows satisfactory behaviour in workability and strength as "SCGPC" but failed to satisfy durability requirements. Hence, replacement of MD and RCA in G100 could be possible only up to 15% in temporary structures or in structural components not exposed to weathering effects.
- Cost of "SCGPC" is higher as compared to conventional SCC, due to higher cost of Chemicals (SS, SH) and admixture. "GGBFS" which is an industrial waste but not locally available adds to cost of "SCGPC". Cost of G100, G100M15, G100M30

and G100M15R15 is 21.4%, 21.3%, 20.8% and 19.7% higher than conventional "SCC".

In summary, the provided data reveals that concrete mix G100M30 consistently exhibits the highest "Compressive strength" at all tested intervals (7-day, 21-day, and 28-day), making it the most robust option for applications and just satisfactory durability hence, G100M30 can be suggested as a most appropriate choice in light of self-compacting behaviour, strength behaviour and durability behaviour. G100M15 follows closely in terms of workability and strength, with satisfactory durability performance.

However, G100M15R15 shows good satisfactory workability and strength but fails to satisfy durability hence RCA is not recommended for use in "SCGPC".

Development of "SCGPC" by controlling the use of cement as binder in reducing the CO_2 emissions, loads on landfill and cost of construction over power the increase in construction cost. Hence, "SCGPC" can be recommended as better option as compared to conventional concrete keeping in view the sustainability development goals.

CHAPTER 8 SCOPE FOR FURTHER RESEARCH

8.1 General

The various aspects of this research can be further extended in a future study. Based on the promising results of this research, some further developments may be carried out, and they are:

- “GGBFS” and “Flyash” has been used in present study. Extension of reseach may include other industrial and agricultural waste and their combinations such as Silica fume, Metakaolin, waste foundry sand and RHA
- Present research has been conducted on “SCGPC” developed under ambient curing conditions, hence other curing methods can be tried for further extension of research.
- “SCGPC” can be tested for its response to acid attacks for long term durability so that its application can be extended to wider horizon.
- Life cycle assessment tools can be used on developed “SCGPC” to assess potential environmental impacts throughout its life cycle.
- High cost is one of the challenge in use of “GPC” due to high cost of chemicals used, hence alternate admixtures can be explored for reducing the cost of “GPC”.
- Performance of used mix in terms of creep, dry shrinkage, resistance to freezing-thawing, and alkali silica reaction (ASR) should be investigated.
- Potential of RCA, and hybrid fibres in the production of high-strength, high-performance, lightweight, and self-consolidating concretes can be investigated.

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Publications Detail

S.No	**Type of Paper (Journal Paper/Conference proceeding/Book Chapter)**	**Name of the Journal/Conference**	**Jounal indexing (Scopus/UGC/ Web of Science)**	**Title of the Paper**	**Published Date (Date/Month/Year)**
1.	Journal Paper	African journal of biological sciences	Scopus	Optimum replacement of waste marble dust as partial replacement of sand in sustainable construction material "	22-06-2024
2	Conference proceedings	IOP conference proceedings: earth and environmental sciences	Scopus	Self-compacting geopolymer concrete using Class F Fly Ash	Published on 16th May 2024
3.	Conference proceedings	International UKIERI Concreter Congress Sustainable Concrete Infrastructure	NA	Flowability and passing ability of Geo-Polymer fly ash based Concretre	Published on 16th May 2024
4.	Journal Paper	European Chemical Bulletin	UGC	Effect of GGBFS on fresh and hardened properties of self-compacting geopolymer concrete cured at ambient temperature	17-05-2023

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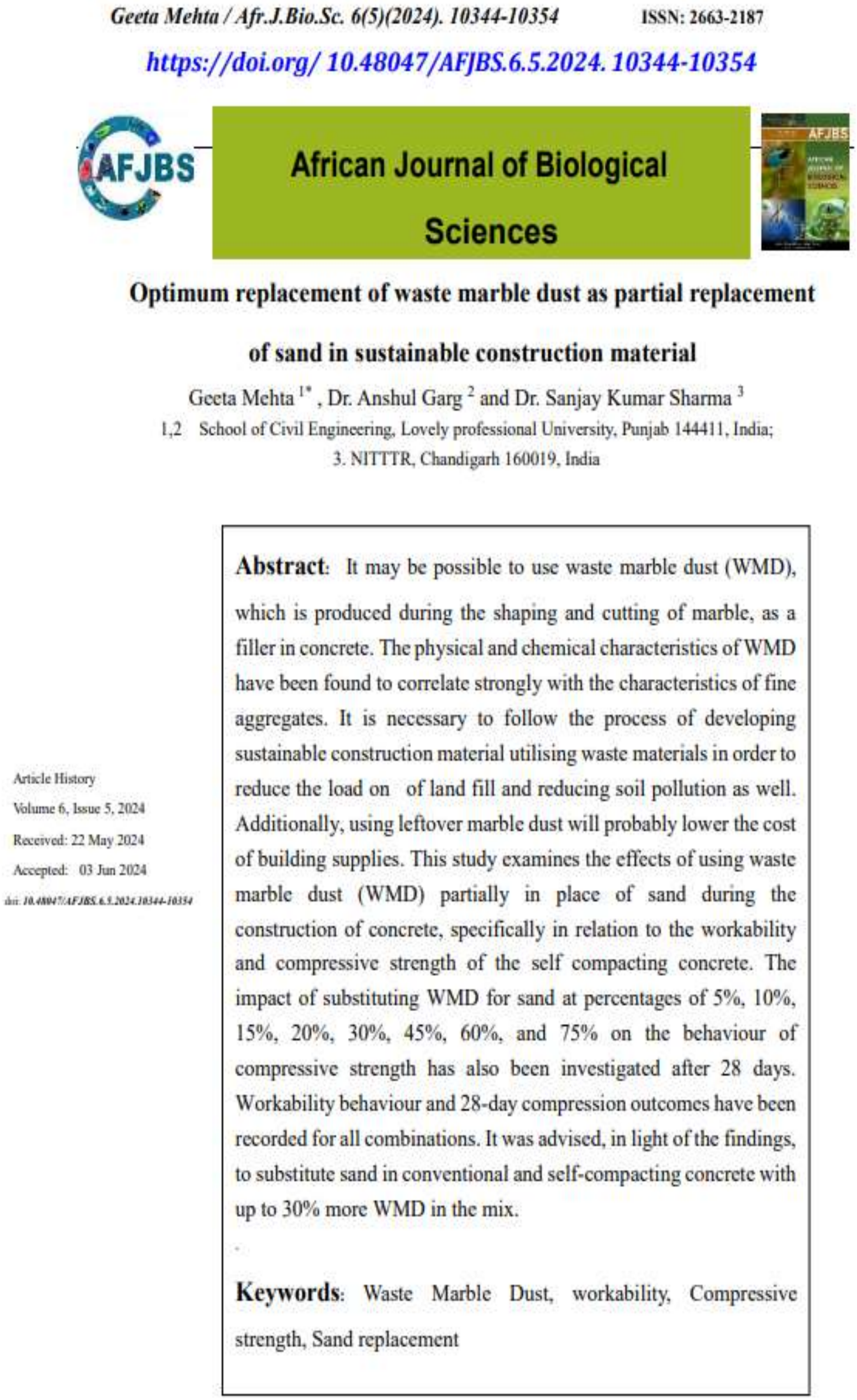

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Optimum replacement of waste marble dust as partial replacement of sand in sustainable construction material

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Abstract: It may be possible to use waste marble dust (WMD), which is produced during the shaping and cutting of marble, as a filler in concrete. The physical and chemical characteristics of WMD have been found to correlate strongly with the characteristics of fine aggregates. It is necessary to follow the process of developing sustainable construction material utilising waste materials in order to reduce the load on of land fill and reducing soil pollution as well. Additionally, using leftover marble dust will probably lower the cost of building supplies. This study examines the effects of using waste marble dust (WMD) partially in place of sand during the construction of concrete, specifically in relation to the workability and compressive strength of the self compacting concrete. The impact of substituting WMD for sand at percentages of 5%, 10%, 15%, 20%, 30%, 45%, 60%, and 75% on the behaviour of compressive strength has also been investigated after 28 days. Workability behaviour and 28-day compression outcomes have been recorded for all combinations. It was advised, in light of the findings, to substitute sand in conventional and self-compacting concrete with up to 30% more WMD in the mix.

Keywords: Waste Marble Dust, workability, Compressive strength, Sand replacement

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