EVALUATING THE EFFECT OF STONE DUST AND GLASS POWDER ON THE FLEXURAL BEHAVIOR OF REINFORCED CONCRETE BEAM AND BOND STRENGTH OF CONCRETE

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Dedication

To My Worthy

Parents and

Teachers.

ACKNOWLEDGEMENT

To Allah almighty, the most merciful and most gracious, who gave me the courage and strength to come this far, and made me able to achieve yet another milestone of my life.

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ABBREVIATIONS

CTR: Control Batch

GP: Glass powder

SCM: Supplementary cementitious material

G10: 10% Cement replacement by Glass powder

G20: 20% Cement replacement by Glass powder

G30: 30% Cement replacement by Glass powder

SD50: 50% sand replacement by stone dust

SD60: 60% sand replacement by stone dust

SD70: 70% sand replacement by stone dust

G10+SD50: 10% Cement replacement by Glass powder with 50% sand replacement by stone dust

G20+SD60: 20% Cement replacement by Glass powder with 60% sand replacement by stone dust

G30+SD70: 30% Cement replacement by Glass powder with 70% sand replacement by stone dust

PCSIR Lab: Pakistan council of scientific and industrial research laboratory

ABSTRACT

Concrete is most widely used man-made material in the construction industry while cement is widely used cementitious ingredient in the present day concrete. However the use of cement lead to global warming due to the emission of carbon dioxide to the atmosphere and the rapid growth in construction industry is leading to shortage of concrete materials. Therefore to overcome on such problems and to address the environmental concerns, apart from other pozzolanic materials (Fly ash, Silica fume, and GGBS etc.) waste glass and stone dust have been replaced individually for evaluating different properties of concrete. Waste glass and stone dust were found the best alternatives to be utilized in concrete by replacing cement and fine aggregate respectively. As the area of replacing both the glass powder and stone dust simultaneously is still scanty so, the main purpose of this study is to investigate the individual as well as combine effect of stone dust and waste glass powder on the flexural behavior of reinforced concrete beam, compressive strength, and bond strength of concrete by substituting different percentages of stone dust with fine aggregate and cement by waste glass powder. In this research waste glass powder is used as 10%, 20%, and 30% replacement of cement while stone dust is used as 50%, 60%, and 70% replacement of sand which results in optimum dosage of crushed glass as 20% and that for stone dust is 60% individually. Furthermore Response Surface Methodology, a statistical analysis through Minitab's software were performed to choose the best three combinations of glass powder and stone dust. Both the predicted results from software analysis and experimental results were found comparable and maximum is achieved at 12% cement replacement by glass with 37% sand by stone dust.

CHAPTER 1

INTRODUCTION

1.1 General

Cement manufacturing industry is one of the major contributors to the release of CO_2 gas to the atmosphere. The cement manufacturing industry contributes about 7% to the total emission of CO_2 gas worldwide of which 50% from chemical process and the rest 50% from burning fuels (Malhotra, 1998). The CO_2 emission from one ton of structural concrete while using 14% cement was estimated to be 410 kg/m3. By replacing cement with fly ash the mentioned amount can be decreased to 290 kg/m3. (Samarin, 1999).

Similarly solid waste management is a serious problem in Pakistan. Every year more than 5 million people die due the solid waste related diseases. Pakistan generated about 48 million ton of solid wastes annually with an annual growth rate of 2%. Waste glass an industrial waste and stone dust the byproduct of stone crushing plants are such waste materials which are disposed to the landfill and dump sites. Due to the environmental concerns and increased disposal cost the waste glass and stone dust has attracted a lot interest worldwide to be used in concrete.

Cement and fine aggregate are the two main constituents among the ingredients of concrete mix. Sand plays the role of filler material and also contribute to the density of concrete while the cement is used as a binding material in concrete. In construction industry cement and sand are the most commonly used binder and fine aggregate. As these materials are unsustainable so due to the the rapidly increased consumption of cement and sand the naturally available resources of these materials are getting exhausted. Pakistan is also facing such problems. Therefore proper investigation is needed in this field to find useful alternatives for cement and sand replacement.

Glass is amorphous in nature and containing large quantity of calcium and silica. Glass show pozzolanic behavior when ground finely. Due to pozzolonic behavior and fine particle size glass can be used as a cement replacement. Similarly the properties of stone dust is almost same to that of the natural occurring sand. Hence the stone dust and waste glass can be the best alternatives for cement and sand. The use of such waste materials and industrial byproducts not only make the infrastructure economical but also reduce the environmental hazards and leads to the sustainable development. Safe disposal of waste materials can also be achieved by recycling and utilizing these solid wastes.

1.2 Objectives

Objectives of the research are:

a. To study the effect of stone dust and glass powder on the bond strength of concrete.

b. To evaluate the effect of stone dust and glass powder on the flexural strength of reinforced concrete beam.

c. To assess the individual as well as combined optimum dosages of glass powder and stone dust.

d. To perform Response Surface Methodology (RSM), a statistical technique through Minitab software for selecting the three possible best combinations.

e. To compare the predicted values from software and experimental values by performing tests.

1.3 Research Significance

The significance of the study is to check the behavior of concrete using glass powder and stone dust individually and in combination. Similarly to create awareness about utilization of waste materials in concrete and investigating waste materials substituted concrete performance with the ordinary plain or conventional concrete.

Here are some other major significances:

- Safe disposal of waste materials can be achieved by recycling and utilizing waste glass and stone dust.
- Use of such waste materials is not only lead to economical infrastructure and sustainable development but also reduce the environmental hazards.
- Glass show pozzolanic behavior which greatly contribute to the later age's strength of concrete.
- The viable and meaningful contribution of stone dust and glass powder to the concrete industry.
- Prevention of depletion of naturally available resources.
- Concrete will show better thermal insulation due to the presence of very small grinded particles of glass powder.
- Stone dust will contribute in making a dense concrete.
- It will encourage the use of easily available local non-conventional ingredients in concrete.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Concrete is a well-known worldwide used material. Keeping in view the modern developing world infrastructure no one can deny the importance of concrete in the modern global village. The natural available resources of concrete ingredients are vanishing rapidly due to the increased rate of infrastructure in today's developing society which may results in an unsustainable development in the very next future. So for countering these problems and to overcome on the depletion of natural available resources of sand and cement, researches have been conducted and many other materials other than waste glass powder and stone dust are being tested and their effects on the properties of concrete have been studied. As the glass shows pozzolanic and even cementitious properties when it is grinded very finely and also stone dust is almost similar to sand in nature and properties when tested for replacement of sand, so finely grinded waste glass powder and stone dust a byproduct of stone crushing plants can be used as a replacement of cement and sand respectively.

Stone dust and waste glass have been used in construction industry as a replacement of cement, fine aggregate, and coarse aggregate and their effect on the behavior of concrete is being studied in term of compressive strength, flexural strength, tensile strength, thermal properties, and workability.

2.2 Concrete

Concrete is a solid hardened material made from water, cement, sand, and coarse aggregate. By mixing these ingredients in a proper design proportion one may achieve the concrete of desired strength and properties. When the water is added to mixed volume of cement, sand, and coarse aggregates, the water reacts with cement and the hydration process start which gives calcium silicates hydrates (C-S-H) and calcium hydroxide (CH). Calcium silicate hydrates responsible for strength of concrete while calcium hydroxide is responsible for durability of concrete. Concrete is a mixture of water, cement, fine aggregate or sand and coarse aggregate or gravel. Cement is a chemical compound consisting of lime, silica and aluminium oxide. The tri-calcium silicate from cement reacts with water to produce calcium-silicate-hydrate which is a needles shaped material that is responsible for high frictional forces among the concrete ingredients. These frictional forces provide enough strength for the ingredients to stay packed together to prevent slippage and sliding over and breakage. And also to withstand the external loads and to prevent crushing. Concrete is widely used all over the world in billions of tonnes each year and this count is increasing with the passage of time and then with the increasing population of the world and rapid development of new habitats.

2.3 Environmental hazards (pollution)

Although concrete play a vital role in the modern world infrastructure but on the other hand due the high rate of concrete construction activities the today's world is look like a concrete jungle. Apart from the useful usage and advantages concrete has some drawbacks also which needs serious attention to be handled. Due to the production of cement in which combustion is involved toxic gases are emitted to the atmosphere one of which is the emission of carbon dioxide. According to the past researches conducted by producing one ton cement is resulting the emission of one ton of corbondioxide to the atmosphere among which half the gases are from combustion while the other half is from the chemical process. One of the major problems cause by the emission of those gases is the green-house effect. That leads to the rupture of the O-zone layer and increased temperature of the earth.

2.4 Depletion of natural resources

For the production of concrete cement, sand, and coarse aggregates are the main and key ingredients to be used. Cement is a combination of chemical ingredients that are obtained from the natural resources. For example silica, lime, alumina etc., are extracted from the earth's crust. Similarly sand is also occurring naturally available in river beds. Those components when once used are hard to extract back from the finished product. Due the rapidly growth of construction projects and rough use these reservoirs of the resources are depleting day-by-day and we do not have any source or proper way to recycle them back. So there is only single possible way to think about the alternative sources and agents which can perform the same duties of cement and sand. The need is based on the concept of sustainable development, that states that we should use the natural resources in such a manner that needs of the next generation are not affected.

2.5 Useful substitutes

To overcome on the depletion of naturally available resources of these different materials researchers are struggling constantly to fine such a use substituents which can be extracted from the waste materials and byproducts, and also which contribute to the performance of concrete and without affecting the properties of concrete. In this run many pozzolanic materials, mineral additives like accelerators, retarders, dispersants, and light-weight additives, and chemical admixtures are being used in concrete which gave satisfactory results. Chemical admixtures are the ingredients added to concrete immediately before or at the preparation of mix of concrete. These are added to reduce the cost of concrete and to enhance or alter the properties of hardened concrete. Among the mineral admixtures are the pozzolans. Pozzolans are the mineral admixtures which has little or no cementing properties of its own but in the presence of moisture react with the CH yielding CSH a gelling product.

2.6 Pozzolans

Pozzolans can be define as" the siliceous or siliceous and aluminous materials which do not have their own cementing properties but when they are finely ground and in the presence of water they react chemically with calcium hydroxide under normal conditions yielding products with gelling and cementing properties which is calcium silicate hydrates or CSH.

2.7 Pozzolanic Materials

The pozzolans is a very broad category which include a wide variety of materials that vary in terms of its origins, compositions, and properties. The natural and the man made materials that possess Pozzolanic nature are used as SCM. Pozzolans can also be prepared by artificial means. For example the metakaolin is obtained from the thermal activation of kaolin clays. Similarly the fly ash is obtained as a by-product of fired coal in the furnace. Fly ash, silica fume, GGBS, metakaolin, and organic residues obtained from burning process such as rice husk ash are the currently well-known pozzolans. In some countries the use of Pozzolanic materials has been termed mandatory. The problem with the high quality Pozzolanic by products is that its supply is limited and many of the local sources have already been depleted. To overcome the problem of depletion of natural pozzolans many alternatives are found which come in the category of artificial pozzolans. An effort is also made to find out the Pozzolanic materials in the societal wastes to reduce the usage of naturally occurring Pozzolanic sources. The countries which are rich in natural pozzolans are Italy, Germany, Greece, and China. These are also the countries where pozzolans are extensively used as a substituent to the OPC.

2.8 Use of Pozzolans

The usage of Pozzolanic materials contribute to the construction industry mainly by three ways. These three ways are contributing to the economy, use of societal and industrials wastes, and the third one is prevention of the poisonous gases to the atmosphere and contribution to the strength and durability of concrete by imparting extra gelling product

The maximum permissible replacement of cement by pozzolans is depending upon the nature and type of pozzolanic material to be used. The replacement depends upon also on the desired properties including the setting time, cost reduction, pollution reduction, and increasing durability without significantly disturbing the performance of concrete and reducing the compressive strength. The higher compressive strength performance and better durability of Pozzolanic substituted concrete are attributed to the Pozzolanic action of consuming CH and production of additional CSH.

The use of pozzolanic materials in concrete contributes to the later age's strength while at initial stages it may reduce the strength by a small amount in case of denser binder. The reactivity of Pozzolanic materials also depends upon the surface area, the finer the material the higher it is reactive and comparatively higher strength can be observed t early stages. Pozzolans also increases the service life of structures and eliminates the cost of replacement of damages in construction. The reason for the higher durability is the reduction of CH in concrete which is an active agent in the deterioration of concrete and also prevent the chlorine attack by blocking the way of harmful ions to enter concrete.

2.9 Glass

Glass is a non-crystalline amorphous solid that is generally transparent or semi-transparent and is widely used for various decorative and technological purposes. The decorative purposes glass is used in windows, doors, tables, cupboards, cooking utensils, dishes etc. while technically the "Glass" is used for all the non-crystalline amorphous solids that show glass like properties when heated to liquid state. The main component of glass composition is silica (quartz) which is also the basic component of sand. There are many types of glasses. The different types of glasses are fused silica glass, soda-lime glass, sodium borosilicate glass AKA Pyrex, lead-oxide glass, alumina-silicate glass and oxide glass. The major use of glass is mainly due to its clear and decorative shape, which is important in the scientific or technological usage like tele-scopes, magnifiers, cameras TVs etc.

Figure 1 waste glass powder

2.10 Properties of glass

Important properties of glass that make it useful and distinct:

1) Melting point of glass is not too much sharp.

2) Glass transmits light, absorbs, and refracts light.

3) Glass is effected mainly by Alkalis.

4) Glass has amorphous and non-crystalline structure.

5) Glass has a very brittle and solid nature.

6) The air and water has negligible effect on the glass.

7) It is available in a variety colors making it suitable to be used for different purposes.

8) Different glasses can be welded together through fusion process.

Despite being used for many centuries the glass is the material which is still not fully understood in terms of usage and composition. To get the maximum output of the glass, the new features and performances many new researches and investigations are performed and are continue.

2.11 Properties of concrete

2.11.1 Slump and workability

Workability is generally define as the ease with which the concrete can be handled, place, and finish in its fresh sate. Workability is measure through different tests one which is slump test a well-known test for indicating the workability of concrete in fresh state. Workability mainly depend on the water cement ration used, use of SCM, and use of admixtures etc.

The amount of water that is required for the hydration of cement is usually less than half of the amount of water present in the concrete mix. All of the excess of amount of water plays role in the workability of the concrete. This extra amount of water is called water of convenience. By adding pozzolans such as glass powder reduces the need for this extra water or water of convenience providing the same workability. The reason behind this is the plasticizing action that results into a reduction in the amount of water in the plastic concrete up to 10% without disturbing the slump value. As the glass powder that is finely ground (<75 Microns) has approximately the same surface area as that of OPC. The glass has smaller specific gravity than that of cement and the cement is replaced with glass by weight, hence the volume of glass is more than that of the cement resulting in larger amount of paste in the fresh concrete. On the other hand glass is a hard material and a late hydrant that means that it does not absorb water from the fresh concrete unlike cement. This behaviour of the glass powder results in higher workability of the fresh concrete and so the slump value increases with the increasing percentage replacement of cement by glass. similarly the stone dust adsorb the water which results in decrease in workability that's why the water to cement ratio is kept 0.5 in this research which will contribute to achieve reasonable workability although using stone dust but less than that of the mix with glass powder substituted.

And similarly in the combine batch of using both glass and stone dust in combination the decrease in workability is counter with the use of glass powder which does not absorb water and having more paste production is resulting a concrete mix with satisfactory workability.

2.11.2 Compressive strength

Compressive strength is the resistance of concrete to the maximum applied load under compression. Water cement ratio, cement strength, quality of raw materials, mode of mixing, properties of ingredients, use of SCM etc. are some main factors affecting the strength of concrete.

In past researches have been carried out on the investigation of compressive strength of concrete while using the glass powder and stone dust and reasonable results were obtained. For The compressive strength of the concrete the compressive strength test is performed in the labs on the concrete cylinder specimens under the established code standard of ASTM as ASTM C39/C39M and the strength of concrete is observed increased as discussed in the preceding sections.

2.11.3 Bond Strength of concrete

Bond strength of the concrete is basically the resistance to the failure of bond between the concrete and reinforcement. The bond strength of concrete is obtained by performing the pull out test through the universal testing machine on the cube specimen having #6 bar in its centre. The reinforcement is pull out from the centre of the cube specimen by applying load through the UTM machine which is discussed in details in the coming section of the thesis. In past many researches have been conducting on the measurement of bond strength of concrete through pull out test by using different materials which gave outstanding results.

2.11.4 Flexural Strength

Flexural strength is also known as the modulus of rupture, bend strength, or rupture strength which depends on the dimensions of the beam and manner of loading applied. Tests were performed on reinforced concrete beams samples in which 4#4 main bars and #2@5" c/c stirrups were provided in 20 inces length. The dimensions used for the beam sample is (6"x 6"x 20") and the samples were casted and tested according to the standard procedure of ASTM code designation. In the past works have been done on the flexural strength of reinforced concrete beam while using glass powder and stone dust and after testing and the behaviour of concrete the flexural strength is found increased.

2.12 Researches Carried Out In Past

2.12.1 General

As the emission of CO_2 to the atmosphere is the main cause of global warming and cement manufacturing industry is the main contributor to the emission of CO_2 to the atmosphere. Malhotra (1998) studied that cement manufacturing industry contribute about 7% of the total emitted carbon dioxide to the atmosphere worldwide.

Parallel to this the devastation of sand is also a serious problem due to the fast growing infrastructure nowadays. Keeping these issues in mind researchers are investigating to find out useful substituents for cement and sand. In this run many products have been tested and their effects on concrete were studied. Among these different materials researchers were mostly attracted by the industrial wastes and by products like stone dust, marble waste, waste glass, silica fume, ground granulated blast furnace slag, and other chemical and mineral admixtures. Use of such materials were found advantageous in sense of contributing to the economy, enhancing the strength of concrete, utilization of waste materials and by products, and also these materials were found environmental friendly.

Islam et al. (2016) conducted research work to study the effect of waste glass powder on the behavior of concrete and mortar. The cement is replaced by waste glass powder with different percentages from 0 to 25% following an incremental order of 5 percent. Specimens were tested at 7, 14, 28, 56, 90, 180, and 365 days. Overall results showed that at 20% replacement the compressive strength is found 2% higher than that of the control specimens at the age of 90 days. It was also concluded that utilization of waste glass decreased the cement production and construction cost by 14% and reduced the emission of CO_2 by 18% to the environment. Raju and Kumar (2014) replaced cement with varying percentages of glass powder from 5 to 40% with increments of 5% and the compressive and tensile strength were studied at the ages of 7, 28, and 90 days. Maximum strength is observed at 20% replacement. The compressive strength is increased by 30%, 24%, and 24% as compared to control batch for 7, 28, and 90 days. It is also observed that flexural strength of concrete with 20% replacement of cement by glass powder is increased by 27%, 20%, and 17% as compared to conventional concrete at the ages of 7, 28, and 90 days.

Srivastava (2014) used the waste glass as a replacement of coarse aggregate and observed that the compressive strength is reduced from 30 to 40% replacement and up to 20% replacement the strengthis increased.

Adaway and Wang (2015) used the waste glass as a partial replacement of sand in order of 15, 20, 25, 30, and 40% and studied the compressive strength of concrete at the age of 28 days. The results showed that at 30% replacement of sand by waste glass the compressive strength is increased by 6% than the control specimen at the age of 28 days.

Das and Gattu (2018) studied the behavior of concrete using stone dust as partial replacement of sand. Stone dust is incorporated as 0, 20, 40, 60, and 80% in concrete and the compressive strength, split tensile strength, and behavior of reinforced concrete beam is studied. The research outcomes show that the compressive strength is increased by 10%, tensile strength by 30%, and flexural strength of RC beam is increased by 12% at 40% replacement of sand by stone dust.

Vijayakumar et al. (2013) partially replaced cement by waste glass at the level of 10, 20, 30, and 40% and test the samples for compressive, flexural, and tensile strength at the age of 60 days. The results showed a considerable increment in the concrete strength and also it is found that using glass powder of particle size less than 75μm reduced the alkali silica reaction in concrete. Abbas et al. (2016) investigated the effect of stone dust on compressive strength of concrete at 7 and 28days. They concluded that optimum percentage for the replacement of sand by stone dust is 60%. The compressive strength is increased by 11.45% at 28 days when the sand is replaced by 60% with stone dust. Ingalkar and Harle (2017) incorporated stone dust in concrete to check its compressive and tensile strength. The fine aggregate is replaced from 10 to 100% with stone dust.

The compressive strength is observed increasing from 40 to 50% replacement while the tensile strength is increased from 60 to 70% replacement of sand by stone dust.

Kode (2007) studied the behavior of concrete by replacing fine aggregate with various percentages of stone dust. The results of the study showed that with the substitution of stone dust the compressive strength is enhanced by 10%, tensile strength by 24%, and flexural strength by 26%

as compare to control specimens. Based on the results obtained the study reveals that stone dust is a good alternative for natural sand.

Balamurugan and Perumal (2013) replaced sand with stone dust from 0 to 100% with increments of 10%. The compressive, tensile, and flexural strength of RCC beam is studied for M20 and M25 grade concrete. The results show that compressive strength is increased by 19.18% and 5.12%, tensile strength is increased by 21.41% and 14.51%, and flexural strength for RCC beams is increased by 9.31% and 8.43% for M20 and M25 grades respectively as compare to conventional concrete.

Srivastava et al. (2015) replaced sand by stone dust from 0 to 100% at an interval of 10 and check the concrete strength at 7 and 28 days. The result of the study showed that the compressive strength is increased from 8 to 27% to that of conventional concrete while at 60% substitution of stone dust the compressive strength of the concrete is enhanced by a significant amount and the workability of the concrete is decreased. Beyond 60% replacement the strength is reduced as compare to control samples and hence it is observed that 60% is the optimum replacement level of stone dust

2.12.2 Conclusion

According to past researches and mentioned literature substitution of waste glass and stone dust in concrete had a positive response to the strength of concrete due to which these can be good alternatives for cement and sand in concrete. Higher compressive strength and better workability can be achieved by partially replacing fine aggregate with stone dust and cement with waste glass powder.

CHAPTER 3

RESEARCH METHODOLOGY

3 Research Methodology

3.1 General

Many studies and researches shows that waste materials with or without pozzolonic properties can be utilize in concrete. Materials with pozzolanic properties can be used in concrete as cement replacement while materials without pozzolanic properties can be utilized as fine aggregate or coarse aggregate in the concrete industry. Similarly the waste materials like stone dust or artificial sand and waste glass can also be used in concrete as fine aggregate and cementitious material respectively. The replacement can be done at reasonable blending ratios. From the previous researches and work performed it came to the front that the use of these materials is not only environmentally friendly but also economical and enhancing the strength of concrete by a considerable amount. Thousands of tons of glass is manufacturing worldwide on the daily basis out of which a considerable amount is wasted which is almost 8% of the total manufactured glass. Parallel to this a huge amount of stone dust which is a byproduct of crushing plants is considered useless and so wasted to dump sites and landfills. Finally all of these wastes are stored in the earth causing serious environmental problems which caught the eye of the environmentalists who are concerned about the environmental hazards. And thus they start thinking about the utilization of these waste materials in different fields like concrete industry etc. to go ahead towards green construction and sustainable development.

The replacement of such materials changes the properties of concrete by taking part in the hydration reaction resulting the gelling like hydration product CSH by consuming the CH released from the cement hydration reaction.

Such action take place due to the pozzolanic nature of glass material. While the stone dust does not undergo through the pozzolanic reaction and imparting strength to concrete through normal reaction like sand. The changes in the properties of concrete due the pozzolanic and non pozzolanic materials are different because of their chemical compositions and reactivities.

Many studies and researches have been conducted to evaluate and identify different problems related to concrete structures and then how to assess them and overcome on these problems through different techniques and approaches. Failure of bond between reinforcement and concrete and failure of reinforced concrete beam in flexure are the main types among the failures in the concrete structures. These problems have been assessed and studied from different aspects, and some useful assessment techniques and approaches are introduce and presented to solve this problem. Providing deeper sections, increasing the section modulus (Z), and using the shorter spans are some the techniques among those solutions which were provided in the past while for bond strength several other techniques were adapted. As the past researches shows that providing the reinforcement as well as incorporating the waste materials having pozzolanic properties and other waste materials with no pozzolanic properties in concrete shows better results in terms of both the economy of the structures and strength with durability. Thus we can also hope that by using such waste materials that are waste glass and stone dust we can assess the problems of failure of bond of concrete with reinforcement and failure of reinforced concrete beam in flexure, study its effects and evaluate the results.

3.2 Materials:

Following are the details of the materials used in experimental work:

3.2.1 Cement:

Type-1 cement OPC under ASTM C150 is used throughout the experimental work for preparation of mix for all batches.

The cement used was "BESTWAY CEMENT" which was procured from the local supplier "ANWAR BROTHERS AND CO" at Saddar bazar Risalpur cantt.

3.2.2 Aggregate:

The fine and coarse aggregates, confirming to the ASTM standard, as ASTM C33/C33M were brought from local quarry of "SADDAR, RISALPUR".

3.2.3 Stone Dust:

The stone dust is also purchased from local quarry of "SADDAR, RISALPUR".

3.2.3 Steel:

The steel reinforcement bars for beam samples were purchased and prepared from the local available supplier "ANWAR BROTHERS AND CO" at Saddar bazar Risalpur cantt.

3.2.4 Glass:

Glass Powder has been procured from "GUNJ GLASS FACTORY, HASANABDAL". The Glass powder used in the research is transparent soda lime glass. The glass is per Standard of JIS R3202-1996.

From **Table-3.1**, the chemical composition of glass shows that the material may have Pozzolanic potential which can be attributed due to the fact that the accumulative chemical composition of SiO_2, Al_2O_3, and Fe_2O_3exceeds 70% by proportion. Another property that governs the Pozzolanic potential is its particle size. The particle size of glass equal to or less than that of the cement particle size is achieved by grinding the waste glass through "BALL MILL GRINGING MACHINE "at PCSIR lab Peshawar.

The particle size of the glass provided by the PCSIR lab Peshawar is ≤74 microns which satisfies the cement particle size and also confirm to show the pozzolanic behavior. Similarly the Blaine Air Permeability Test area of glass performed at "COMSATS University Abbottabad" is 2119.97 cm^2/ gm which also gave an evidence of the material to ensure as Pozzolanic Material. The chemical composition of the glass was provided by the GUNJ Glass Factory.

The physical and chemical properties of Ordinary Portland Cement and Glass are shown in the table.

Table 1 chemical and physical properties of glass and cement

Chemical Properties									Physical Properties	
Constituents	Ca0	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Na_2O	Fineness	Color
	%								%	-
OPC	65.7	21.9	3.4	3.7	1.5	2.9	0.4	0.9	91.2	gray
GLASS	8.79	74.33	0.15	0.087	3.91	0.15	0.03	11.69	95.4	Grayish white

3.3 Experiments

3.3.1 Materials Characterization Tests

For mix design the following tests were performed on the procured materials in the concrete lab of "MILITARY COLLEGE OF ENGINEERING (NUST) RISALPUR CANTT". All the tests performed are briefly discussed as following.

I. Specific Gravity of C.A, & F.A
II. Moisture Content of C.A & F.A
III. Water Absorption of C.A & F.A
IV. Fineness Modulus of Sand and Stone Dust
V. Bulk Dry Density of C.A
VI. Max. Size of Coarse Aggregate
VII. Fineness of Cement and Glass Powder

Specific Gravities

Specific gravity is the ratio between the densities of a particular material to the density of the water. Specific gravity of fine and coarse aggregates, cement, and glass were find under the ASTM standards as ASTM C127-88 and ASTM C128.

Coarse and Fine Aggregates:

After cleaning the graduated cylinder it is weighed on a sensitive digital weight balance and some water of known volume is poured into the graduated cylinder. Find out its new weight and noted.

After that the surface saturated dry (SSD) aggregate of known weight were placed into that cylinder containing the water. The raised up volume of the cylinder is noted and its difference before and after the placement of aggregates is calculated which is termed as volume of placed aggregates. The weight of the aggregate was divided by the volume of aggregates which gave us the density of the material. After that density of the aggregate is divided by the standard density of water which resulted in the specific gravities for the material.

Cement:

For finding out the specific gravity of cement the same procedure is repeated as that for the coarse and fine aggregates. But the water was replaced by kerosene oil in order to prevent the hydration reaction.

Glass:

The same procedure as that of the aggregates is followed to find out the specific gravity of glass powder.

Moisture Contents of Fine and Coarse Aggregates

To find out the moisture content of the aggregates ASTM standard as ASTM C-566 is followed. Aggregate was taken and spread in the open air at room temperature to be in contact with air for 2 to 3 hours. Then the aggregate is weighed and about 2 kg of the sample is placed in the oven for the next 24 hours without disturbing at constant temperature. The sample is removed from the oven after 24 hours and weighed again on a digital weight balance. The new weight (oven dried weight) is noted and the weight lost is found out. After that the weight lost is divided by the dry weight of the sample and multiplied by 100 that gives the percentage amount of moisture present in the aggregate.

Water Absorption Test:

For finding the water absorption test method under ASTM standards as ASTM C127-88 and ASTM C128. After washing the sample of the aggregate put it the water at room temperature for 24 hours. Then the sample is removed from the water after 24 hours and allowed to drain for a few minutes. Then in the case of fine aggregate the sample is put in open air so that the sun light does not come in contact with sample.

And in the case of coarse aggregate it is turned into SSD from using a towel and put it in open air for an hour or two. Then the sample is weighed and noted as "A". After that the sample is placed in the oven for the next 24 hours is remove after 24 hours and weighed again and noted the dry weight as "B". The difference is found out by A-B, and divided by the B i.e. the dry-weight and

Table 2 gradation of fine aggregate

multiplied by 100. It gives the percentage weight of water

Figure 2 water absorption of coarse and fine aggregate

absorption.

Fineness Modulus of Fine Aggregate:

According to ASTM standard as ASTM C136-05 for finding the fineness modulus of fine aggregate, sieves of 3/8", #4, #8, #16, #30, #50, #100, and pan were taken. An oven dried sample of 2 kg weight of fine aggregate is placed it on the top sieve. After fixing the sieves in sieve shaker in the given sequence shake them for 20 minutes. Then the shaker is stopped and sieves were removed from the top one by one and mass retained on each sieve was noted.

Then the percentage retained on each sieve, percentage passing from each sieve, and cumulative percentage retained were calculated. Summed up all the cumulative percentages retained and divided by 100. The resulted figure gave the fineness modulus of the fine aggregate.

Bulk Dry Density Of coarse aggregate

Take a container of known volume and weight and fill it with loose aggregate in three layers with 25 blows each layer with steel rod (Rodded Compaction). Keep the top surface of the aggregate and the container at the same level and weight it. Find out the weight of the aggregate at that point

Sieve No	Mass Retained	Cumulative Mass Retain	%Cumulative Mass Retain	% Passing	Grading Limits (ASTM C33)
4	0	0	0	100	95 to 100
8	41	4.1	4.1	95.9	80 to 100
16	118.7	11.87	15.97	84.03	50 to 85
30	566.1	56.61	72.58	27.42	25 to 60
50	113	11.3	83.88	16.12	5 to 30
100	130	13	96.88	3.12	0 to 10
Pan	14.3	1.43	98.31	1.69	----

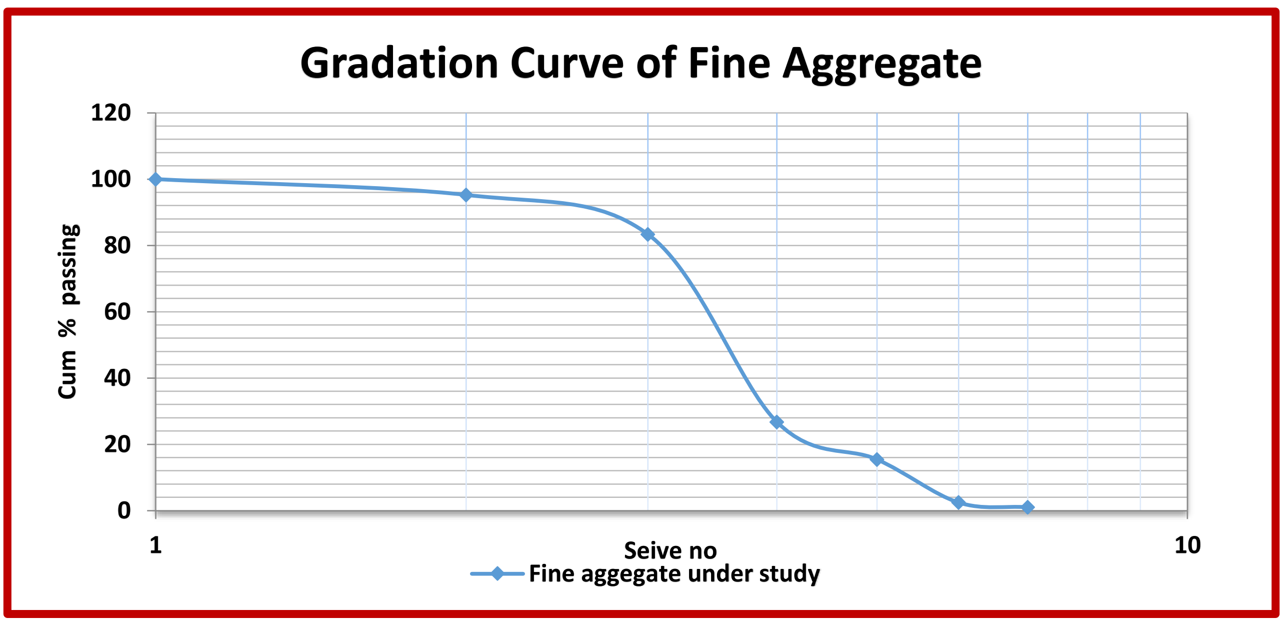


Figure 3 gradation curve of fine aggregate by subtracting weight of the container from the combine weight of the container with aggregate and divide by the volume of the container. The resulted value is the rodded compacted density of the coarse aggregate.

Maximum size of coarse aggregate

To find out the maximum size of coarse aggregate according to ASTM standard as ASTM C136, sieve analysis is performed on a sample of 2-kg. Sieves with size from 5mm to 40mm were used. The sample is placed on the top sieve and shaken for 20 minutes. Then the sieves were removed, and the sieve size which allowed 100% aggregate to pass is checked out. This was the maximum size of the aggregate.

Table 3 gradation of coarse aggregate

Sieve No	Mass Retained	Cumulative Mass Retain	%Cumulative Mass Retain	% Passing	(ASTMC33) Limits
25	0	0	0	100	100
19	120	6	6	94	100-90
12.5	1051	52.55	58.55	41.45	……
9.5	566	28.3	86.85	13.15	20-55
4.75	259	12.95	99.8	0.2	0-10
PAN	14.3	1.43	100	0	…...

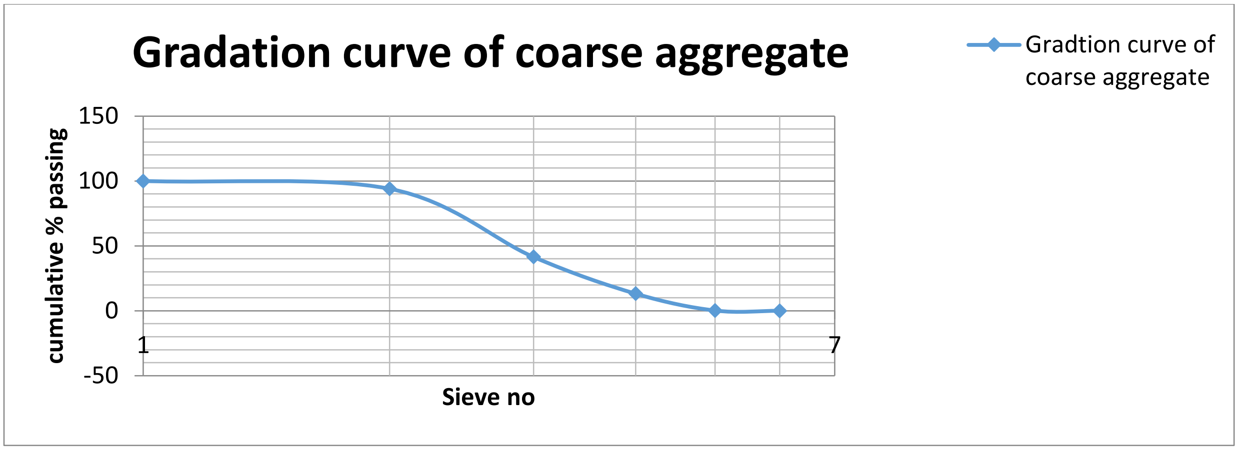


Figure 4 gradation curve of coarse aggregate

Fineness of Cement:

To find the fineness of hydraulic cement the standard procedure under the ASTM standard as ASTM C184-94e1 is followed. A sample of 100 gm cement is taken and put it on an already weighted sieve #200 and then shake it for 15 mints manually. After that the retained sample on sieve #200 is weighted.

The difference between the sieve weight and the sieve sample weight was calculated which is further subtracted from 100 which was the resultant passing percentage of the cement. If the retained weight is 10% then it indicates that cement is in fresh state otherwise the cement is not in fresh state.

Figure 5 fineness of cement

Table 4 Physical property of materials

<table>
<tr><th colspan="7">CEMENT</th></tr>
<tr><td>Property</td><td>Particle Size</td><td>Fineness</td><td>Normal Consistency</td><td colspan="2">Initial Stetting Time</td><td>Final Stetting Time</td></tr>
<tr><td>Value</td><td>≤ 75μ</td><td>91.2%</td><td>31%</td><td colspan="2">48 min</td><td>341 min</td></tr>
<tr><th colspan="7">GLASSS</th></tr>
<tr><td>Property</td><td colspan="2">Particle Size</td><td>Fineness</td><td colspan="2">Color</td><td>Water Absorption</td></tr>
<tr><td>Value</td><td colspan="2">≤ 75μ</td><td>95.4%</td><td colspan="2">Gray</td><td>Nill</td></tr>
<tr><th colspan="7">SAND</th></tr>
<tr><td>Property</td><td colspan="2">Particle Size</td><td>Absorption Capacity</td><td colspan="2">Moisture Content</td><td>Fineness Modulus</td></tr>
<tr><td>Value</td><td colspan="2">4.75mm to 0.075mm</td><td>6.28%</td><td colspan="2">4.8%</td><td>2.73</td></tr>
<tr><th colspan="7">STONE DUST</th></tr>
<tr><td>Property</td><td colspan="2">Particle Size</td><td>Absorption Capacity</td><td colspan="2">Moisture Content</td><td>Fineness Modulus</td></tr>
<tr><td>Value</td><td colspan="2">4.75mm to 0.075mm</td><td>8.37%</td><td colspan="2">2.4%</td><td>2.92</td></tr>
<tr><th colspan="7">COARSE AGGREAGTE</th></tr>
<tr><td>Property</td><td>Max. Aggregate Size</td><td>Specific Gravity</td><td>Particle Size</td><td>Density</td><td>Absorption Capacity</td><td>Moisture Content</td></tr>
<tr><td>Value</td><td><25mm</td><td>2.50</td><td>25 - 4.75mm</td><td>1658 kg/m^3</td><td>2.48%</td><td>0.45%</td></tr>
</table>

3.4 Fresh Concrete Properties

3.4.1 Slump Test:

Standard procedure for slump test under the ASTM standard as ASTM C-143 is used to find out the workability of the fresh concrete mix of all batches. For this purpose the slump cone apparatus is taken and put it on a flat surface and fill with freshly made concrete in three layers compacting each layers with 25 blows by a compacting rod. Then after the filling of cone it is lifted uniformly from both side handles which results fall of the fresh concrete.

Then the compaction rod is placed horizontally on the top of the cone, and the difference between the top of the cone and the fallen top of the concrete is measured by a measuring scale. The value is noted as the slump value.

3.5 Hardened Concrete Properties

i. Compressive Strength Test
ii. Bond Strength Test
iii. Flexural Strength Test

3.5.1 Compressive Strength Test:

Compressive strength is the measure of maximum compressive loading concrete can withstand. The compressive strength test is performed under the standard procedure of ASTM as ASTM C39/C39M and ASTM C837/M for cylindrical specimen having standard dimensions as 6 inches dia and 12 inches length**.** For this purpose the samples were removed from curing tank after the completion of curing period and placed in open air for 2 to 3 hours. After that the compressive testing machine is set to the standard values by load measuring needle at zero and the specimen is placed in between the compressing plates of the machine and the loading is started by turning the loading switch on. The specimen were observed until visible cracks were appeared, at that point the concrete resisted no more loading. Noted down the value of the max load that concrete specimen resisted and this value is taken as the maximum compressive strength of the concrete.

Figure 6 Compressive Strength Test

3.5.2 Bond Strength Test:

Bond strength is the measure of bond between concrete and reinforcement or the resistance between reinforcement and concrete. For Bond strength test the procedure of ASTM C-234 is followed. According to which cube specimen of (6”x6”x6”) with reinforcement in its center were prepared to perform pull out test. According to ASTM standard ASTM C-234 reinforcement of diameter 12.5 mm is embedded up to 4 inches (100 mm) in the center of cube and the specimens were casted. Then after curing, for testing the bond strength through pull out test procedure the cubic sample is placed in universal testing machine so that the reinforcement is gripped between the lower jaws of UTM and the concrete portion of the specimen is placed on the upper moveable piston of the universal testing machine. After placing the sample in the UTM turn on the load switch of the machine and applied load at the rate of not greater than 22KN/mm2. Observed the load increment and sample behavior until the occurrence of failure of the bond between reinforcement and concrete and dispatching of reinforcement from the sample. Note the maximum load at the failure point of the bond between reinforcement and concrete and calculate the bond strength of the sample by using the following formula.

Bond stress = p/πdl

d = Diameter of the reinforcement (mm) =12.5mm

l = Embedded length of the reinforcement (mm) =100mm

p= Load in KN

Caution:

Place the sample in inverted position on the upper moveable piston of the UTM so that the reinforcement is passed from the whole in the upper moveable piston and gripped easily in the lower jaws of the machine and also hold the sample until its gripped tightly in the lower jaws so that the sample can be placed properly and exactly on the center of the upper moveable piston.

Figure 7 pull out test setup

3.5.3 Flexural Strength Test:

To study the flexural behavior of reinforced concrete beam different samples of conventional concrete, glass powder substituted concrete, stone dust substituted concrete, and samples of combined batch of glass powder with stone dust were casted. On the basis of analysis RCC beams are classified as under reinforced, balanced, and over reinforced sections. The concrete and steel both will reaches to the stress and corresponding strains simultaneously due to the external applied load. In under reinforced beam the steel fail first and then concrete and in over reinforced beam the concrete fail first then the steel while in balanced condition both the concrete and steel failed simultaneously. For casting the beam samples wooden moulds having face to face dimensions 150mm x 150mm x 500mm are prepared in which the beam samples of conventional concrete, glass and stone dust substituted concrete and samples of combined batch of stone dust and glass powder substituted concrete having dimensions 150mm x 150mm x 500mm are casted. For reinforcement #4 and #2 bars are used. Two #4 bars are provided at the top and two #4 bars are provided at the bottom. In 20 inches span of the beam a total of 5 stirrups are provided in which two stirrups were provided @2.5" from both sides and 3 stirrups are provided @ 5" c/c in the remaining distance of 15 inches. Put the reinforcement in the moulds and cast the samples and on next day after demoulding put them to the curing.

As the three point load deflection method is very accurate and convenient for investigating the flexural behavior of brittle materials so the three point load method is the best approach for computing the deflections under the applied loads in order to investigate flexural behavior. After completion of 28 days curing the beams were subjected to three point loading by using universal testing machine. For measuring the deflections strain gauges are attached to the UTM by touching the surface of the beam with its needle and set its needle at zero by turning its outer ring. Note down the value at which it take maximum flexural stress.

3.5.3.1 Details of the beam and reinforcement is given in the following picture:

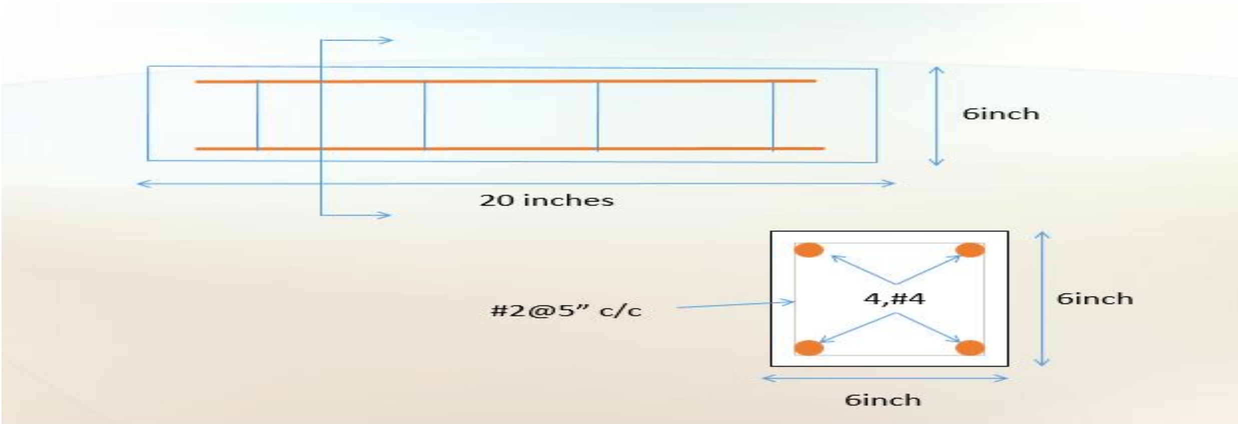


Figure 8 Beam Details

3.5.4 The methodology and experimental work is divided into four phases.

In first phase the materials were procured from the local available industries and quarry sites and then tests were performed on the materials. Cement and steel are brought from the local purchaser "ANWAR BROTHERS AND CO SADDAR BAZAR RISALPUR CANTT: "and glass is procured from "Gunj glass factory Hassanabdal" and grinded at "PCSIR laboratory Peshawar". Coarse and fine aggregates, and stone dust were also procured from locally available quarry sites and tests were performed on these materials.

In second phase mix design is performed after the characterization of materials and trial samples were casted for 7, 14, and 28 days after mix design to reconfirm the performed mix design and strength criteria.

In third phase specimen were casted for compressive strength, flexural strength, and bond strength. A total of 10 batches i.e. one batch of conventional concrete, 3 batches of glass powder substituted concrete, 3 batches of stone dust substituted concrete, and 3 batches of utilizing both glass powder and stone dust in combination were prepared. A total of 10 sets of each containing 9 specimens (3cylinders, 3 cubes and 3 beams) were casted. Control batch is casted without substituting glass powder and stone dust. In next phase glass powder batches were casted in which after casting the control specimens in the first batch, 10%, 20%, and 30% glass powder is substituted with cement in the 2^{nd} , 3^{rd} , and 4^{th} batches respectively. After 28 days compressive, flexure, and pull out tests were performed on these specimens and results were compared with the conventional concrete and optimum percentage of incorporated glass powder which is 20% is obtained. Similarly in next phase sand is replaced as 50%, 60%, and 70% by stone dust in 5^{th}, 6^{th}, and 7^{th} batches and after performing tests on 28days optimum dosage which is 60% is obtained. The obtained optimum dosages of glass powder and stone dust obtained from statistical analysis through Response Surface Methodology (RSM) were further used in combination to evaluate the behavior of concrete. In this run stone dust and glass powder were used as 17% glass powder with 45% stone dust, 19% glass powder with 48% stone dust, and 15% glass powder with 56% stone dust in 8^{th}, 9^{th}, and 10^{th} batches. As a result of performing tests on these batches 17% glass powder and 46% stone dust came to front as the optimum dosages upon which concrete gave maximum strength and also economy can be achieved by utilizing such percentages of the mentioned waste materials.

In fourth phase hardened concrete tests were performed after the 28 days curing. Compressive strength test is performed on cylindrical samples while pull out tests is performed on cubes samples and RC-beams samples were put down to flexure strength test and their effect were studied. As a result of these tests optimum dosages were came into front as 20% for cement replacement by waste glass powder, 60% for sand replacement by stone dust, and for using both in combination it is observed that cement replacement by 17% glass powder and sand replacement by 46% stone dust are the best combination for achieving strength and contribution to the economy.

Results for the combined batches from response surface methodology are given below.

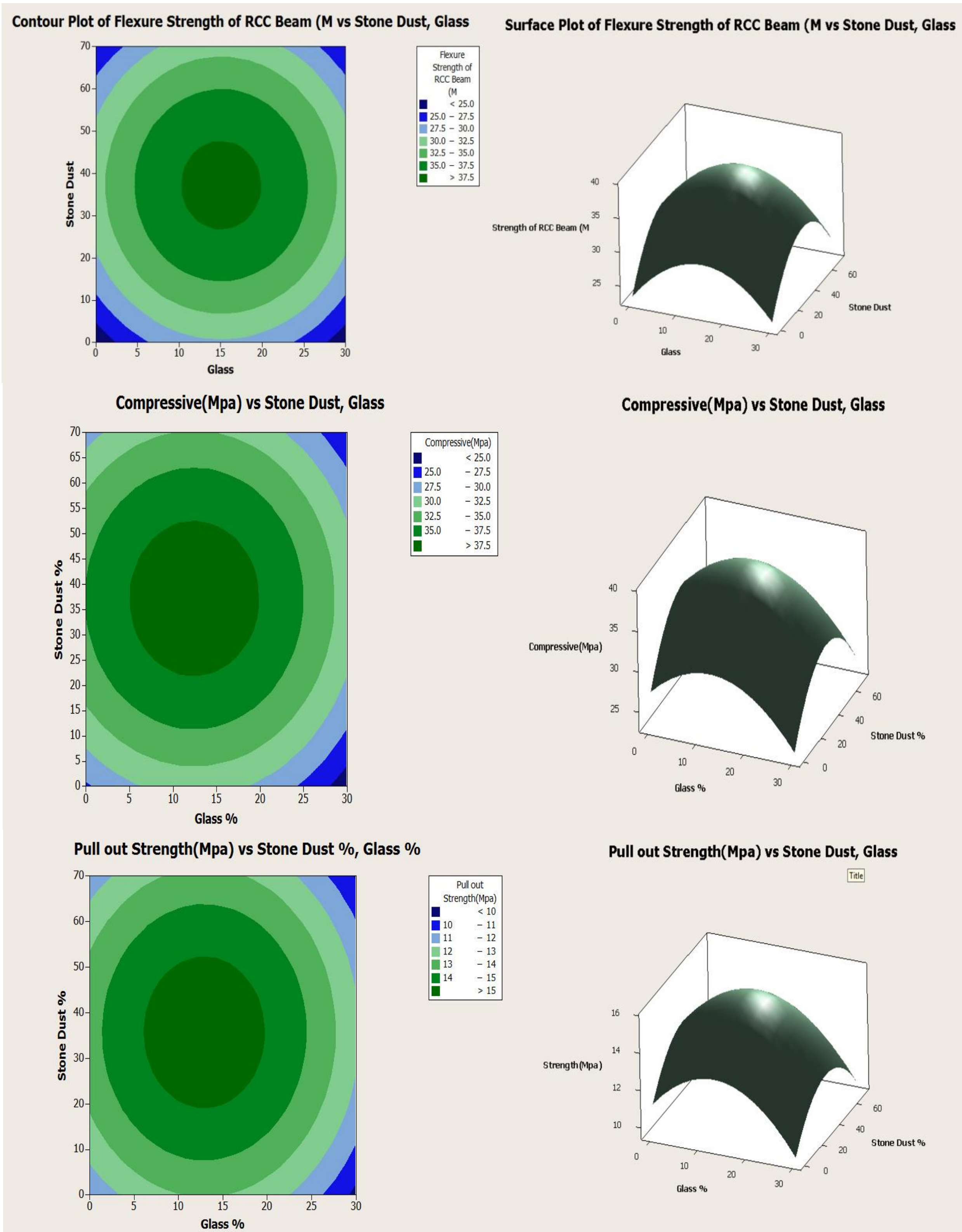
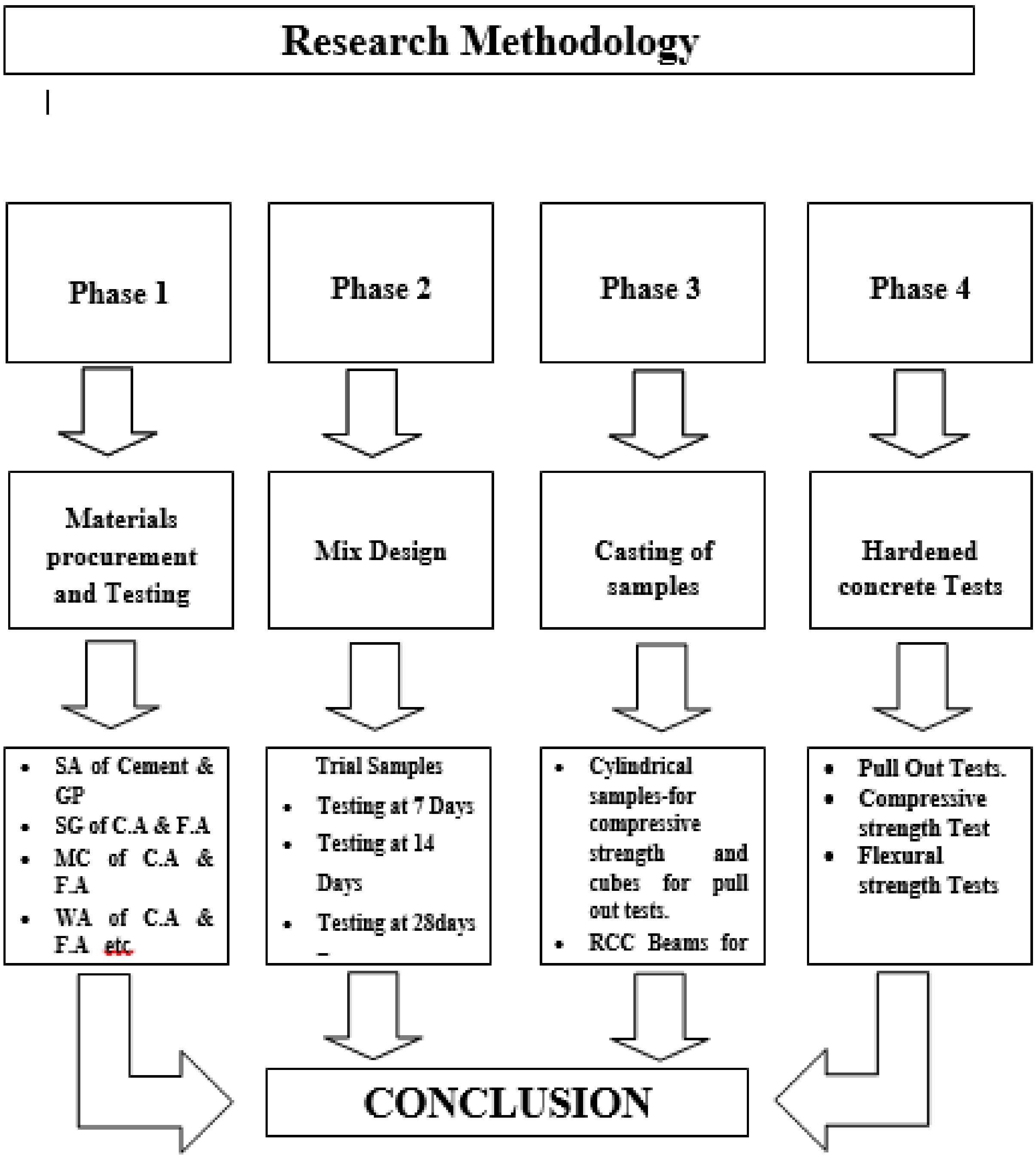


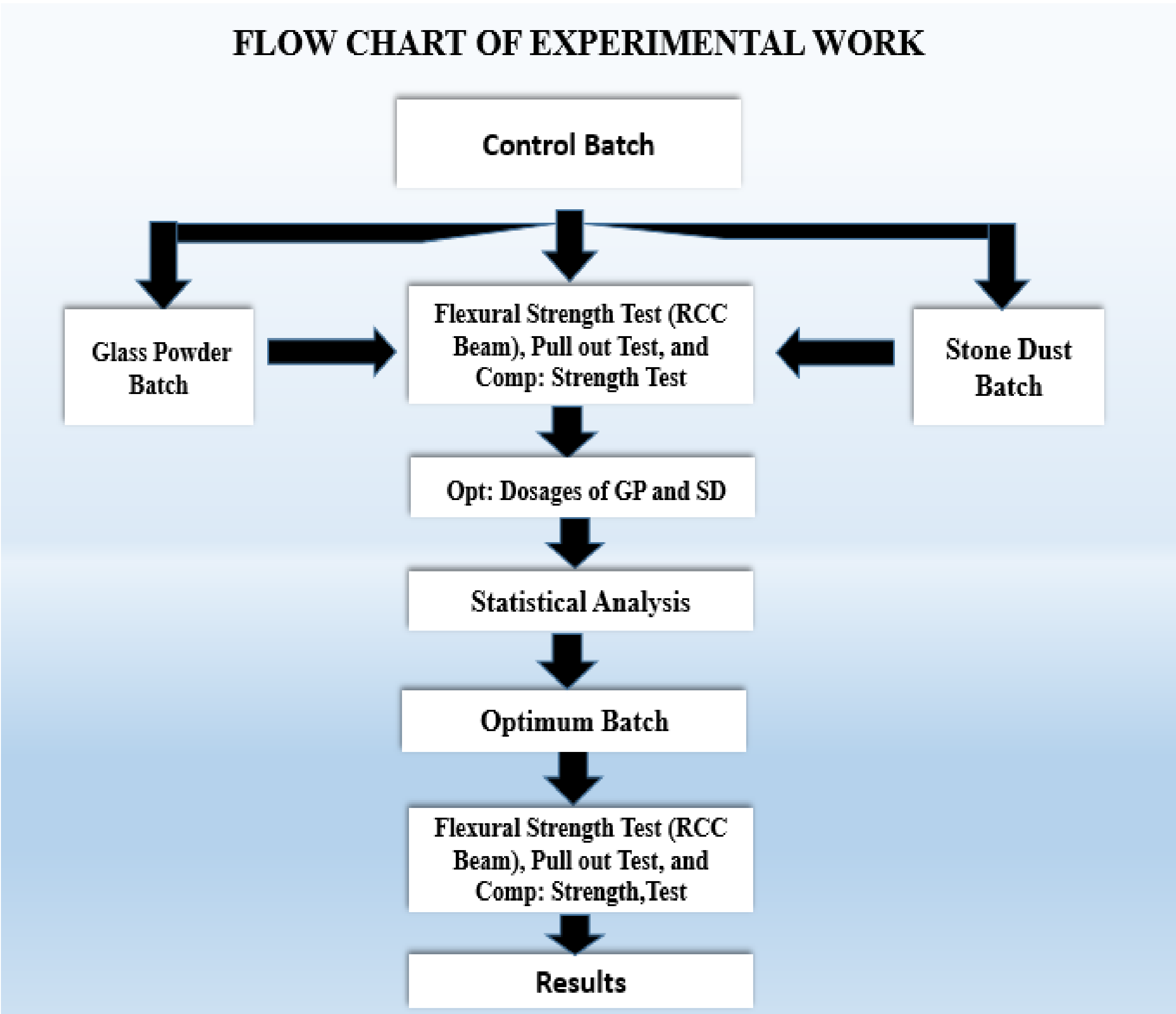
Figure 9 results from response surface methodology

Table 5 quantification of materials

Mix	Cement	F.A	C.A	Glass/Stone Dust	Pull Out Test	No Of RC-Beams	Comp: Strength
CTR	100	100	100	00	3	3	3
G15	90	100	100	10	3	3	3
G20	80	100	100	20	3	3	3
G25	70	100	100	30	3	3	3
SD50	100	50	100	50	3	3	3
SD60	100	40	100	60	3	3	3
SD70	100	30	100	70	3	3	3
12G+37SD	88	67	100	12/37	3	3	3
15G+42SD	85	58	100	15/42	3	3	3
17G+48SD	83	52	100	17/48	3	3	3
No: Of Total Samples					30	30	30

3.5.5 Flow Chart and Lay Out Of Experimental Work




FLOW CHART OF EXPERIMENTAL WORK
Control Batch
Glass Powder Batch
Flexural Strength Test (RCC Beam), Pull out Test, and Comp: Strength Test
Stone Dust Batch
Opt: Dosages of GP and SD
Statistical Analysis
Optimum Batch
Flexural Strength Test (RCC Beam), Pull out Test, and Comp: Strength,Test
Results

CHAPTER 4

RESULTS & DISCUSSIONS

4.1 General:

In this chapter results of the tests performed is discussed. After performing Fresh concrete test (slump test) and hardened concrete tests which are compressive strength test, pull out test for bond strength, and flexural strength test on reinforced concrete test their results were analyzed and now in this chapter these tests results are discussed as follow.

4.2 Properties of Fresh Concrete:

4.2.1 Slump:

For measuring the concrete workability, slump test is performed which measure the workability and consistency of the each batch in fresh state. The workability of each batch of glass powder and also that of the stone dust and combined batches is measured and their results were studied. Slump test results of glass powder batches is shown in the following table.

Table 6 Slump values of Glass powder batches

Concrete	**Slump**	
	mm.	**Inch**
Control Mix	**65.85**	**2.6**
G10 Mix	**97.32**	**3.9**
G20 Mix	**129.30**	**5.1**
G30 Mix	**148.78**	**5.9**

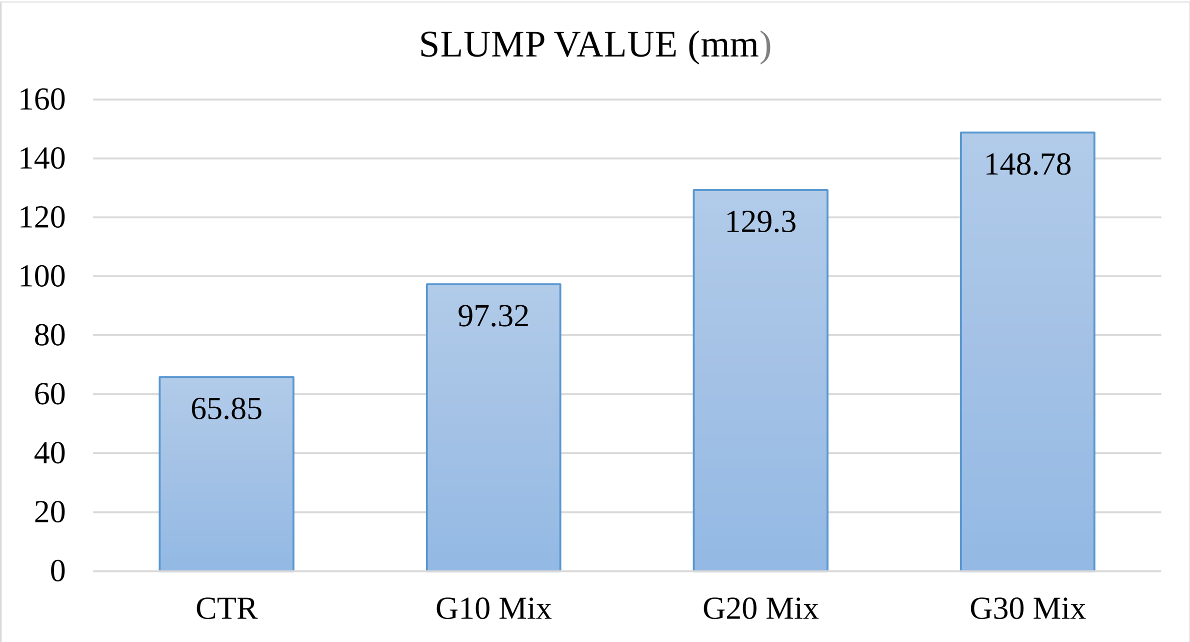


Figure 10 Graph showing Slump Values

As from the above graph and slump values table it is clear that with increasing percentage of glass powder workability of the mix is increasing. The possible reasons for the increment in workability may be due to:

i. The Amorphous and hard brittle nature it is believed that glass does not absorb water or absorb very less amount of water.
ii. Due to the non-crystalline and spherical shape of the glass
iii. As glass is lighter material than the cement and the replacement is done by weight so more volume is occupied by the glass powder as compare to cement which resulting in more paste. The increased amount of paste enhanced workability and so increasing the slump values.

Table 7 Slump values of stone dust batches

Concrete	Slump	
	mm.	Inch
Control Mix	65.85	2.6
SD50 Mix	52.43	2.1
SD60 Mix	43.32	1.7
SD70 Mix	34.86	1.4

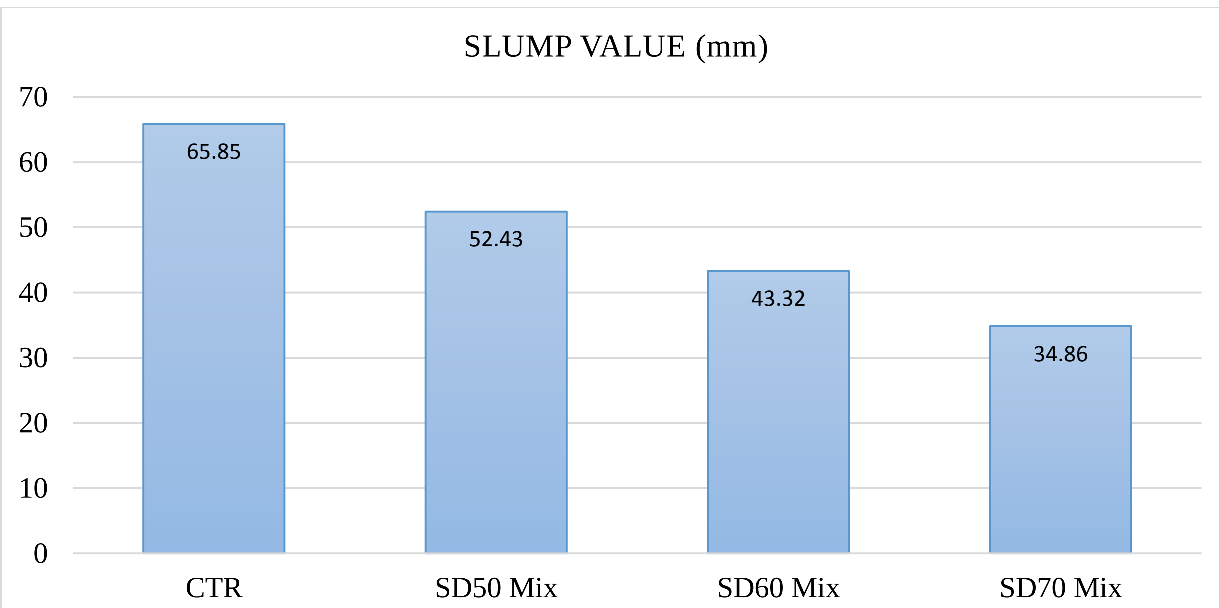


Figure 11 Graph showing Slump Values

From the above table and graphical representation of slump values of stone dust substituted concrete it is clear that by increasing the percentage of stone dust replacement, workability of the concrete is decrease. The possible reasons for this are:

- Stone dust has a good absorption capacity of water as compare to natural sand.
- The crushed and angular particle shape and rough texture of stone dust may also results in decreasing the workability.

Table 8 slump values of combine batches

Concrete	**Slump**	
	mm.	Inch
Control Mix	65.85	2.67
12G+37SD	60.53	2.43
15G+42SD	54.23	2.26
17G+48SD	48.21	1.92

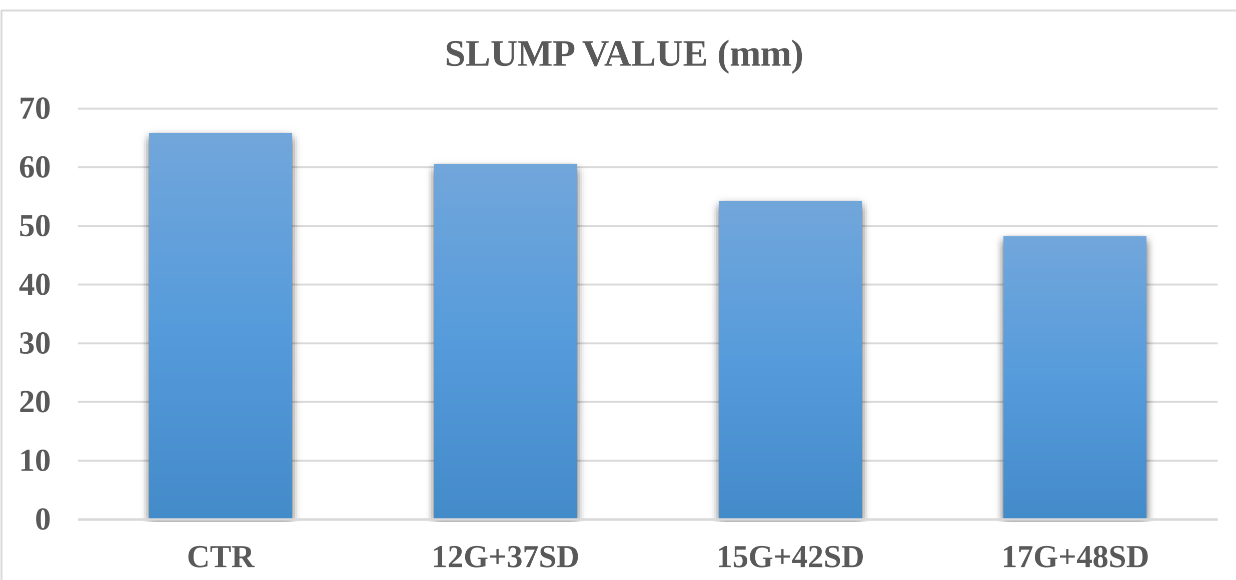


Figure 12 Graph showing Slump Values

The above results show that the slump value for the combined batches decreasing. For 12% glass powder and 37% stone dust, 15% glass powder with 42% stone dust, and 17% glass powder with 48% stone dust the workability is decreases which may be due to the less amount of glass powder and little bit higher amount of stone dust resulting in remaining insufficient amount water for hydration process completion.

4.2.2 Compressive Strength:

Compressive strength of concrete is basically the load carrying capacity of concrete in crushing before failure. The results of the compressive strength of tested samples are given below in the table.

Table 9 compressive strength test results

Batch	**Load(KN)**	**Compressive(Mpa)**
Control	495	28.02
G10	503	28.47
G20	562	31.81
G30	400	22.64
S50	564	31.93
S60	632	35.78
S70	482	27.28
12G+37SD	670	38.49
15G+42SD	682	38.21
17G+48SD	663	37.93

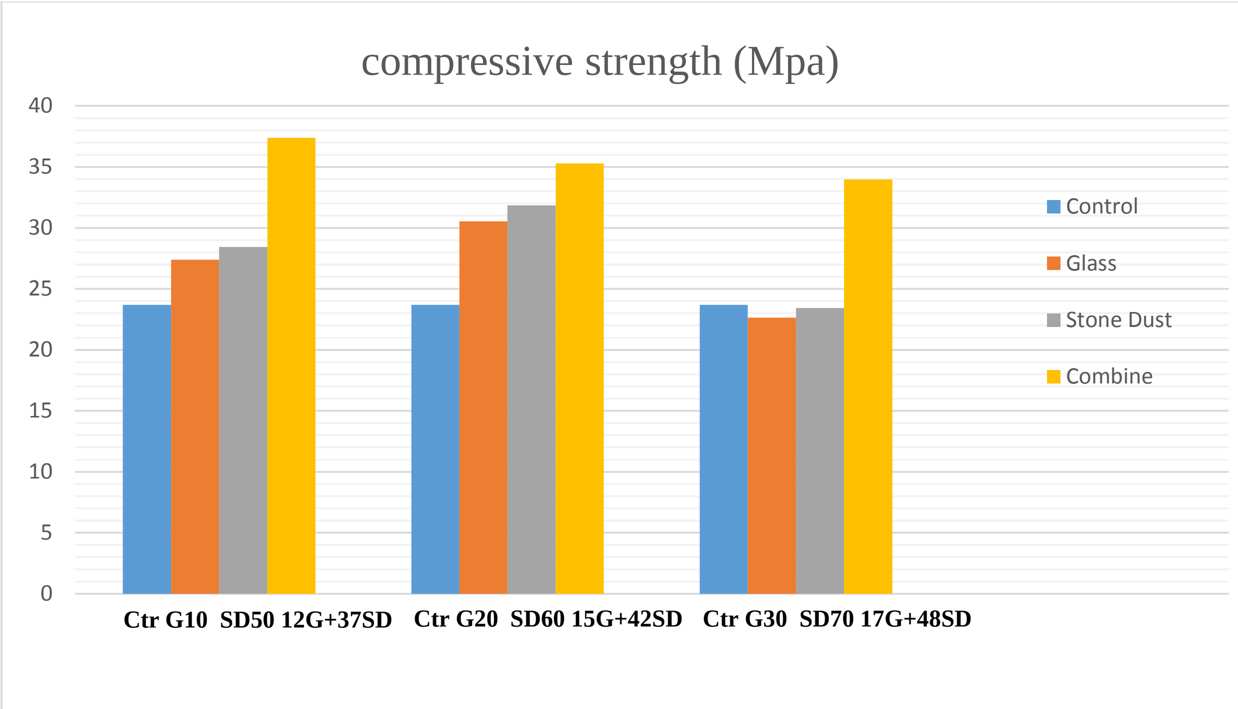


Figure 13 Average Compressive Strength

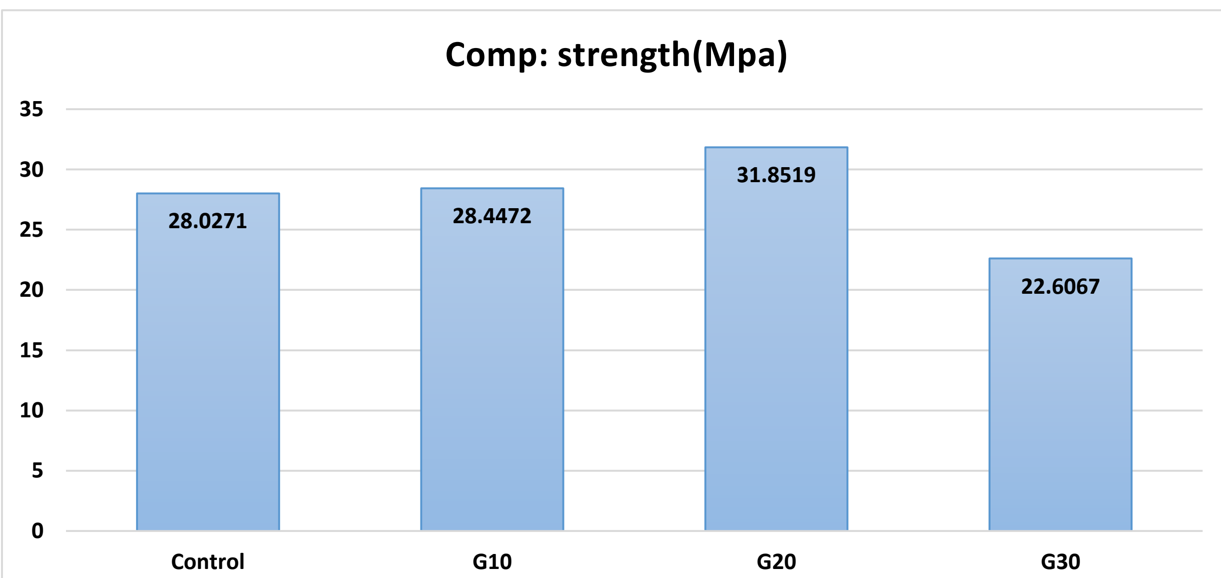


Figure 14 Graph showing compressive strength of glass powder vs control samples

All the above mentioned tests were conducted at the age of 28 days. The results of glass incorporated, stone dust replaced, and glass powder and stone dust utilized in combination are given in the table against the conventional concrete strength. It can be seen from the graph and table 4.4 that the glass incorporated concrete specimens gave higher strength at 10% and 20% replacement which is due to the consumption of available CH amount by the glass powder through the pozzolanic activity while at 30% replacement its strength decreased as compare to that of the control specimen which is due to the reason that the total available amount of CH is consumed by some of the glass particles and the rest of the glass particles are remained un-reactive which may causes dilution effect resulting in decrease in strength. Due to less water absorption of glass is also result in decrease in strength. At the age of 28 days G10 increase the strength by 1.5%, G20 increased the strength by 13.67%, while G30 decreased the strength by 19.3% respectively. So 20% of glass powder is selected as the optimum dosage to be utilized in concrete by keeping in mind the strength and performance of concrete.

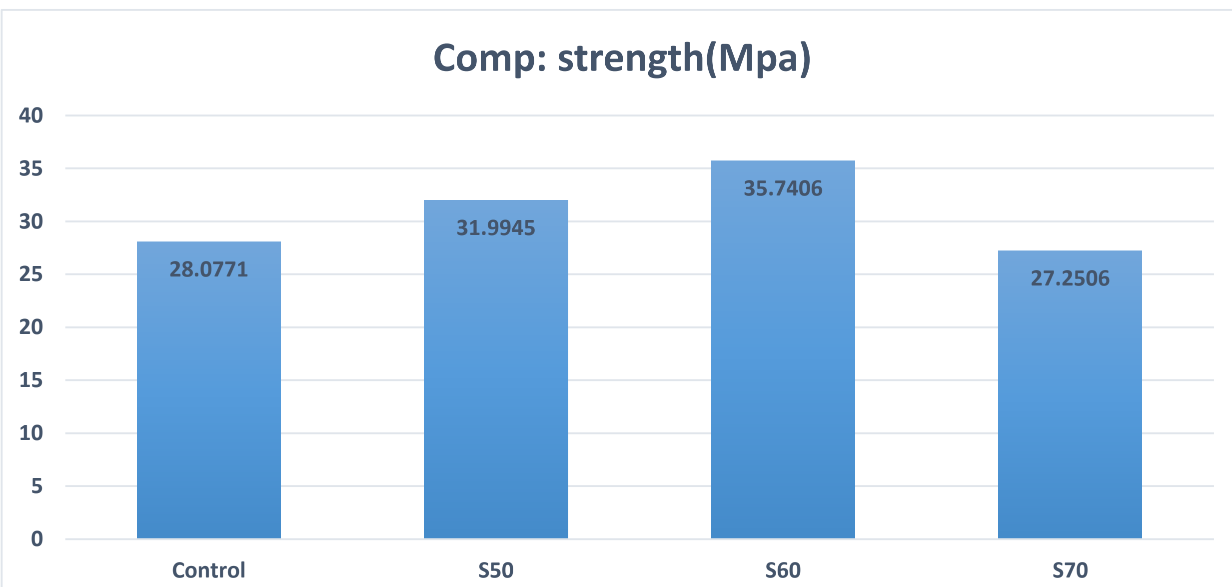


Figure 15 Graph showing compressive strength of stone dust vs control samples

Similarly in case of stone dust the strength is increased by 14.2% and 27.29% with 50% and 60% while decreased by 3% with the replacement of sand by 70% of stone dust as compare to the conventional concrete. The initial increment in the strength may be due to the balance use of stone dust with sand and also due to the angular shape and rough texture of stone dust particles but mainly the increment may be due the optimum amount utilized in concrete by replacing sand and due to the water absorption of stone dust. While on the other hand stone dust particles are not so stronger like sand particles and so using stone dust in excess amount i.e. 70%, more than 60% is resulting in the decrease of strength due to the more water absorption from the mix which results decreased in the available water for hydration process and so cement paste is not coating all the particles resulting in porous concrete which decreased the strength. So 60% is the optimum dosage at which the specimens gave maximum strength.

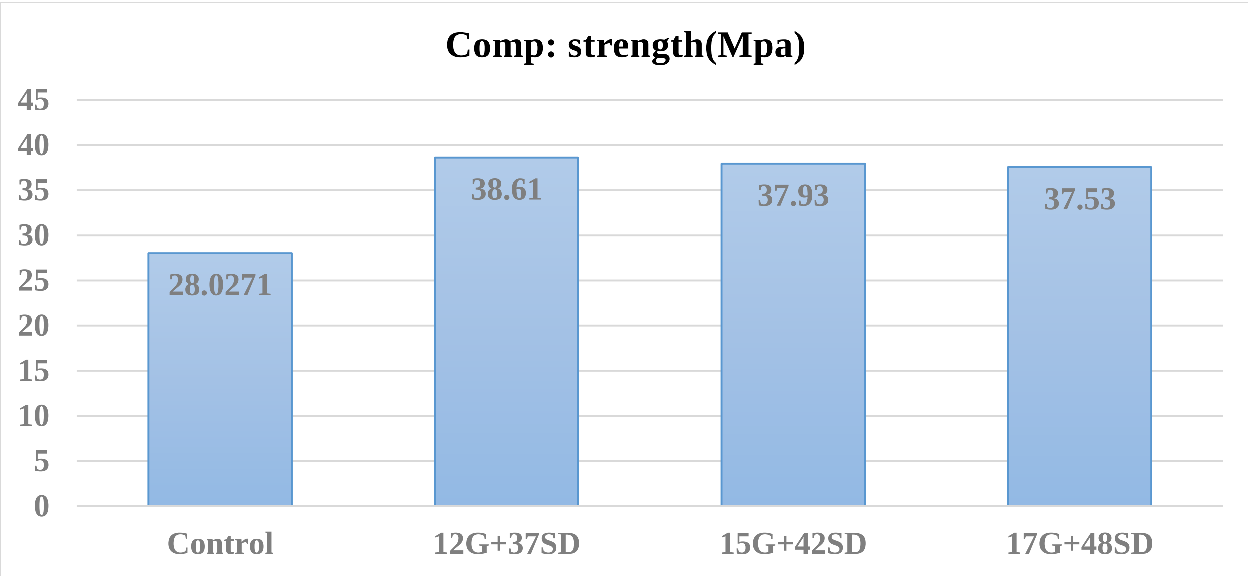


Figure 16: compressive strength of stone dust and glass powder vs control samples

In combined batches of glass powder and stone dust results of all the three combination were found almost same and much closed to each other. Among the above three combination which are 12% glass powder with 37% stone dust, 15% glass powder with 42% stone dust, and 17% glass powder with 48% stone dust, the maximum strength which is 37.79% of the control specimens is achieved at the first combination by replacing cement with 12% glass powder and sand with 37% stone dust while at the other two combinations the strength is increased by 35.36% and 33.94% as compare to that of the conventional concrete. Among the three combination the strength is decreased at the latter two replacements which is due to the more water absorption from the mix which results decreased in the available water for hydration process and so cement paste is not coating all the particles resulting in porous concrete which decreased the strength. The latter two combinations increased the strength by a very small amount but gave almost the same strength as that of the first combination with respect to the control batch, and so by analyzing the results it is observed that while using glass powder and stone dust in combination the optimum dosages of replacing cement by 12% glass powder and sand by 37% stone dust can be used safely. But as we observed that due to the other two combination there is no significant reduction in the strength of concrete so for the sake of economy, utilization of waste materials, and conservation of natural resources the best choice is to use the combination of 17% glass powder with 48% stone dust which results in almost the same strength to that of the optimum dosages.

Comparison of predicted values from RSM and experimental values is given below:

Table 10 Comparisons between predicted value and experimental value

Property	Percentage of Waste Glass	Percentage of Stone Dust	Predicted Value	Experimental Value	Percentage Difference
Compressive Strength (Mpa)	12	37	38.86	38.49	-0.95
	15	42	38.54	38.21	-0.85
	17	48	37.58	37.93	-0.93

4.2.3 Bond Strength:

Bond strength is actually measuring the pull out strength or the resistance between reinforcement and concrete. The tests were carried out under the ASTM C-234 on the cubes specimens and their results are discussed as under.

Table 11 bond strength test results

Batch	Load(KN)	Pull out Strength(Mpa)
Control	45	11.46
G10	47.6	12.12
G20	52.33	13.33
G30	37	9.42
S50	48	12.22
S60	55.3	14.08
S70	41.66	10.61
12G+37SD	61	15.54
15G+42SD	58	14.77
17G+48SD	52	13.24

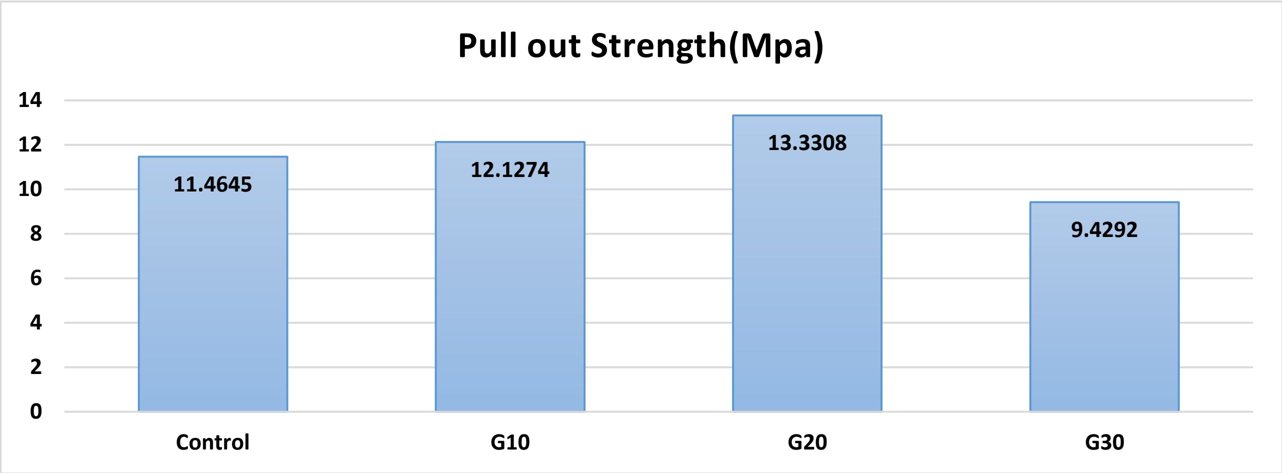


Figure 17 pull out strength glass vs control

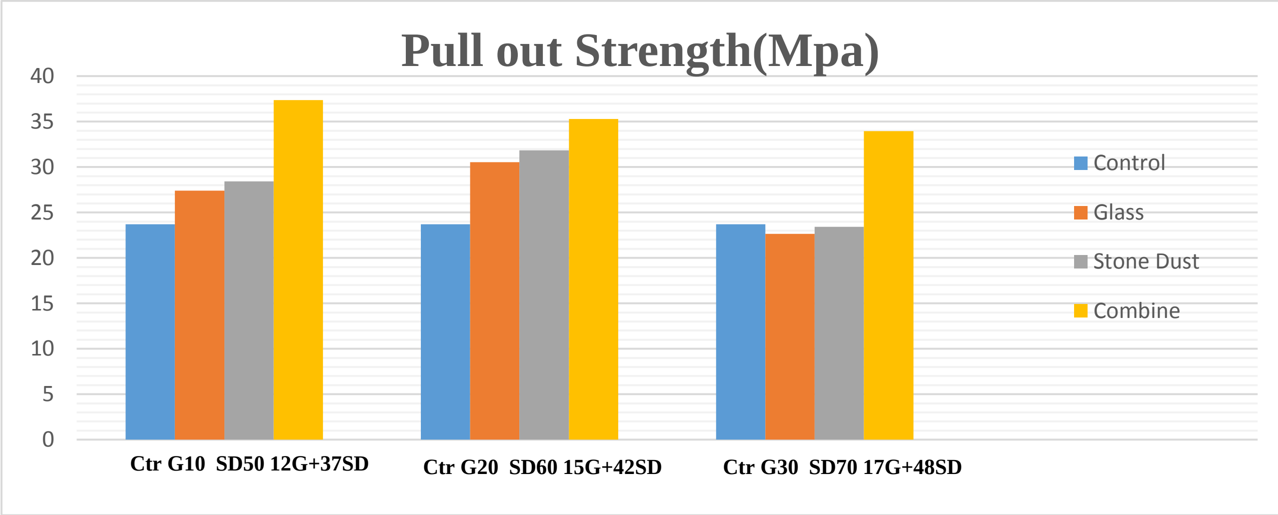


Figure 19 Pull out strength of control, glass, stone dust and combine batch

From the above results of pull out test it is clear that bond strength of concrete having cement replacement by glass powder is increased initially at 28 days with the increase of percentages of glass powder and at 30% replacement the strength is decreased as compare to control specimens. At 10% and 20% replacements the strength is increased by 5.8% and 16.3% respectively as compare to control specimens while at 30% replacement the strength is reduced by 17.8%. The increment in bond strength is due to the consumption of CH produced during the hydration process, by the glass powder through pozzolanic activity and also may be due to the finely grinded particles of glass powder which contribute to the pozzolanic activity and strength of the concrete. While at 30% replacement of cement by glass powder the strength is decreased by 17.8% to that of the conventional concrete which may be due to the reason that the amount of CH produced during hydration process is less than that of the amount of glass powder utilized at 30% level i.e. glass is substituted in excess amount and hence the available amount of CH is utilized by the same amount of glass powder while the remaining amount of glass powder is remained un-reactive in the mix which results in the loss of strength of concrete and so the bond strength of concrete is reduced by using 30% of glass powder.

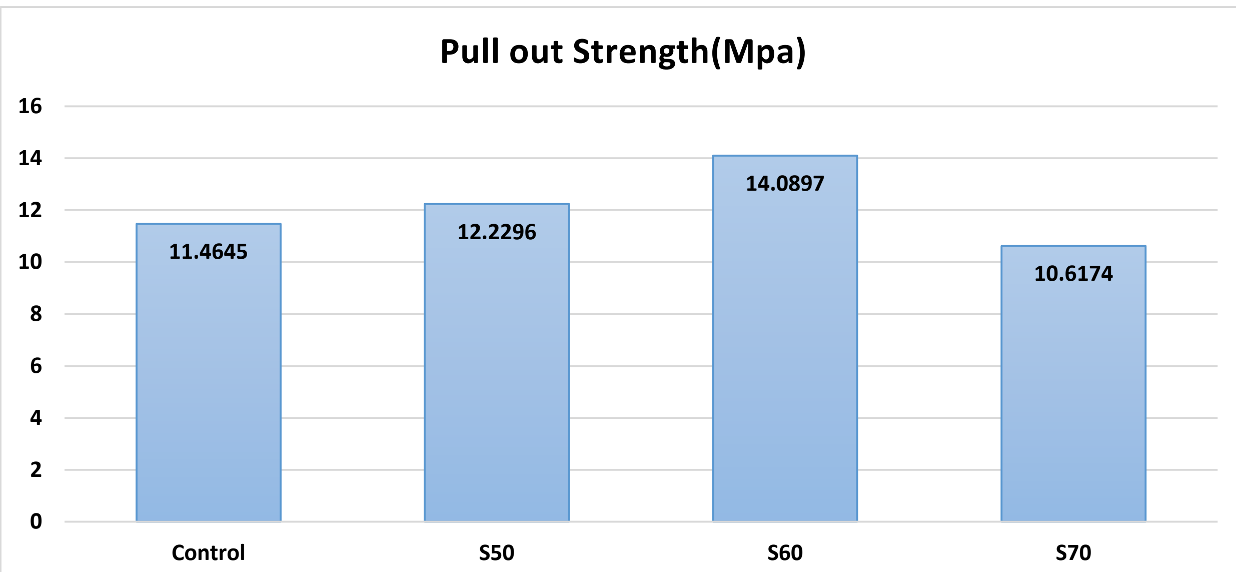


Figure 21 pull out strength results of stone dust vs control samples

From the substitution of glass powder in concrete it is revealed that 20% is the optimum dosage of glass powder to be utilized in concrete as a cement replacement.

In case of stone dust it is observed from the results of the tests performed on the pull out specimens at 28 days that the bond strength is increased by 6.6% and 23% when sand is replaced 50% and 60% by stone dust and then decreased by 7.4% at 70% replacement of sand by stone dust. The increment in the strength initially may be possibly due to the angular and little bit coarser particle size of the stone dust particles which contribute to the perfect bond making with other ingredients of concrete and also due to the rough texture of stone dust. The other possible reason of the strength increased initially is due to the high water absorption capacity of the stone dust which results in a dry mix up to some extent and hence increasing the strength. Similarly the reduction in the strength may be due to the replacing of sand by stone dust in excess amount which means that we can replace sand by stone dust up to a specific limit which will increase the strength and beyond that limit the strength is start decreasing. So 70% substitution of stone dust is the limit beyond the optimum dosage which results in decrease in strength. Analyzing the results of all three substitutions of sand dust, 60% replacement of sand by stone dust is came to front as the optimum dosage of using stone dust in concrete in term of strength achieved.

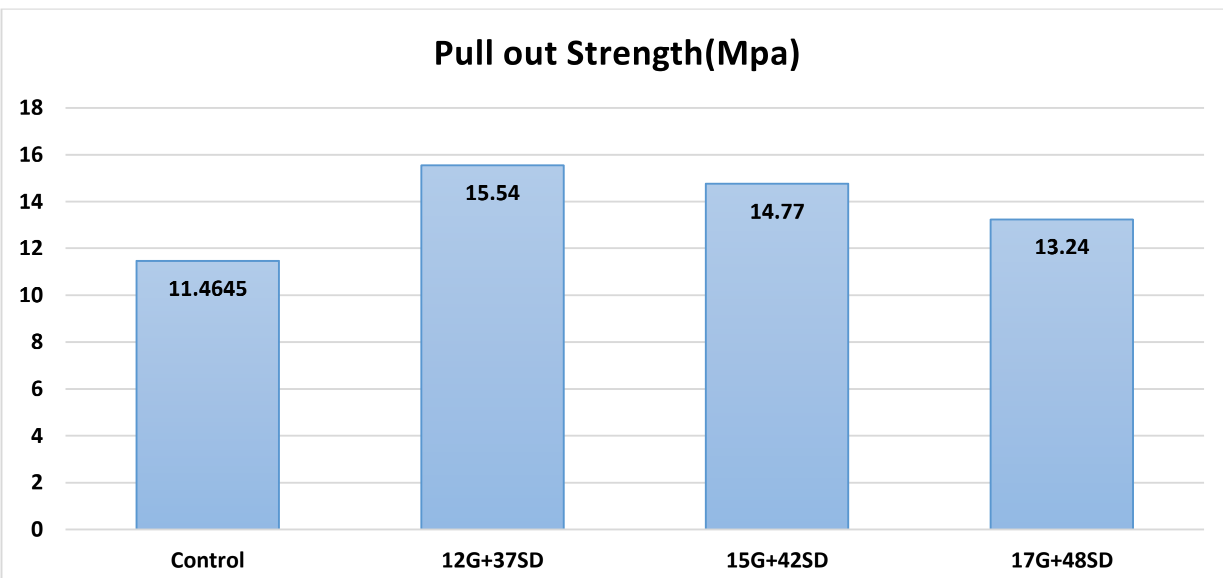


Figure 22 pull out strength results of glass and stone dust vs control samples

While using the glass powder and stone dust in combination as 12% glass with 37% stone dust, 15% glass with 42% stone dust, and 17% glass with 48% stone dust it was observed from the statistical analysis through Response Surface Methodology and experimental results shows that the strength is increased by 35.60%, 28.88%, and 15.53% as compare to the conventional concrete. Although the first combination of 12% glass powder with 37% stone dust gave higher strength than the other two combinations but if we observed the above mentioned results then it is clear that we can achieve almost the same higher strength by using the maximum replacement percentages of both the materials in combination in a mix. So by using 17% glass powder with 48% stone dust is contributing to many factors like economy, increasing the strength, consumption and utilization of waste materials, green construction, and sustainable development.

Comparison of predicted values from RSM and experimental values is given below:

Table 12 Comparison of predicted values from RSM and experimental values

Property	**Percentage of Waste Glass**	**Percentage of Stone Dust**	**Predicted Value**	**Experimental Value**	**Percentage Difference**
Pull out Strength (Mpa)	12	37	15.53	15.54	**+0.06**
	15	42	15.37	14.77	**-3.90**
	17	48	15	13.24	**-11.73**

4.2.4 Flexural Strength:

Flexural strength can also be describe as the modulus of rupture, bend strength, or rupture strength which depends on the dimensions of the beam and manner of loading. The test results of flexural strength of beams are shown in the following table.

Table 13 flexure strength results

Batch	Load(KN)	Flexure Strength of RCC Beam (Mpa)
Control	90	23.70
G10	104	27.39
G20	116	30.55
G30	86	22.65
SD50	108	28.44
SD60	121	31.86
SD70	89	23.44
12G+37SD	142	37.39
15G+42SD	134	35.29
17G+48SD	129	33.97

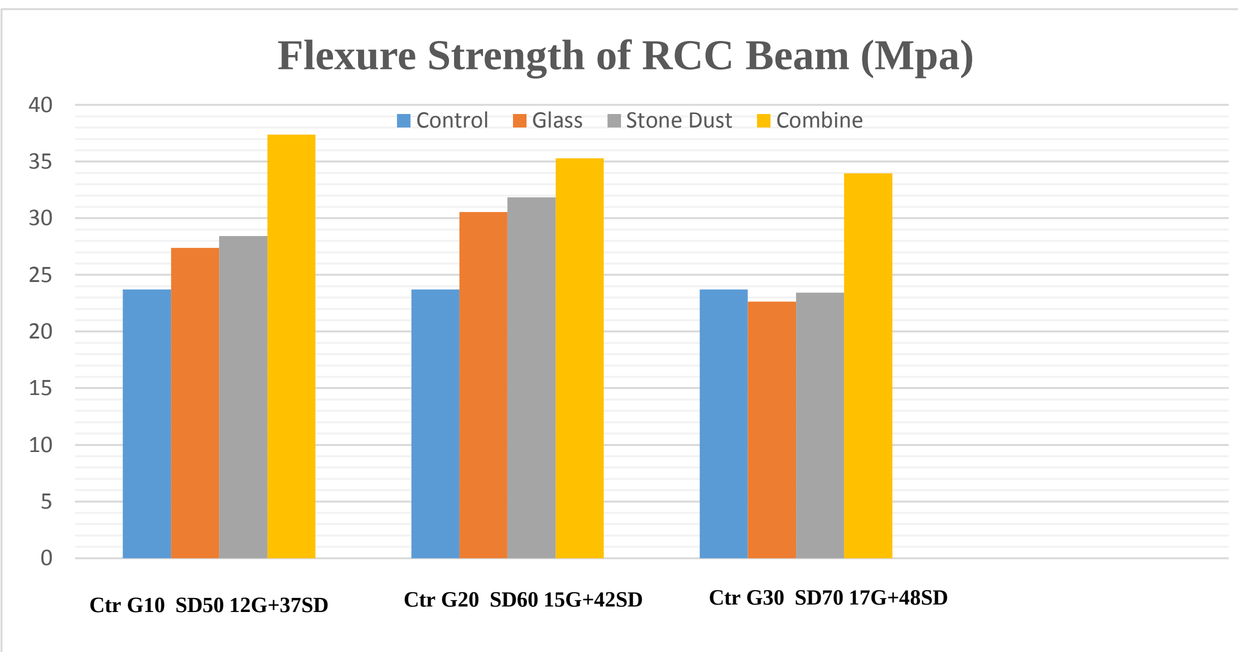


Figure 23 Flexure strength test results

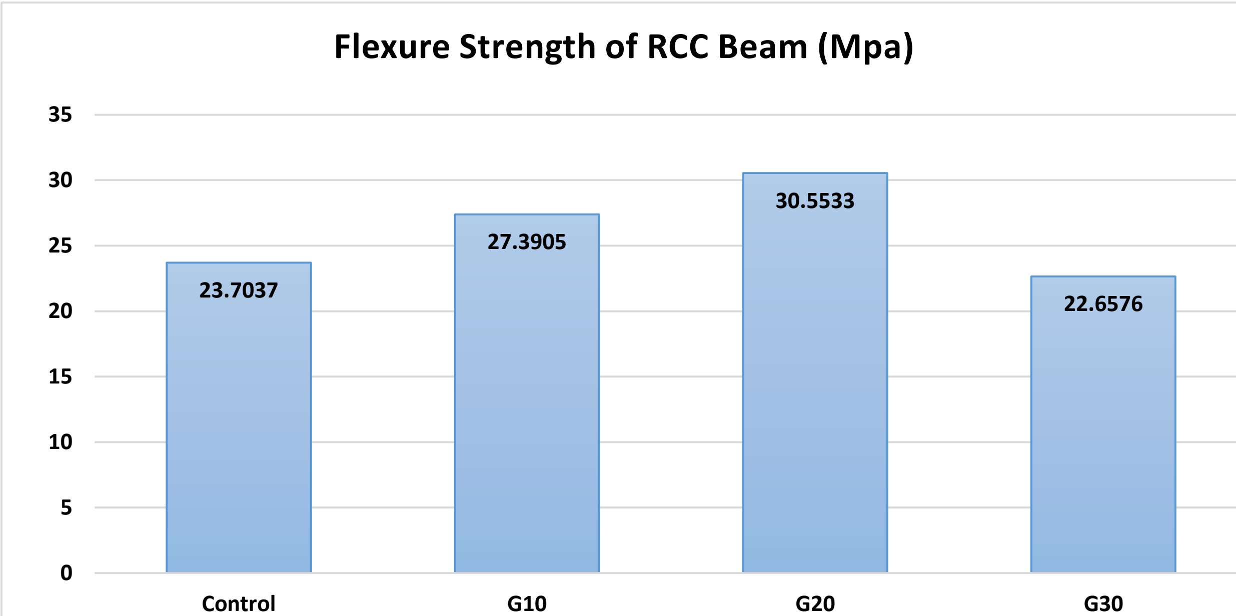


Figure 24 Flexure strength of glass vs control

From the above results of flexure strength test on reinforced concrete beams we can conclude that by replacing the cement with glass powder flexure strength of concrete get increased.

The obtained higher value is strength is due to the reinforcement nature of the beam samples. When the glass is substituted in concrete as 10% and 20% and the specimens were tested the flexural

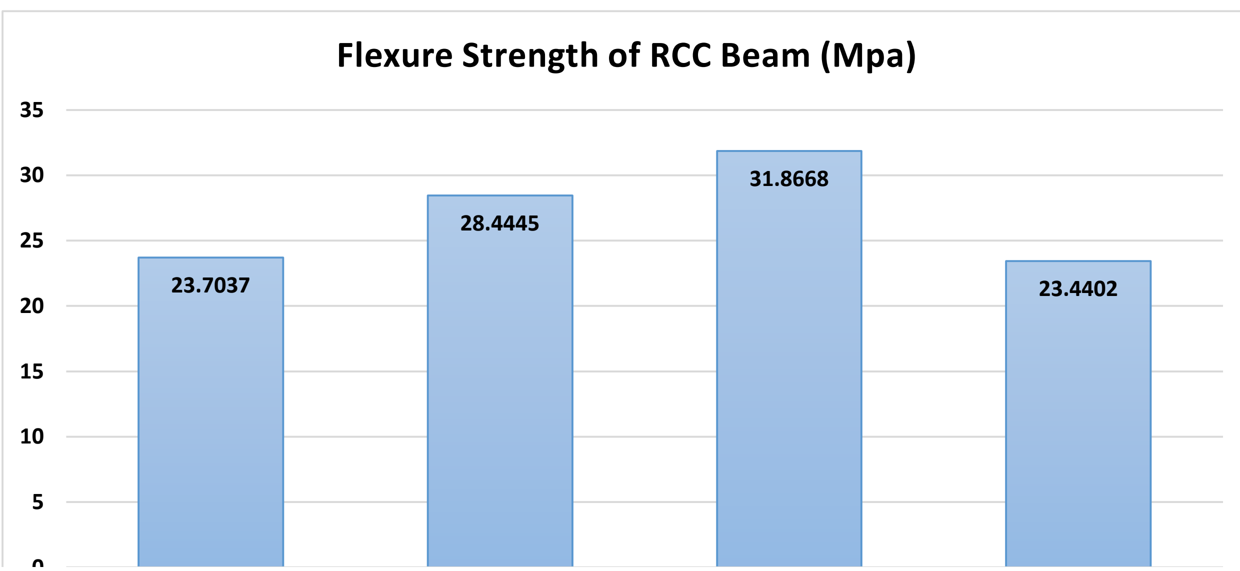


Figure 25 flexural strength of stone dust vs control sample strength of the specimens is increased by 23% and 12% respectively. The increment is due to the pozzolanic nature of glass which produce additional CSH by utilizing already produced CH by hydration process. At 30% replacement of cement by glass powder the strength decreases by 14% which is probably due to the excess amount of glass powder available in the concrete after utilizing the already available amount of CH to CSH by glass powder through pozzolanic action. After comparing all the three substitution of glass powder with cement 20% glass powder is highlighted as the optimum dosage in case of flexural strength of concrete.

Similarly in the case of stone dust the flexural strength of concrete is also increased by 30% and 25% at 50% and 60% replacement of sand by stone dust. The increase in strength is due to the strong bond provided by the angular shape and little coarser particle size of the stone dust and also as the stone dust if highly water absorbing material so the lowering slump and workability is resulting in increasing the strength of concrete. When the sand is replaced with 70% by stone dust the strength get reduced by 17% which is due to the fact that strength of concrete is increasing when stone dust is replaced up to a specific limit which is our case is 60%, and after this limit the strength get decreased when the sand is replaced with stone dust. So after studying the behavior of stone dust substituted concrete using 50%, 60%, and 70% stone dust, 60% stone dust is decided as the optimum dosage to be use in concrete instead of sand to preserve the natural resources.

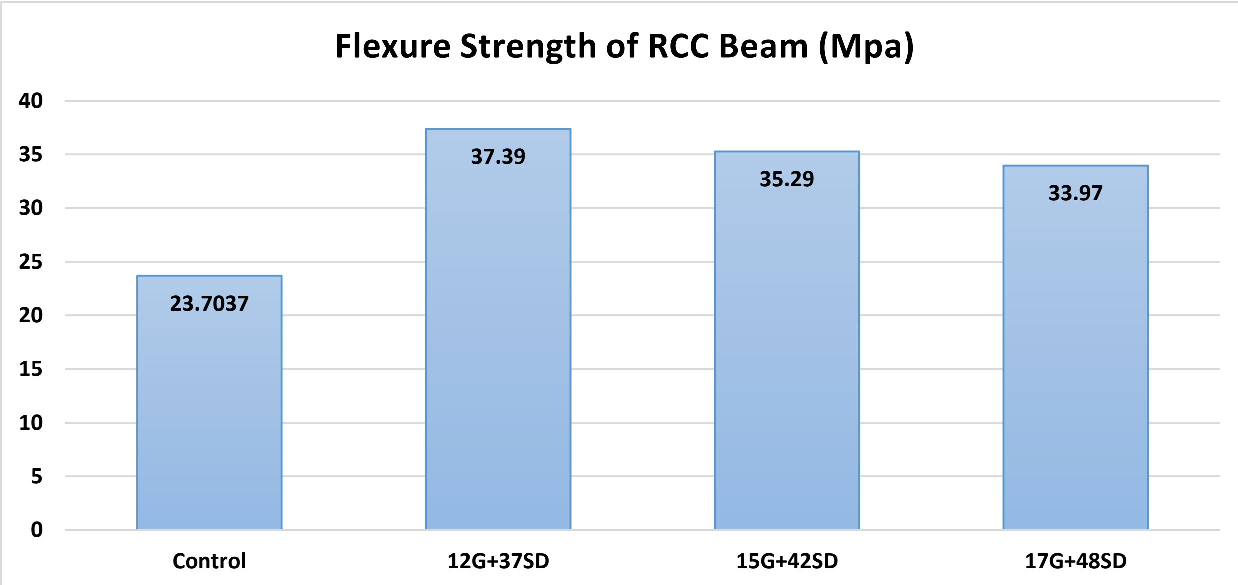


Figure 26 flexural strength of glass and stone dust vs control sample

After studying the behavior of concrete while using stone dust and glass powder individually when the stone dust and glass powder is used in combination in concrete and tested for flexural strength of concrete using reinforced concrete beams the strength of the concrete is increased by a considerable amount. The strength of concrete is increased by 57.76%, 49%, and 43% respectively when the variations of 12% glass with 37% stone dust, 15% glass with 42% stone dust, and 17% glass powder with 48% stone dust is used. In all the three variations the increment in strength is almost same but in latter two variations the strength decreased with a very small amount as compare to the first variation. Although 12% glass with 37% stone dust is the optimum dosage but due to the other two variations strength of concrete is decreased by a very small amount and hence on the other hand a handsome amount of waste materials is utilized so keeping these things in mind it is better to use the variation with higher amount of waste materials having negligible reduction in the strength of the concrete. Using the variation with higher amount of waste materials will also contribute to the economy and prevention depletion of natural resources.

Table 14 Comparison of predicted values and experimental values

Property	Percentage of Waste Glass	Percentage of Stone Dust	Predicted Value	Experimental Value	Percentage Difference
Flexure Strength (Mpa)	14	38	38.17	37.39	2.04
	16	42	37.92	35.29	6.93
	17	46	37.52	33.97	9.46

CHAPTER 5

Conclusions and Recommendations

5.1 Conclusions

From the above obtained results of slump values, compressive strength, flexural strength, and bond strength of glass powder and stone dust substituted concrete individually and in combination the main conclusion of the study is obtained as follow:

1. When cement is replaced by glass powder the workability of concrete is increased. While by substituting the stone dust with sand the workability is decreased and when glass and stone dust is used in combination the workability of concrete is decreased.
2. In case of using glass powder at 20% replacement of cement by glass powder is obtained as optimum replacing percentage at which the compressive strength, flexural strength, and bond strength were increased by 13.67%, 12%, and 16.30%respectively as compare to conventional concrete.
3. By replacing sand with stone dust the compressive strength, flexural strength, and bond strength were increased by 27.29%, 25%, and 23% respectively as compare to control specimens at 60% replacement of sand with stone dust. So 60% replacement of sand by stone dust is obtained as optimum dosage.
4. When both the cement and sand is replaced with glass powder and stone dust simultaneously in combination then higher values were obtained at the replacement of 12% glass powder with 37% stone dust. Compressive strength, flexural strength, and bond strength were increased by 37.79%, 57.76%, and 35.60% respectively as compare to conventional concrete. But the results showed that at other two replacements in combination the increment in strength is not significant and almost equal to that of the

strength achieved at 12% glass and 37% stone dust, so for the sake of economy, prevention of natural resources by utilization of waste materials, and going toward sustainable development 17% glass powder with 48% stone dust is considered as optimum dosages while using glass powder and stone dust simultaneously.

5.2 Recommendations

5.2.1 for Industry:

1- This research represents the meaningful use of waste materials like glass and stone dust in concrete industry which could results in the preservation of depletion of natural available resources.

2- According to this research 20% glass powder ad 60% stone dust individually and also 17% glass powder with 48% stone dust simultaneously in combination could be safely used in concrete.

3- Bond strength, flexural strength, and also compressive strength would be enhanced by using glass powder and stone dust as partial replacement of cement and sand, and this technique would provide a premise to use glass powder and stone dust for the augmentation of mentioned strengths in concrete.

4- As so for Pozzolanic properties are concern, this research would also be reference to use glass powder having particle size < 75 microns as Pozzolanic material in concrete industry.

5.2.1 for Research:

1- A study is recommended to be conducted to assess different properties of concrete by using combination of other materials with glass powder.

2- In this research cement and fine aggregate were replaced while further research work can be designed to study the behavior of concrete by using different other variations and different water cement ratios.

3- For the durability of concrete a study is also recommended to be conducted while using glass powder and stone dust.

References

1. Islam, G. S., Rahman, M. H., & Kazi, N. (2016). Waste glass powder as partial replacement of cement for sustainable concrete practice. Int. J. Sustain. Built Environ.
2. Raju, S., & Kumar, P. R. (2014). Effect of using glass powder in concrete. *International Journal of Innovative Research in Science, Engineering and Technology*, *31*, 21-427.

Raju, S., & Kumar, P. R. (2014). Effect of using glass powder in concrete. *International Journal of Innovative Research in Science, Engineering and Technology*, *31*, 21-427.

3. Srivastava, V., Gautam, S. P., Agarwal, V. C., & Mehta, P. K. (2014). Glass Wastes as Coarse Aggregate in Concrete. *J. Environ. Nanotechnol*, *3*(1), 67-71.
4. Adaway, M., & Wang, Y. (2015). Recycled glass as a partial replacement for fine aggregate in structural concrete–Effects on compressive strength. *Electronic Journal of Structural Engineering*, *14*(1), 116-122.
5. Bhaluni, V. K., & Sood, H. (2018). Analyzing Effect of Waste Glass Powder in Concrete by Partial Replacement of Cement. *International Journal of Engineering Science*, *18802*.
6. Vijayakumar, G., Vishaliny, M. H., & Govindarajulu, D. (2013). Studies on glass powder as partial replacement of cement in concrete production. *International Journal of Emerging Technology and Advanced Engineering*, *3*(2), 153-157.
7. Malhotra, V. M. (1999). Role of supplementary cementing materials in reducing greenhouse gas emissions. In *Infrastructure regeneration and rehabilitation improving the quality of life through better construction. International conference* (pp. 27-42).
8. Abbas, S. Y., Srivastava, V., & Agarwal, V. C. (2015). Effect of stone dust on compressive strength of concrete an experimental investigation. *International Journal of Engineering Science and Research Technology*, 4(2).
9. Das, B., & Gattu, M. (2018). Study on Performance of Quarry Dust as Fine Aggregate in Concrete.
10. Suman, B. K., & Srivastava, V. Utilization of Stone Dust as Fine Aggregate Replacement in Concrete. *Journal of Multidisciplinary Engineering Science and Technology (JMEST). ISSN*, 3159-0040.
11. Patil S.P., Vhate D. D., Banchhor H.R. (2018). Study of Effect on Compressive Strength by Replacing Natural Sand with Crushed Sand. International Journal for Research in Applied Science & Engineering Technology, 6(4).

12. Ingalkar R.S., and Harle S.M. (2017). Replacement of Natural Sand by Crushed Sand in the Concrete. *Landscape Architecture and Regional Planning*, 2(1).

13. Singh, A. K., Srivastava, V., & Agarwal, V. C. Stone Dust in Concrete: Effect on Compressive Strength. International Journal of Engineering and Technical Research.3 (8).

14. Balamurugan, G., & Perumal, P. (2013). Behavior of concrete on the use of quarry dust to replace sand–an experimental study. *BEHAVIOUR*, *3*(6).

15. Kode, V. R., Murty, D. S. R., & Swarna Kumar, P. (2007). Appraisal of crushed stone dust, as fine aggregate in structural concrete. *Civil engineering & Construction Review*, *20*(7), 52-58.