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Study of Strength of 3 D Printable Concrete by Partial Replacement of Quartz Powder by Steel Slag

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Abstract: 3-D concrete printing is an emerging technology that combines digital technologies and new insights from material technologies to allow free-form construction without the use of frame work. Conventional construction methods have many limitations because which has shown remarkably poor productivity as compared to other sectors in the economy. With the discovery of printable concrete most of the limitations conventional concrete construction can be solved. Our idea is to develop a printable concrete mix by incorporating steel slag which is a waste material from steel industry. Construction using 3-D concrete printers has not been started yet in India, but it had been successfully done in many other countries. Construction using 3-D concrete printer can overcome many of the problems faced by conventional construction. But the technology is not fully developed since there is no specification for the mix in the Indian Standard. We aim to develop a low cost concrete mix to make it more affordable than the one available in the market presently.

Keywords* — *Compressive strength, flexural strength, optimum percentage, quartz powder, reference mix, steel slag.

I. INTRODUCTION

Construction is one of the largest sector of the global economy with construction related spending at 10 trillion globally, equivalent to 13% of GDP. However, construction has shown poor productivity. Since the discovery of modern concrete in the 19 century many researchers have sought to automate concrete construction without much success. Thomas Edison's attempt to create a machine to build concrete houses in a single pour, which he patended in 1917 was a well-documented failure due to the technological challenges in concrete [1].

Concrete as a construction material appears deceptively simple, but has many hidden challenges. Many advancements in concrete construction technologies have been made since then including innovative development in concrete pumping technologies and admixtures technologies. However, it is common place to find construction sites transporting, placing, compacting and curing concrete using technologies that are more than 100 years old. Concrete construction remains labour intensive, costly and highly accident prone. Annual production of concrete is reaching nearly 30 million tons worldwide, make it the most widely used construction material.

Formwork represents a significant source of waste, given that all formwork is discarded sooner or later, contributing to the generally increasing amount of waste worldwide.

According to a study from 2011, 80% of the total worldwide waste is generated in the construction industry, with significant contributions from formwork timber which has limited reuse value. Unlike the conventional approach of casting into a mould, 3-D concrete printing is an emerging technology, and it is also referred to as Additive Manufacturing (AM) is a technology which builds a solid object via a layer-by-layer process [1].

3D printing of concrete can be done in three steps: preparation of data, preparation of concrete mix and printing of structure. In the first step, the digital model of the object is made and is sliced using suitable softwares. A plan for laying the concrete in layers by the printer is made by the software. Then a proper concrete mix is prepared such that the concrete doesn't harden rapidly causing blockage in the nozzles and has a good workability. In the last step the concrete is made to flow through the nozzles according to the path programmed in the printer. (Additive manufacturing of concrete in construction: potentials and challenges of 3D printing) [4].

II. LITERATURE REVIEW

S.T Borole (2016), done research in order to explore the feasibility of utilizing the steel slag as a replacement for natural aggregate in concrete. The experimental

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investigation was carried out on 3 test specimens of cubes, cylinders and beams each to study the strength properties and as a result of replacing fine aggregate by steel slag in various percentages namely 0%, 25%, 50% of steel slag in M30 mix. Compressive strength were carried out on cubes of 150mm×150mm×150mm size, split tensile strength was carried out on cylinder of 150mm×300mm and flexural strength was done on beam of 100mm×100mm×500mm size. The results were compared with the conventional concrete. Results showed that compressive strength increases with increase in percentage of steel slag by 25% by weight of fine aggregate and above this value it decreases. Also split tensile and flexural strength increases up to 25% by weight of fine aggregate. Here 25% is the optimum percentage [11].

Harsh Gupta and Anil Kumar Saxena (2017), found out that in India, the government has banned the extraction of natural sand in maximum areas. To overcome this scarce and costly fine aggregate, a well-deserved alternate option is introduced. Steel slag, a well-known byproduct of steel obtained while cutting and shaping from various steel furnaces or industries. Here the proportion of the concrete mix materials are calculated by mix design calculation. A sample of concrete mix is prepared by conventional hand mixing method. Workability of fresh concrete is obtained by slump cone test. Concrete mould of specimen size 150mm×150mm×150mm is used. Test such as compaction factor, compressive strength test, split tensile strength test and flexural strength test is done. From these, the result in compressive strength, split tensile strength, and flexural strength, the concrete of M35 grade shows comparatively good results from the conventional concrete mix. Hence it is concluded that, the use of steel slag up to 30% does not show any harm to the concrete mix and can be taken as an alternate of fine aggregate [10].

Mahadev Shreenath (2016), found out the effect of replacement of fine aggregate by steel slag aggregate. The main objective of the work is substituting sand by granulated blast furnace slag for different percentage replacement. The materials used in the present study are cement, fine aggregate, coarse aggregate, steel slag and water. The experimental program is designed based on the percentage replacement of fine aggregate by steel slag to study the mechanical properties of the concrete at different grades of concrete. The specimen prepared after replacement of fine aggregate by steel slag for 0%, 25%, 50%, 75%, and 100% are studied for compressive strength, flexural strength and tensile strength for curing period of 28 days.The compressive strength, tensile strength, and flexural strength of concrete increase at partial replacement level and decrease at full replacement of concrete [12].

Anurag Jain (2018), has done research on steel slag as replacement on fine aggregate in terms of high strength concrete. The objective was to determine the optimum dosage of steel slag as partial replacement of sand with various percentages 10%, 20%, 30%, and 40% of steel slag waste in M25, M30, M35 concrete and also to study the effect of compressive, split tensile and flexural strength characteristic properties. Compressive strength at 7, 14, 28 and 50 days were higher than with the use as partial substitution of steel slag by sand with the level of 10%, 20% and 30% and lower than 40% of steel slag. The increment in flexural strength test is about 36.7% for 28 days using for M25 grade of concrete and 24.7% for 28 days [6].

N. Bhuvaneswari (2018), done research on the partial replacement of fine aggregate by steel slag and weld slag in concrete and improving the mechanical properties of the slag waste. In this, materials are used to investigate the impact of fresh and hardened properties of concrete when the natural coarse aggregate is replaced with steel slag and weld slag in concrete. Mechanical properties like compressive strength, split tensile strength, flexural strength and ultrasonic pulse velocity and bond strength were tested. Durability studies such as water absorption and sorptivity tests were conducted to check absorption of water in HPC. This study was divided into two phases. In the first phase basalt aggregate, tap water, natural sand, cement, superplasticizer were used. In the second phase basalt aggregate was replaced by steel slag and waste water was used as mixing water. Compressive strength and split tensile strength of concrete shows an increase in strength and no strength loss in flexural strength till the replacement of aggregate and later strength decreases gradually. The strength achieved in steel slag concrete was slightly lower than the weld slag concrete. Polypropylene fibre was also used in the study and it shows 10% increase in strength of concrete as compared to normal concrete [9].

Mr.I. Michael Raj and Mr.J. Venkatesh (2018), investigated and it includes the determination of different properties of locally available steel slag. The utilization of steel slag in the concrete element by replacing it partially with fine aggregate. The main objective is to find out a suitable and effective/alternative material for partial replacement of fine aggregate. To find out possible utilization of waste materials in construction industry that in turn considerably minimize the use of fine aggregate and ultimately reduce construction cost. To explore the possibilities of improving mechanical properties of concrete using steel slag instead of fine aggregate partially to evaluate the effect of using steel slag in concrete. Here the mix proportion of M40 concrete made up of replacing some percentage of fine aggregate with steel slag. Flexural strength for various trial mixes of slag and fine aggregate proportioned concrete element is to be found out. Materials used are coarse aggregate, fine aggregate, cement, steel slag. The material testing for various materials used in this project are carried out to determine their properties, convenient to obtain required quality and strength. Design of concrete mix had done in

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this phase for the M40 concrete and the mix proportion for the control mix is 1:1.018:2.33 [8].

Gaurav (2018), investigated and steel slag can be used in the construction industry as aggregate in concrete by replacing natural aggregates. In this, mix design is done as per the Bureau of Indian Standards, IS10262-1982 for M20 and M40 grade concrete with good degree of quality control. For the mix designed, specimens are cast and investigated experimentally. Preliminary attempt is made to study the effect of partial replacement of fine aggregate by steel slag in the properties of concrete. The properties include compressive strength, split tensile strength and flexural strength of M20 conventional concrete by replacing 0%, 10%, 20%, and 30% of steel slag was added and test were conducted. The materials used in this study are cement (53 grade), fine aggregate, coarse aggregate, steel slag of specific gravity 2.5 to 3.5 and potable water. For this, different test on hardened concrete were conducted at the age of 28 days like compressive strength on 150mm×150mm×150mm size cube, splitting tensile strength on 150mm×300mm cylinder, flexural strength on beam of 100mm×150mm×500mm. It is observed that the compressive strength, split tensile strength and flexural strength is highest at 20% replacement of fine aggregate by steel slag, whereas at 30% replacement there is reduction in strength [7].

A.V Rahul (2018), studied about the 3D printable concrete. For this study Portland cement (53 grade), fly ash (class F), silica fume were used as binders. PCE based superplasticizer and methyl cellulose based VMA was used as chemical admixtures. In addition polypropylene fiber of length 12mm and thickness of 40micro meter was used. Purified form of polypropylene was used as rheological modifier. Quartz powder and 2 grades of quartz sand were used as fine aggregate. Three types of mixes were developed with three additives-silica fume, nanoclay, and VMA. They were evaluated based on buildability, extrudability, robustness, etc. The mixture with silica fume showed the maximum structural buildup. The proportions all day ingredients were proposed by using the particle packing method. To achieve high strength, lower water to binder ratio of 0.32 was used [5].

J.Saravanan and N.Suganya (2019), studied on the evaluation of steel slag aggregate concrete in comparison with the conventional natural concrete. The objective of the research was to find combined aggregate gradation using steel slag aggregate, which will significantly reduce the amount of cement required by 10% to 15% without compromising concrete properties. To achieve this objective, several optimization techniques were being applied to M40 design. Theoretical Particle Packing Method and Particle Density Method for standardizing aggregate gradations is also applied. The materials used are cement, coarse aggregate, steel slag, sand, and casting is done. In this, cubical specimen of 150mm, and cylindrical specimen of 150mm diameter and height 300mm, the size of the prism is 100mm×100mm×60mm were used. Test such as compressive strength test, split tensile strength test, flexural strength test, E-form concrete test is conducted.The test results gives that, compressive strength of steel slag increases 6% and split tensile strength of steel slag increases 25% and flexural strength of steel slag increases 34% as compared to the conventional coarse aggregate concrete [3].

A.V Rahul (2019), investigated on a concrete mix consisting of fly ash, cement, silica fume as binders, quartz powder and two grades of quartz sand as fine aggregate, polypropylene fiber and superplasticizer was used. Mould cast cubes and beams were prepared according to ASTM standards. Cubes where of size 50mm×50mm×50mm, beams were of size 140mm×60mm×60mm. For the testing of printed concrete, specimens were cut out from a 3D printed wall prototype. Tests for determining porosity, bond strength, compressive strength and flexural strength were done. The results showed that porosity was found to be higher for the specimen extracted from wall elements compared to mould cast. Bond shear strength was lower for specimens cut from wall elements compared to mould cast. Compressive strength and flexural strength almost remained the same [2].

Concluding remarks:

Based on the literature reviews, we got to know about the latest advancements that had taken place in the 3D concrete printing industries. 3DCP is proved to be advantageous compared to the conventional construction in many aspects. However, the cost of construction is more when 3DCP technology is adopted.

Thus the main aim of our project is to produce a concrete mix that is economic than the ones prevailing in the market. For this we decided to make partial replacement to the material that is of high cost comparable to other components in the mix with a more economic material.

For this purpose, we have chosen a reference mixture proportion as shown in table 1 [2],[5].

Table 1 : Mixture Proportions

Sl.No	Material	Quantity (kg/m^3)
1	Sand 1	369
2	Sand 2	369
3	Quartz powder	492
4	OPC	574
5	Fly ash	164
6	Silica fume	82
7	Water	262
8	Superplasticizer	1.35
9	Polypropylene fibers	1.8

The reference mixture design had a combination of portland cement and fly ash as binders. The proportions of all dry

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ingredients were optimized by using the particle packing method using the commercial particle packing software EMMA. The modified Andreassen model with a distribution modulus (w) of 0.25 was used. The comparison of the combined particle size distribution of all solid dry ingredients for the final mixture proportion. To achieve high strength, a low water to binder ratio of 0.32 was used. Polypropylene fiber was used at normal dosage of 1.8 kg/m^3 to control plastic shrinkage cracks [5].

In this reference mix design, we will be incorporating steel slag as a partial replacement of Quartz powder. Steel Slag of varying percentages from 0%, 10%, 20%, 30%, 40% and 50% of quartz powder were used to prepare different mixes and cubes and beams were casted. 3 cubes of 50mm×50mm×50mm and 3 beams of 160mm×40mm×40mm were casted for the 6 batches as mentioned. After 28 days of curing the cubes and beams are tested to find out the compressive and flexural strength and optimum percentage of steel slag is determined.

III. OBJECTIVES

The objectives of this project are:

- To produce a printable concrete mix that is economic than the one prevailing in the market by replacing quartz powder with steel slag.
- To find out the variations in compressive strength for the various mixes with varying percentage of replacement of quartz powder by steel slag.
- To find out the variations in flexural strength for the various mixes with varying percentage of replacement of quartz powder by steel slag.

IV. SCOPE

By making use of 3D concrete printing we could solve the limitations of conventional construction. Some of the possibilities are: [4]

- Using 3D printing technologies for the construction of structures would greatly reduce the cost involved with it as it reduces the number of materials used and also avoids the wastage of the materials. It also reduces the labor cost as the requirement of manpower is less subsequently reducing the cost associated with accidents and injuries.
- The designs which are uploaded in the form of CAD can be printed in no time. Thus, 3D printers can complete the construction of a single storeyed building within 12 to 24 hours leading to speedy construction of structures.
- With the advancements made in technologies it has been proved that the structures constructed using 3D printing have higher strength and durability which can withstand extremes of temperature.
- Even intricate designs can be accurately constructed easily without any increase in cost and permitting the better usage of space.
- This method is more sustainable because most of the materials used in these processes are recyclable and reusable. Also, the carbon footprint produced by this method is much lesser than the conventional methods.
- This method helps in the easy verification of designs by creating prototypes which would eliminate the occurrence of errors in the mass productions.
- The use of formworks, scaffolds etc., can be avoided which would reduce about 40% of the construction cost.
- Increasing sustainability in construction by reducing wastages of formwork.

V. MATERIALS USED

The materials used are cement, silica fume, fly ash as binders and quartz sand (1 and 2), quartz powder and steel slag as fine aggregates, superplasticizer and polypropylene fibre .

A. Cement

53 Grade OPC provide high strength and durability to structures because of its optimum particle size distribution and superior crystallized structure. Being a high strength cement, it provides numerous advantages wherever concrete for special high strength application is required such as in the construction of roads, bridges etc. It attains higher strength ie; a designed strength of minimum 53MPa for 28 days. The fineness of cement is a measure of the size of particle of cement. For a good quality cement, the fineness should have less than 10% of cement particles greater than 90μm. The specific gravity of cement is around 3.15. As per IS 269, the initial setting time shall not be less than 30 minutes.

B. Silica Fume

Silica fume is an ultrafine material with spherical particles less than 1μm in diameter, the average being about 0.15μm. The bulk density of silica fume depends on the degree of densification in the silo and varies from 130kg/m3 to 600kg/m3. The specific gravity of silica fume is generally in the range of 2.2 to 2.3. It has a higher fineness value compared to OPC. The standard consistency of silica fume is 63%. The initial time is less for silica fume compared to cement.

C. Fly Ash

The burning of harder, older anthracite and bituminous coal typically produces class F fly ash. Class F fly ashes can have volatile effects on the entrained air content of concrete, causing reduced resistance to freeze/thaw damage. It can also increase the concrete's final strength, chemical resistance and its durability. The specific gravity of fly ash varies from 2.1 to 3.0. The fineness of fly ash was less than 45μm, have reached the highest compressive strength. The

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initial setting time is of 45 minutes from the average and final setting time can be about 1 to ¾ hours.

D. Quartz Sand (1 and 2)

The main raw material of glass are quartz sand. Different grades of quartz sand are available. In this grade 1 and grade 2 are used. Grades depend on their particle size. Quartz sand 1 has a particle size of 0.5mm to 1.1mm and quartz sand 2 has a particle size of 1mm to 2mm.Quartz sand is also known as industrial sand, it has 2 main elements silica and oxygen. Specifically, silica sand is made up of silicon dioxide (SiO_2). The most common form of SiO_2 is quartz, a chemically inert and relatively hard mineral.

E. Quartz Powder

It is common of all minerals and is composed of silicon dioxide or silica. It is an essential component of igneous and metamorphic rocks. The size varies from specimens weighing metric ton to minute particles that sparkle in rock surfaces.

F. *Steel Slag*

Steel slag is a by-product of molten iron processing and different types of steel slags are formed depending on a specific type or grade of steel and the furnace used during steel production. It is produced in large quantities during steel making operations that use electric arc furnaces. Steel slag can be used in many applications. In most cases the valorisation and use of these by-products prevent landfill reduce energy consumption, reduce CO_2 emissions and help preserve natural resources. Steel slag can be used for various purposes as a civil engineering material and includes the following:

- The study of friction created between the road and vehicle tyre.
- The effect of temperature on steel slag aggregate.
- The effect of steel slag and plastic waste as a binder on the properties of soil.
- The use steel slag as aggregate in concrete.

Steel slag can be used as aggregates in concrete to replace natural aggregate because it has favourable mechanical properties including strong bearing and shear strength, good soundness characteristics and high resistance to abrasion and impact. They have a rough vesicular nature with many non-interconnected cells which gives a greater surface area than smoother aggregates of equal volume. This feature provides an excellent bond with concrete binder. Replacing some or all natural aggregates with steel slag is helpful for reducing environmental pollution and the consumption of resources. Therefore steel slag is a promising kind of filler because it works as both functional filler and aggregate.

G. Superplasticizer

Polycarboxylic ether (PCE) based superplasticizer that can address the underlying mechanisms of hydration kinetics, development of surfaces area and surface charges in IAC system. Superplasticizers are admixture for concrete which are added inorder to reduce the water content in a mixture or to slow the setting rate of the concrete while retaining the flowing properties of a concrete mixture. Admixtures are used to modify the properties of concrete or mortar to make them more suitable to work by hand or for other purposes such as saving mechanical energy.in the case of hardened concrete the use superplasticizer will increase compressive strength by enhancing the effectiveness of compaction to produce denser concrete. Risk of drying shrinkage will be reduced by retaining the concrete in liquid state for longer period of time. The poly-carboxylates (PCE) is the new generation superplasticizer that provides the workability enhancement at low water to cement ratios, resulting in the production of durable and flowable concrete, is the backbone of these technologies.

H. Polypropylene Fibre

Polypropylene fibre, also known as polypropene or PP,is a synthetic fibre transformed from 85% propylene and used in a variety of applications. It is used in many different industries. The fibre is thermoplastic, resilient, light weight and resistant to mildew and many different chemicals. Polypropylene fibres reduce the plastic shrinkage crack area due to their flexibility and ability to conform to form. The addition of 0.1% by volume of fibres is found effective in reducing the extent of cracking by a factor of 5-10. The extent of crack reduction is proportional to the fibre content in the concrete. Polypropylene is manufactured from propylene gas in presence of a catalyst such as titanium chloride. Polypropylene is a by-product of petroleum.

VI. EXPERIMENTAL PROGRAMME

A. Tests on Binders

Cement, silica fume and fly ash are the binders used for the concrete mix in this study. Fineness test (as per IS 4031,1988), specific gravity test (as per IS 4031 Part 2), standard consistency test (as per IS 4031 Part 4) and initial setting time (as per IS 4031, IS 269) on the binders were done.

B. Tests on Fine Aggregates

Specific gravity of quartz sand 1 and 2 was determined as per IS 2386 (Part III).

C. Tests on Specimen

The experimental program is designed based on the percentage replacement of quartz powder by steel slag to study the mechanical properties of concrete at different grades of concrete. The specimen prepared after replacement of quartz powder by steel slag for 0%, 10%, 20%, 30%, 40% and 50% are studied for compressive strength (as per IS 516) and flexural strength (as per IS 516, IS 456) for curing period of 28 days.

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VII. CALCULATION OF MATERIALS FOR VARYING PERCENTAGE OF STEEL SLAG REPLACEMENT

Volume of 1 cube = 50mm × 50mm × 50mm

Volume of 3 cubes = 375000mm3 = 3.75×10^{-4} m^3

Volume of 1 beam = 160mm × 40mm × 40mm

Volume of 3 beams = 768000mm^3 = 7.68×10-4 m^3

Total volume including wastage of 15% = 1.31445×10^{-3} m^3

For 1st batch – 0% of steel slag.

The quantity of materials required according to the reference mix for 1m^3 are shown in table 2.

Table 2 : Quantity of materials required according to the reference mix for 1m^3 for 1st batch

Sl.No	Materials	Quantity
1	Quartz sand 1	0.48 kg
2	Quartz sand 2	0.48 kg
3	Quartz powder	0.65 kg
4	OPC	0.754 kg
5	Fly ash	0.215 kg
6	Silica fume	0.107 kg
7	Water	0.344 kg
8	Superplasticizer	1.774 g
9	Polypropylene fibre	2.36 g

For 2nd batch – 10% of quartz powder is replaced by steel slag. The quantity of materials required are shown in table 3.

Table 3 : Quantity of materials required for 2nd batch

Sl. No	Materials	Quantity
1	Quartz sand 1	0.48 kg
2	Quartz sand 2	0.48 kg
3	OPC	0.754 kg
4	Fly ash	0.215 kg
5	Silica fume	0.107 kg
6	Water	0.344 kg
7	Superplasticizer	1.774 ml
8	Polypropylene fibre	0.002 kg
9	Steel slag	0.065 kg
10	Quartz powder	0.585 kg

For 3rd batch - 20% of quartz powder is replaced by steel slag. The quantity of materials required are shown in table 4.

Table 4 : Quantity of materials required for 3rd batch

Sl.No	Materials	Quantity
1	Quartz sand 1	0.48 kg
2	Quartz sand 2	0.48 kg
3	OPC	0.754 kg
4	Fly ash	0.215 kg
5	Silica fume	0.107 kg
6	Water	0.344 kg
7	Superplasticizer	1.774 ml
8	Polypropylene fibre	0.002 kg
9	Steel slag	0.13 kg
10	Quartz powder	0.52 kg

For 4th batch - 30% of quartz powder is replaced by steel slag. The quantity of materials required are shown in table 5.

Table 5 : Quantity of materials required for 4th batch

Sl.No	Materials	Quantity
1	Quartz sand 1	0.48 kg
2	Quartz sand 2	0.48 kg
3	OPC	0.754 kg
4	Fly ash	0.215 kg
5	Silica fume	0.107 kg
6	Water	0.344 kg
7	Superplasticizer	1.774 ml
8	Polypropylene fibre	0.002 kg
9	Steel slag	0.195 kg
10	Quartz powder	0.455 kg

For 5th batch - 40% of quartz powder is replaced by steel slag. The quantity of materials required are shown in table 6.

Table 6 : Quantity of materials required for 5th batch

Sl.No	Materials	Quantity
1	Quartz sand 1	0.48 kg
2	Quartz sand 2	0.48 kg
3	OPC	0.754 kg
4	Fly ash	0.215 kg
5	Silica fume	0.107 kg
6	Water	0.344 kg
7	Superplasticizer	1.774 ml
8	Polypropylene fibre	0.002 kg
9	Steel slag	0.26 kg
10	Quartz powder	0.39 kg

For 6th batch - 50% of quartz powder is replaced by steel slag. The quantity of materials required are shown in table 7.

Table 7 : Quantity of materials required for 6th batch

Sl.No	Materials	Quantity
1	Quartz sand 1	0.48 kg
2	Quartz sand 2	0.48 kg
3	OPC	0.754 kg
4	Fly ash	0.215 kg
5	Silica fume	0.107 kg
6	Water	0.344 kg
7	Superplasticizer	1.774 ml
8	Polypropylene fibre	0.002 kg
9	Steel slag	0.325 kg
10	Quartz powder	0.325

VIII. RESULTS AND DISCUSSIONS

A. Preliminary Test Results of Fine Aggregates

The preliminary test results of fine aggregates are shown in table 8.

Table 8 : Test results of fine aggregates

Sl.No	Aggregate	Size	Specific gravity
1	Quartz Sand 1	0.5 – 1.1 mm	2.65
2	Quartz Sand 2	1 – 2 mm	2.649

The fine aggregates include quartz sand 1 and quartz sand 2. The particle size of them were found to be between

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0.5mm - 1.1mm and 1mm - 2mm respectively. Also their specific gravity was found to be 2.65 and 2.649.

B. *Preliminary Test Results of Binders*

The test results of fineness, specific gravity, standard consistency and initial setting time of binders are shown in table 9.

Table 9 : Test results of binders

Sl.No	Binders	Fineness	Specific gravity	Standard consistency	Initial setting time
1	OPC	1%	3.1	34%	40mins
2	Fly Ash	13%	2.36	27%	1hr
3	Silica Fume	77%	2.25	63%	15mins

a) *Fineness*

The fineness of cement is a measure of the size of particles of cement. It can be used to express the specific surface of the cement. For a given weight of cement the specific surface is more for finer cement than coarser cement. For a good quality cement it should have less than 10% of cement particles greater than 90 micrometer. The cement we choose was found to had a fineness of 1 % which is within the limit.

Fly ash should have less than 34% of particles greater than

45 micrometer. The fly ash which we used had a fineness

of 13% which is within the limit.

Silica fume particles are extremely small with more than 95% of the particles less than 1 micrometer. We got 77% particles coarser than 90 micrometer.

b) *Specific Gravity*

It is normally defined as the ratio of weight of given volume of material to equal volume of water.

Portland cement usually has a specific gravity of around 3.15. The cement we used was found to had a specific gravity of 3.1, within the limit.

Specific gravity of fly ash varies between 1.9 to 2.96. The fly Ash we used had a specific gravity of 2.36 which is within the limit.

Specific gravity of silica fume is a relative number that tells how silica fume compared to water. Silica fume has a specific gravity of around 2.2 which is lighter than Portland cement. The silica fume we used had a specific gravity of 2.25 which is also around the range.

c) *Standard Consistency*

Standard consistency of cement is that consistency which permit the vicat plunger to penetrate to a point 5-7 mm from the bottom of the vicat mould. Water less than standard consistency would not attain full strength. When water more than standard consistency is provided it results in excess water and strength reduction. Standard consistency of ordinary Portland cement varies between 25-35%. Cement we used had a standard consistency of 34 % which is also within the limit.

The standard consistency of fly ash that we used was found to be 27%.

Silica fume has a higher fineness value compared to OPC. As said earlier finer the binder higher its specific surface and it needs more water for complete hydration and for workability. Hence it has a higher standard consistency of 63%.

d) *Initial Setting Time*

As per IS 269 initial setting time of cement shall not be less than 30 minutes. The cement we used had an initial setting time of 40 minutes which is permissible.

For fly ash the initial setting time was found to be 1 hour.

The initial setting time is less for silica fume compared to cement. The pozzolanic action of silica fume seems to be very active at early hours of hydration. The silica fume we used had an initial setting time of 15 minutes which is lesser than that of OPC and fly ash.

C. *Test Results of Specimens*

a) *Compressive Strength Test Results*

The results of compressive strength for various mix proportions of steel slag blended concrete measured at 28 days of curing are given in table 10.

Table 10 : Test results of compressive strength

Sl.No	Percentage replacement of quartz powder by steel slag (%)	Average load at failure (kN)	Compressive Strength (N/mm^2)
1	0	80	32
2	10	90	36
3	20	110	44
4	30	120	48
5	40	112	44.8
6	50	95	38

The results indicated that the compressive strength at 28 days increased upto 30% of steel slag replacement and then decreased. Optimum strength was found at the replacement level of 30% . The graph of compressive strength test result is shown in figure 1.

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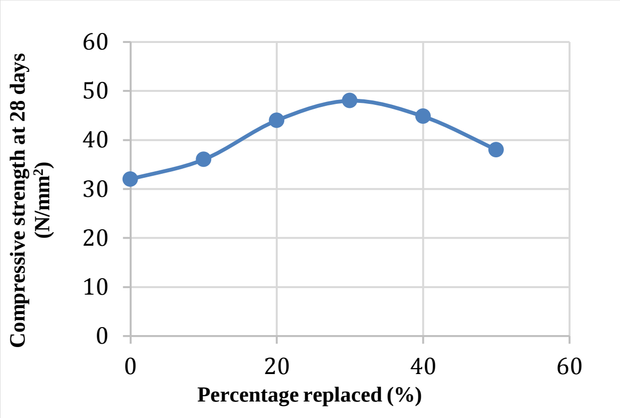

Figure 1 : Graph of compressive strength test

It concludes good strength results up to 30% of replacement afterwards at 40% it decreases. The strength increases gradually.

b) Flexural Strength Test Results

The results of flexural strength for various percentages of steel slag blended concrete measured at 28 days of curing is given in table 11.

Table 11 : Test results of flexural strength

Sl.No	Percentage replacement of quartz powder by steel slag (%)	Average load at failure (kN)	Flexural Strength (N/mm^2)
1	0	1.6	4
2	10	2.1	5.25
3	20	2.4	6
4	30	2.8	7
5	40	2.2	5.5
6	50	1.6	4

The flexural strength was found to be improved by replacement levels but it reduced after 30%. The optimum value was found at replacement proportion of 30% for quartz powder and after that any further replacement of slag decreases the flexural strength. The graph of flexural strength test result is shown in figure 2.

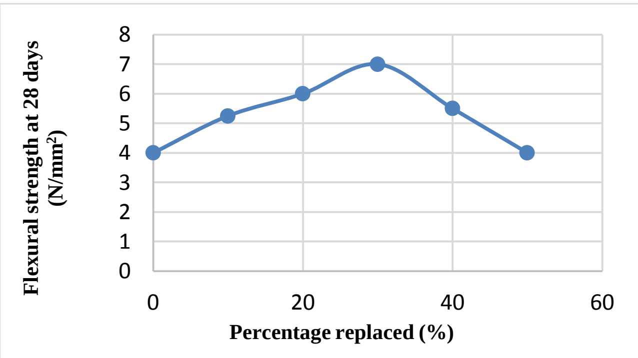

Figure 2 : Graph of flexural strength test

It concludes good strength results up to 30% of replacement afterwards at 40% it decreases. The strength increases gradually.

IX. CONCLUSION

This work relates the use of waste steel slag as a fine aggregate for printable concrete and recommends the approval percentage level for use of concrete in replacement of fine aggregates. This approval is important because the compressive and flexural strength increases up to certain level of replacements. At first preliminary tests were carried out on binders and fine aggregates. Then by adopting a reference mix design the calculations of materials for varying percentage of quartz powder replacement with steel slag was done. Using these calculated quantity of materials 3 cubes of size 50mm×50mm×50mm and 3 beams of size 160mm×40mm×40mm were casted for each varying percentages and they were tested for compression and flexural strength.

- The compressive strength was found to increase from 0% steel slag replacement to 30% replacement. At 30% replacement level compressive strength was found to be maximum. For further replacement the compressive strength gradually decreased.
- The flexural strength was found improved till 30% replacement levels but it reduced for further increase in replacement percentage.
- The results indicated that optimum strength was found by the replacement level of 30 %. Strength reduction was observed at further replacements of fine aggregate with granular slag
- The strength is increased, because of increase in unit weight of concrete due to incorporation of slag.
- Reduction in strength at higher replacement level is due to rough surface of slag aggregates, this requires finer material to overcome this frictional force and improve the strength.
- The mass utilization of waste material like steel slag as partial replacement quartz powder in printable concrete helps in reduction of cost of construction and proves to be socially beneficial by reducing the stocks of slag in the plants which results is health hazards.
- Thus, 30% of quartz powder replacement with steel slag is found to be the optimum value to produce a more economic printable concrete mix.
- Hence with 30% replacement of quartz powder with steel slag we can produce a concrete mix that is economic than the one prevailing in the market.

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