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Experimental Study on Concrete with Msand and GGBS as Partial Replacement for Fine Aggregate and Cement

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Abstract: The current investigation focuses on finely ground and processed industrial by-product obtained from blast furnace slag is introduced as a partial substitution in concrete replacement material for cement to improve concrete properties sustainability and artificially produced fine aggregate known as M-sand serves as an alternative fine aggregate in concrete production and construction works partial incorporation as a substitute for** fine **substitute for fine aggregate utilized in cement-based concrete systems fine aggregate used as a replacement material in concrete. Initially, several laboratory Experiments were conducted on cement to investigate its experimental work materials the analytical investigation were tested according to standard procedures to determine their characteristics. Tests conducted on cement included density ratio, fineness, the consistency properties of cement together with its initial and final setting time behavior, along with evaluation of compressive strength at 3, 7, and 28 days. Fine aggregate tests included sieve analysis, mass per unit volume and fineness modulus, specific gravity, and bulking of sand. Coarse aggregate was examined through water absorption, flakiness index, elongation index, and aggregate crushing value tests. Clean Good-quality drinking potable water was used for the mixing of concrete mixes. In the current investigation second stage of the investigation, the percentage of M-sand was maintained constant at 60%, while GGBS was incorporated as a cement replacement at varying proportions of in increments of This design of concrete mix proportions for M30 considered in this investigation prepared in accordance accompanied by IS 10262 guidelines. construction material specimens specimens were maintained under standard curing conditions for periods of 56, and 91 days to analyze the fresh and hardened properties of cement-based materials concrete. Fresh concrete properties were assessed using workability tests such as The workability of fresh concrete was evaluated using the slump cone test, Vee-Bee consistometer test, and compaction factor test. The structural performance characteristics of hardened assessed through the mechanical strengths including compressive, split tensile, and flexural behavior tests. durability performance of the concrete was evaluated also investigated studied through performing acid attack investigations on concrete samples.

Finally, the experimental results obtained from concrete containing M-sand and GGBS were assessed and contrasted with those of conventional construction material to evaluate their overall performance and suitability in construction applications.

I. INTRODUCTION

A. General

In civil engineering, concrete is a widely adopted construction material across globally because of its It is characterized by strength, durability, and versatility, with cement, fine aggregate, coarse aggregate, and water as its main constituents. Among these constituents, Fine aggregate has a significant role in significant function in determining this performance along with durability in concrete. Historically, river sand has been the primary fine aggregate material used. extensively used as fine aggregate in construction activities. However, continuous extraction of river sand has created environmental imbalance. and strict government regulations on sand mining have created a shortage of natural sand resources. Rapid urbanization and infrastructure development in India have significantly increased the demand for construction materials, leading to a sharp escalation in the cost of river granular materia. Excessive granular materia mining from riverbeds has also resulted in serious environmental issues such as lowering of groundwater tables, erosion of riverbanks, destruction of aquatic ecosystems, and reduction in vegetation near river channels. Therefore, the construction industry has started exploring alternative materials to replace natural river sand.

Several alternative materials such as manufactured sand (M-sand), industrial by-products, recycled aggregates, bottom ash, and slag materials are being investigated as substitutes for river sand. Among these materials, manufactured sand has gained considerable attention due to its suitability and availability. Processed sand is produced by through obtained by mechanical crushing of hard granite rocks to obtain fine particles of required size and grading. Since it is developed under controlled conditions, it provides better quality consistency compared to natural river sand. However, due to the angular shape of its particles angular irregular particle shape with a rough surface texture,M-sand may reduce this workability of concrete mixes because of the increased surface area. Even with this limitation, the use of manufactured sand has become highly beneficial because it reduces dependency on natural sand resources and supports sustainable construction practices.

1) Manufactured Sand (M-Sand)

Artificially produced fine aggregate is a viable in place of natural river sand in concrete applications applications considered an effective substitute for natural natural sand in cement concrete production processes production. This increasing scarcity of conventional river sand and its rising transportation cost have encouraged the utilization of manufactured sand in construction activities. Since manufactured sand is produced from locally available hard granite stones, it can be easily obtained near construction sites, thereby reducing transportation expenses and overall project cost.

Another major advantage of M-sand is its cleanliness and absence of organic impurities, clay, and silt materials that are commonly found in natural sand. This improves the quality and strength characteristics of concrete. Additionally, the controlled manufacturing process helps in achieving uniform grading and better particle distribution.

The growing use of manufactured sand is mainly driven by the following factors:

- Scarcity of natural river sand: Excessive mining and environmental restrictions have limited the availability of river sand in many regions.
- Increasing demand in construction activities: Fine aggregates constitute a major portion of concrete and mortar, resulting in a continuously growing demand for sand materials in infrastructure projects.
- Environmental concerns: Uncontrolled sand mining causes riverbank erosion, groundwater depletion, and ecological imbalance, making sustainable alternatives necessary.
- High transportation costs: Suitable natural sand sources are often located far from construction sites, increasing transportation expenditure.
- Availability of quality materials: Manufactured sand can be produced in large quantities with controlled quality, making it a reliable construction material.

Thus, the utilization of manufactured sand not only reduces the problem of shortage of natural river sand as well as contributing to economical and environmentally eco-friendly construction practices.

 Presence of silt and clay in natural sand: Natural river sand often contains considerable amounts of silt, clay, and other impurities. These unwanted materials negatively alter the mechanical performance strength cementitious. Excessive impurities might also weaken the adhesion between the hydrated cement matrix and the aggregate phase.

 Utilization of quarry waste materials: Low-value by-products generated during the crushing of rocks in quarries can be effectively utilized in the production of manufactured sand. This helps in reducing material wastage and converting quarry by-products into useful construction materials with higher economic value.

Figure 1.1: Manufactured Sand

B. Manufacturing Process

Manufactured sand is generally produced using Vertical Shaft Impactor (VSI) crushers, which operate on the principle of rock-on-rock or rock-on-metal impact. This process helps in obtaining properly shaped and graded fine aggregates suitable for concrete production. To achieve high-quality manufactured sand, particle size reduction and uniform particle shape are essential.

Unlike conventional crushing methods that may produce flaky and elongated particles, VSI technology improves the particle shape and texture of sand, resulting in more appropriate for construction applications. The findings manufactured sand has the ability to further become processed through washing, grading, and blending operations to improve its quality before being supplied for use in concrete works.

One of the major advantages of manufactured sand production is that all processing stages can be controlled within the manufacturing plant itself. This enables better quality control and ensures consistent production of fine aggregates with the desired physical properties.

Manufactured sand produced through VSI crushers generally satisfies the criteria of Zone -II grading as mentioned in according to BIS specifications (IS codes) 383:1970. The percentage of particles finer than 75 microns is usually maintained below the permissible limit through proper washing or dry classification methods.

Dry classification techniques are increasingly being adopted worldwide for the production of M-sand. These methods separate fine and coarse particles without the use of water, resulting in reduced super-fine content and improved quality of manufactured sand suitable for concrete production.

C. Properties Of Manufactured Sand

1. Higher Strength of Concrete

Manufactured sand possesses proper grading, angular particle shape, and consistent texture, which play a role in to improved bond strength between cement paste and aggregates These characteristics reduce segregation, bleeding, honeycombing, and void formation in concrete. As a result, concrete prepared with M-sand generally exhibits higher compressive strength and better overall performance.

2. Durability of Concrete

Since manufactured sand is produced from selected hard rocks under controlled conditions, it provides better a comparison of physical and chemical characteristics was made to natural river sand. The study reduced permeability of hydrated cement mixture made with M-sand minimizes moisture penetration and protects reinforcement steel from corrosion. This increases the durability and extends the service life of reinforced cement (RCC) structures, especially within severe ambient conditions.

3. Workability of Concrete

The size, particle morphology and surface texture of fine granular material affect concrete workability characteristics Manufactured sand with controlled grading requires less water for achieving the desired workability. Reduced water demand enhances concrete strength and improves the mixing characteristics handling, and ease of placement concrete at construction sites.

4. Reduction in Construction Defects

The incorporation of M- fine aggregate helps in minimizing common construction defects such as segregation, bleeding, honeycombing, capillary voids, and shrinkage cracks. Its uniform particle distribution and proper fineness contribute to better concrete compaction and finishing quality.

5. Economy

Manufactured sand is recognized as an economical viable effective replacement for conventional river sand in cement concrete applications because of its local availability and lower transportation cost. In addition, improved strength and durability characteristics reduce maintenance expenses and increase the long-term performance of structures.

6. Environmentally Friendly Material

The use of manufactured sand reduces excessive extraction of river sand, thereby minimizing environmental problems including issues like riverbank erosion, groundwater exhaustion, and ecological disruption.Hence, M-sand is regarded as an environmentally sustainable construction material.

2) Advantages Of Manufactured Sand

- Manufactured sand is well graded and provides consistent quality.
- It is free from organic impurities and harmful soluble materials that could influence the setting and strength properties of concrete.
- M-sand does not contain excessive quantities of silt, clay, or dust, which helps in maintaining strong bonding at the interfacial transition zone developed at the interface between the cement paste and aggregates.
- The controlled manufacturing methodology ensures this production of sand with desired engineering properties suitable for building construction activities.
- Manufactured sand is derived from hard granite stone rocks using advanced fragmenting technology, resulting in durable and high-quality fine aggregates.
- It significantly enhances the overall and structural performance performance structures.
- The use of manufactured sand (M-sand) supports environmentally sustainable construction practices by decreasing river sand usage resources.
- Manufactured sand particles are generally cubical in shape and are produced using advanced crushing technologies such as the rock-on-rock process. This manufacturing method helps in obtaining particle characteristics similar to naturally weathered river sand.
- Modern and advanced crushing machines are used in the production of M-sand to achieve the required grading, particle size distribution, and consistent quality suitable for construction purposes.

3) Disadvantages Of Manufactured Sand

1. Reduced Workability of Concrete

Concrete prepared with manufactured sand may exhibit lower workability due to the following reasons:

- The particle shape of M-sand is angular, cubical, or flaky rather than rounded.
- Manufactured sand generally contains a higher percentage of fine particles.

Remedies

- Proper control of particle shape and grading.
- Use of plasticizers or superplasticizers to improve workability.
- Addition of fly ash or mineral admixtures to enhance concrete performance.

2. Rapid Drying of Concrete

Concrete containing M-sand may lose moisture quickly because of:

- Higher water absorption capacity of manufactured sand.
- Smaller particle size leading to faster absorption of water.
- Increased surface area causing rapid evaporation.

Remedies

- Use of retarding admixtures and plasticizers.
- Addition of fly ash to improve moisture retention.
- Proper curing and protection of concrete surfaces from drying.

3. Segregation of Concrete

Segregation may occur in M-sand concrete due to:

- Flaky or irregular particle shapes.
- Insufficient amount of fines.
- Separation of particles during transportation and placement.
- Inadequate mixing of concrete ingredients.

Remedies

- Proper control of particle shape and grading.
- Prevention of segregation during transportation by maintaining adequate moisture.

- Use of fly ash and mineral admixtures.
- Partial blending with natural river sand.
- Addition of fibers to improve cohesion.
- Use of efficient mechanical mixers for uniform mixing.

4. Honeycombing in Concrete

Honeycombing defects may occur because of:

- Reduced workability and slump retention.
- Inadequate compaction and vibration.
- Segregation during transportation and placement.
- Insufficient fine particles in the mix.

Remedies

- Use of plasticizers, retarders, and mineral admixtures.
- Proper compaction and finishing of concrete.
- Use of well-graded manufactured sand with adequate fines.
- Ensuring proper cohesion and homogeneity of the concrete mix.

4) Processed supplementary cementitious material derived from blast furnace slag (GGBS)

Reduce heat of hydration by-product generated during during this manufacture of ferrous material in blast furnaces. It is extensively employed serves as an effective supplementary cementitious material in cement concrete, because it improves workability, strength, and durability.

During the iron manufacturing process, basic inputs like iron ore, limestone, and coke are heated during temperatures of about 1500°C inside a blast furnace. This process produces hot liquid iron and slag material as by-products. The hot slag melt mainly contains siliceous and aluminous components, lime, and magnesium oxides, which are similar to the compounds present in cementitious materials.

The liquid-phase slag is quenched rapidly using pressurized water streams in a process defined as granulation. Rapid cooling converts the slag into glassy granules generally smaller than 5 mm in size. These granules are then dried and finely ground in grinding mills to produce processed blast furnace slag in fine powder form powder.

The primary **reactive substance** constituents of the supplementary cementitious material GGBS include:

- Calcium oxide (CaO)
- Silicon dioxide (SiO_2)
- Aluminum oxide (Al_2O_3)
- Magnesium oxide (MgO)

Because of its cementitious and demonstrates significant pozzolanic activity Finely ground a by-product generated during the is commonly incorporated as a as a partial replacement of cement in concrete production to enhance performance characteristics production.

D. Production Of A Supplementary Cementitious Material

The mineralogical composition of GGBS differs from ordinary Portland cement. These variations in chemical composition significantly influence the cement hydration mechanism, strength development, durability properties related to the concrete mixture. GGBS- as a function of concrete generally exhibits improved long-term strength, reduced heat of hydration, and enhanced resistance against chemical attacks compared to conventional concrete.

Plagi

Mineral	GGBS	Portland Cement
CaO	30%-50%	55%-66%
SiO2	28%-40%	22%-24%
Al2O3	8%-24%	0-8%
MgO	1%-18%	5%

Table 1.1: Mineralogical Composition in GGBS and Portland cement

1) Benefits of GGBS in Concrete

The inclusion associated with Ground Granulated Blast Furnace Slag (GGBS) offers several positive aspects in in relation to mechanical compressive strength characteristics and long-term durability and long-term response. The important benefits of GGBS in concrete are listed below:

- GGBS enhances the compressive load-bearing characteristics strength and the durability behavior of concrete structures structures.
- This material reduces this permeability belonging to concrete by minimizing this formation related to pores and voids.
- Concrete containing GGBS exhibits better workability and improved consistency.
- GGBS concrete possesses excellent pumping and compaction characteristics.
- The inclusion of GGBS enhances this durability the resistance behavior of concrete against chemical attack by sulfates and aggressive environmental conditions.
- It reduces chloride penetration, thereby protecting reinforcement steel from corrosion.
- The thermal heat of hydration process generated in GGBS concrete is lower compared to conventional concrete, which helps in minimizing thermal cracks.
- GGBS improves resistance against alkali-silica reaction in concrete.
- It increases the chemical stability and prolonged period performance of concrete structures.
- Concrete prepared with GGBS provides a smoother surface finish and improved appearance.
- The color of GGBS concrete is generally lighter and more uniform than ordinary concrete.
- The chances of efflorescence formation are comparatively lower.
- Maintenance and repair costs of structures are reduced due to enhanced durability.
- Unlike ordinary Portland cement production, GGBS utilization does not significantly contribute to carbon dioxide emissions, making it an environmentally sustainable material.

2) Durability Performance Of Concrete

Durability of concrete is defined as its ability to resist environmental weathering effects, chemical degradation, and abrasion over long-term service conditions. And environmental effects while preserving its intended engineering properties and performance characteristics throughout its operational period of the structure life. Durable concrete performs satisfactorily for a long period under specified exposure conditions with minimal maintenance.

The durability requirements of concrete vary depending on environmental exposure and structural conditions. Concrete can be considered durable when the following conditions are satisfied:

- The cement paste is dense and well-compacted possesses dense and impermeable nature.
- Adequate air entrainment is provided to resist freeze-thaw cycles.
- Properly graded, strong, and chemically stable aggregates are used.
- The constituent materials contain minimum impurities such as chlorides, sulfates, salts, and organic matter.

Ordinary Portland Cement, a widely used hydraulic cement in construction concrete is exhibiting strong alkaline characteristics generally having a pH value greater than 12.5. This high alkalinity provides protection against corrosion of reinforcement steel. However, when concrete is exposed to acidic environments, the pH value gradually decreases, leading to deterioration of hydrated cement compounds.

Acid attack occurs when acidic substances come into contact with concrete surfaces. Under acidic conditions, calcium compounds present in hydrated cement paste begin to dissolve, resulting in loss of strength and deterioration of the concrete matrix. Portlandite is one of the first compounds to dissolve when the pH falls below 12.5.

As the pH level further decreases, hydrated cement products undergo decomposition and form unstable hydrogel compounds. The reaction between acids and cementitious materials produces soluble calcium salts, which are washed away from the concrete surface, causing progressive material damage.

Acid attack affects both hydrated and unhydrated cement compounds as well as calcareous aggregates present in concrete. The severity of acid attack is largely governed by the pH magnitude of the acidic environment:

- When this pH is between 6.5 and 5.5, the attack is considered mild.
- When the pH ranges from 5.5 to 4.5, the attack becomes severe.

- When the pH falls below 4.5, the attack is classified as very severe.

Therefore, improving the durability characteristics of The properties of concrete can be enhanced through the incorporation of supplementary cementitious materials. such as GGBS serves as a vital role in enhancing the ability resist against aggressive environmental conditions and chemical attacks.

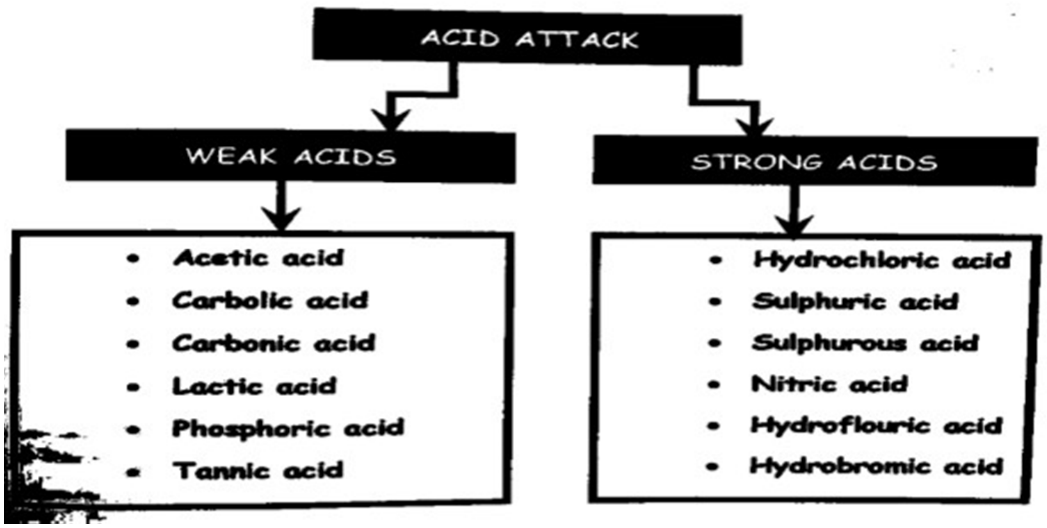

Fig 1.2. Classification of Acids

3) Hydrochloric Acid Attack on Concrete

When hydrochloric acid reacts with hydrated cement compounds in concrete, both soluble and insoluble products are formed. The soluble calcium salts produced during the reaction are gradually leached out by water, while insoluble compounds and amorphous hydrogels remain within the deteriorated concrete layer. The interaction between acidic solutions and cement hydrates leads to decomposition of the cement matrix and progressive loss of concrete load-bearing capacity.

The reaction involving calcium hydroxide and hydrochloric acidic medium can be given as:

Ca(OH)2+2HCl→CaCl2+2H2OCa(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2OCa(OH)2+2HCl→CaCl2+2H2O

- During this reaction produces calcium hydroxide serves as present in hardened cement paste is converted into calcium chloride, which is highly soluble and easily removed from the concrete surface. As calcium hydroxide is depleted, the formation of calcium silicate hydrate (C–S–H) gel and other chemical hydration process in cementitious systems compounds ettringite compounds begin towards decompose, causing deterioration associated with the hardened concrete structure.

Hydrochloric acid attack is therefore considered among the major categories of acidic deterioration in concrete structural systems.Continuous exposure to acidic environments results in surface erosion, reduction in strength, and increased permeability of concrete.

4) Preparation Of 1% Hcl Solution Molarity

Molarity (M) represents the number of moles present in the solute present in relation to each unit litre from solution.

Molarity (M)= Quantity of moles ofsoluteVolume of solution in litresMolarity\,(M)=\frac{\text{Number of moles of solute}}{\text{Volume of solution in litres}}Molarity(M)=Volume of solution in litresNumber of moles of solute

Molality

Molality (m) is defined as the molar quantity of solute present present per kilogram of solvent.

Molality (m)=Number of moles of soluteMass of solvent in kgMolality\,(m)=\frac{\text{Number of moles of solute}}{\text{Mass of solvent in kg}}Molality(m)=Mass of solvent in kg Number of the number of moles of the solute present Normality

Normality (N) represents the quantity of solute measured in gram equivalents for each litre of solution

Normality (N)=Number of equivalentsVolume of solution in litresNormality\,(N)=\frac{\text{Number of equivalents}}{\text{Volume of solution in litres}}Normality(N)= the measured volume of the solution in litresNumber of equivalents

The relationship between normality and molarity is expressed as:

N=n×MN=n\times MN=n×M

where *n* represents the number of replaceable hydrogen ions (H^+) or hydroxyl ions (OH^-).

Calculation for Preparation of 1% HCl Solution

1. Percentage concentration is generally expressed on a weight basis.
2. The concentration and density of the stock hydrochloric acid solution are usually 37.3% and 1.189 g/ml respectively.
3. The reciprocal of density is calculated as:

11.189=0.841 ml/g\frac{1}{1.189}=0.841\,ml/g1.1891=0.841ml/g

4. Multiplying by 100 gives:

0.841×100=84.1 ml/100g0.841\times100=84.1\,ml/100g0.841×100=84.1ml/100g

5. The quantity of stock solution containing 1 g of HCl is calculated as:

84.137.3=2.25 ml/g\frac{84.1}{37.3}=2.25\,ml/g37.384.1=2.25ml/g

6. Therefore, for preparing 1000 ml of 1% HCl solution:

10×2.25=22.5 ml10\times2.25=22.5\,ml10×2.25=22.5ml

Hence, 22.5 ml of stock hydrochloric acid solution is required for preparing 1000 ml of 1% HCl solution.

7. Similarly, for preparing 30 litres of 1% HCl solution, approximately 675 ml of stock hydrochloric acid is required.

5) Objectives Of The Present Work

This major The main aims of this investigation are outlined as follows:

- In order to design this concrete mix for concrete designed for following Bureau of Indian Standards IS 10262:2009 specifications guidelines.
- In order to analyze the behavior of concrete in terms of both in plastic and in the hardened state states states.
- In study the fresh concrete workability behavior performance such as value, workability parameters such as compaction factor and Vee-Bee time associated with M30 grade concrete concrete grade prepared by partial replacement of natural sand using M-sand was incorporated as a partial substitute for fine aggregate at replacement levels of 0%, 20%, 40%, 60%, and 80%, respectively 100%.
- To determine this optimum dosage of admixture required to achieve the desired slump range of 25–75 mm.
- To evaluate the physical strength mechanical properties such as compressive strength and split tensile strength and resistance to bending of varying percentage levels of M-sand replacement level
- To analyze the performance of concrete specimens undergoing hydrochloric acid exposure.
- To investigate the ideal replacement percentage of natural with manufactured fine aggregate material.
- Intended to partially replace cement replaced with a finely processed by-product of blast furnace slag known as GGBS a proportion of at a substitution proportion of 10%20%, 30%, 40% after determining the optimum M-sand content.
- To study the load-bearing strength characteristics properties GGBS based on mechanical properties including compressive strength, split tensile strength, and flexural strength at different curing durations
- To study this durability engineering behavior of concrete subjected to hydrochloric acid attack after incorporating GGBS and M-sand.

6) Scope Of The Present Work

The research work presented here investigates this contribution of substitution river accompanied through partial replacement of natural sand with manufactured sand during grade concrete with six different mix proportions mixtures were formulated and prepared incorporating M-sand varying replacement percentages of 0%, 20%.

The load-bearing properties of concrete including resistance to, split splitting tensile strength were assessed evaluated. After determining this optimum percentage replacement of M-sand, Partial Cement was partially substituted with GGBS at various levels of 10%, 20%, 30%, 40%.

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Concrete cubes of Concrete cylindrical specimens of dimensions 150 mm × 300 mm were cast and evaluated for split tensile strength at different curing periods.

Standard concrete Specimens in cylindrical form were and assessed for determining the different curing periods.Concrete standard prism specimens with dimensions of 500 mm × 100 mm × 100 mm were prepared were also fabricated and tested inside flexural strength.

7) Organization Of The Dissertation

- Chapter 1 **presents the introduction to concrete, the necessity of M-sand and GGBS, objectives of the study, scope of work, and structuring of the dissertation.**
- Chapter 2 **deals accompanied by the literature review on literature related to manufactured sand, GGBS, and concrete properties.**
- Chapter 3 **describes the experimental methodology, materials used, and testing procedures adopted in the investigation.**
- Chapter 4 **presents the details of experimental experimental tests on fresh and hardened concrete.**
- Chapter 5 **discusses this test results, observations, and analytical interpretations.**
- Chapter 6 **summarizes** the conclusions and recommendations of the present study.

II. LITERATURE REVIEW

Such a chapter discusses earlier research on research concerning the influence of manufactured sand (M-sand) and investigations on the effect of The review includes analysis of the physical and chemical properties of these materials and corresponding influence on fresh state properties of concrete,and their effect on the behavior of hardened concrete behavior. Various researchers have examined the strength, durability, and workability performance of concrete containing M-sand GGBS. A brief summary of important research contributions is presented below.

1) Study by conducted a investigation regarding this mechanical load-bearing strength and long-term durability performance of GGBS concrete Their investigation involved M40 grade concrete blended with cement substitution levels at replacement levels of 10%, 20%, 30%, 40%, and 50% using GGBS, along with 50% substitution of one material with another unprocessed. The samples were assessed for assessment of compressive, splitting tensile, and flexural strength properties. Durability studies such in particular the permeability in concrete Permeability chloride ion penetration (RCPT) test and sorptivity test, together with deterioration of concrete due to acid exposure tests were performed also performed. The results indicated improved chloride ingress resistance penetration and chemical corrosion in GGBS concrete mixes.
2) Sonali K. Gadpalliwar, R. S. Deotale, and Abhijeet R. Narde (2014) carried out an experimental investigation use GGBS, agricultural waste-derived rice husk ash (RHA) along along quarry in concrete. Their the study was segmented into three phases. The initial stage focused on natural sand was replaced with the incorporation of quarry fine particulate aggregate at quantities ranging from 0% to 100% to identify the optimum replacement proportion. In the second phase, cement was blended with GGBS at replacement levels. the final phase, a blend was incorporated as a partial replacement material for cement. The study concluded that quarry sand and mineral admixtures resulted in higher strength characteristics of cement-based concrete.
3) R. Subashini along with T. Sonia (2016) investigated the effectiveness of GGBS serving as a micro-filler in concrete mixtures in concrete. Portland cement concrete containing manufactured fine aggregate (sand) and supplementary cementitious material additives at replacement levels of 5%, 10%, and 15% was fabricated and subjected to testing axial load-bearing capacity under compressive stress and diametral tensile strength strength tests were undertaken conducted a 15% substitution of GGBS produced better strength performance compared to lower replacement levels.
4) Hudson (1997) assessed the strength performance characteristics of concrete incorporating high proportions of fine materials. A comparison was made between natural sand and crushed sand keeping the water–cement ratio constant at 0.70 throughout the study. Different percentages of material finer than 75 microns were incorporated in the concrete mixes. observed results revealed significant growth in compressive strength when incorporating of fine particles.
5) Balapgol et al. (2002) evaluated the effect of natural together with crushed sand about concrete strength properties at a uniform water–cement ratio was maintained. The investigation included varying percentages of material passing through a 75-micron sieve. The study reported noticeable enhancement in compressive strength when crushed sand was used.
6) Syam Prakash (2007) investigated the behavior of ready-mix concrete made using manufactured sand as aggregate of smaller particle size. Experimental

III. MATERIAL PROPERTIES

1) Better protection from carbonation.
2) Lower penetrability.
3) Better protection from forceful air conditions.
4) Decreased shrinkage and creep.
5) Expanded solidness.

A. Concrete

Concrete is a combination of glue and particles at its optimum level essential structure. The fine- and coarse-grained aggregates totals exist covered using a glue based on Portland cement concrete together with water. The glue hardens and increments strength through a compound response known as hydration, achieving the stone the resulting mass is called concrete. The way in up to a certain novel property because cement is tracked down in this cycle: it is flexible and moldable when newly blended, serious areas of strength for yet strong when solidified.

Concrete is the foundation of designs and framework all over the planet, including houses, schools, and emergency clinics, as well as air terminals, scaffolds, expressways, and rail frameworks, because of its toughness, strength, and minimal expense. As arising nations become more metropolitan, horrendous climate events require more sturdy structure materials, and the cost of other framework materials keeps on climbing, the most-delivered product on Earth will just turn out to be more sought after.

B. Cement

In cement concrete, cement serves as a binding agent. Cement is made by creating a personal blending comprising calcareous, siliceous, and aluminous constituents fixings under elevated temperatures and afterward pulverizing this subsequent clinkers are ground into a fine powder. Cement forms the most expensive component pertaining to concrete and is found between shapes and sizes. The chemical substance composition, fabrication process, and degree pertaining to the to which cements are ground all influence their properties. When cement and water during mixing, a chemical reaction occurs, leading to leads to this concrete glue set and hence cement into a stone-like mass. Concretes are ordered into two gatherings in light of their compound cosmetics, setting, and solidifying properties:

- Portland Cement
- Special Cement

PORTLAND CEMENT

This constitutes the most extensively cement type generally used in practice, and it gets its name from the fact that its qualities are similar to those of a well-known natural stone quarried in Portland (U.K). The discovery of Ordinary Portland Cement identified as credited the pioneer and a Yorkshire masonry worker.

COMPOSITION OF PORTLAND CEMENT

Cement is considered as used as made up within three main ingredients: lime-bearing and silica-bearing materials, and alumina. In addition, most cement contains minor amounts of iron oxide, magnesia, sulphur trioxide, and alkalies. Cement is made by heating an intimate mixture of the following elements to white heat followed by inter-grinding clinker in combination a very a particulate powder. During the comparison cement, this magnitudes of the various constituents are as follows:

Mineral Constituent	Amount present in Cement (%)
Lime (Ca0)	55% - 66%
Silica (Si0$_2$)	22% - 24%
Alumina (Al_2O_3)	0% - 8%
Iron oxide. (Fe_2O)	0.5% - 6%
magnesium oxide (Mg0)	0.1% - 5%
Sulphur trioxide (SO_3)	1% - 2.75%
alkalis, namely soda (Na_2O) and potash (K_2O)	0.5%

Table: Mineralogical Composition of Cement

The proportions of these compounds significantly influence the setting time, strength development, and durability characteristics of cement.

3.2.1.3 TYPES OF PORTLAND CEMENT

There are several types of Portland cement, namely available for different construction implementations. The attributes of these cements mainly differ due to variations in chemical composition and fineness.

The commonly used categories of Portland cementitious material are:

- primary binder in concrete technology (OPC)
- blended hydraulic cement incorporating pozzolanic constituents (PPC)
- a cement type used for faster strength gain in concrete
- used in mass concrete works to control temperature rise
- a specialized cement used in architectural finishes and decorative worksSulphate Resisting Portland Cement
- Water Repellent used as a primary binder in concrete
- cementitious material Blast Furnace Slag Cement

The most widely used cement in construction (OPC)

The most widely used cement in construction represents the most prevalently used utilized under general construction works. It is suitable for buildings, pavements, bridges, and reinforced concrete structures. The specifications and properties of OPC are provided in according to Indian Standard (IS) specifications issued by BIS: 269.

3.2.1 Determination of specific gravity as per IS 2720 Part III

Expressed as expressed as this ratio between a material and that of a reference substance. For solids and liquids, water constitutes generally used as the reference material.

In practical terms, it may also be expressed specified volume of a substance to the weight of an equivalent volume of water.

The experimental determination of specific gravity cement undertaken to find commonly carried out using a density bottle or Le Chatelier flask in conformity with following India's national standards body specification Indian Standard 2720 (Section III). This test facilitates in determining the quality and suitability belonging to cement in order to concrete production.

Fig.2. Specific Gravity Apparatus

3.2.1 FINENESS TEST (IS: 4031–1996 Part I)

Fineness of cement refers with respect to particle size distribution and total As this fineness of cement increases surface area per unit weight also increases. Finer cement particles thus provide an increased surface area available for hydration, which increases rate at which load-bearing capacity develops in concrete.

The fineness of Portland cement is commonly determined using sieving the cement sample through a standard 90-micron sieve. If the material remaining on the sieve screen retained on the sieve is within the permissible limit specified by standards, the cement is considered suitable for construction purposes.

Represents determined by the following methods:

- Particle size distribution by sieve analysis method
- Air Permeability Method for determining specific surface area

In the sieve analysis method, cement is sieved through a 90-micron IS sieve, and the percentage of particles retained on the sieve can be expressed as evaluated. Higher fineness generally improves the chemical reaction with water process together with early concrete strength development process; however, excessively fine cement may increase and shrinkage.

The specific surface area of cement may also be determined using an air permeability apparatus such as the Blaine apparatus used for, which measures aggregate particles per unit gram of cement

3.2.2 Determination of standard consistency as per IS 4031:1988 (Part IV)

Standard consistency is described as amount of water demand required to produce that allows the penetration of the Vicat plunger between 5 mm and 7 mm from the base of the Vicat mould.

The water requirement for preparing cement paste. suitable for further testing such as setting time and soundness tests.

The consistency of cement paste mainly depends on:

- Fineness based material
- Chemical constituents present in cement materials
- Atmospheric conditions
- Age based material

This standard consistency value is generally given as a percentage of water by amount of cement. the present parameter represents important for ensuring uniformity and quality control in cement testing procedures.

is utilized to decide the starting setting time, all out setting time, and concrete adequacy.

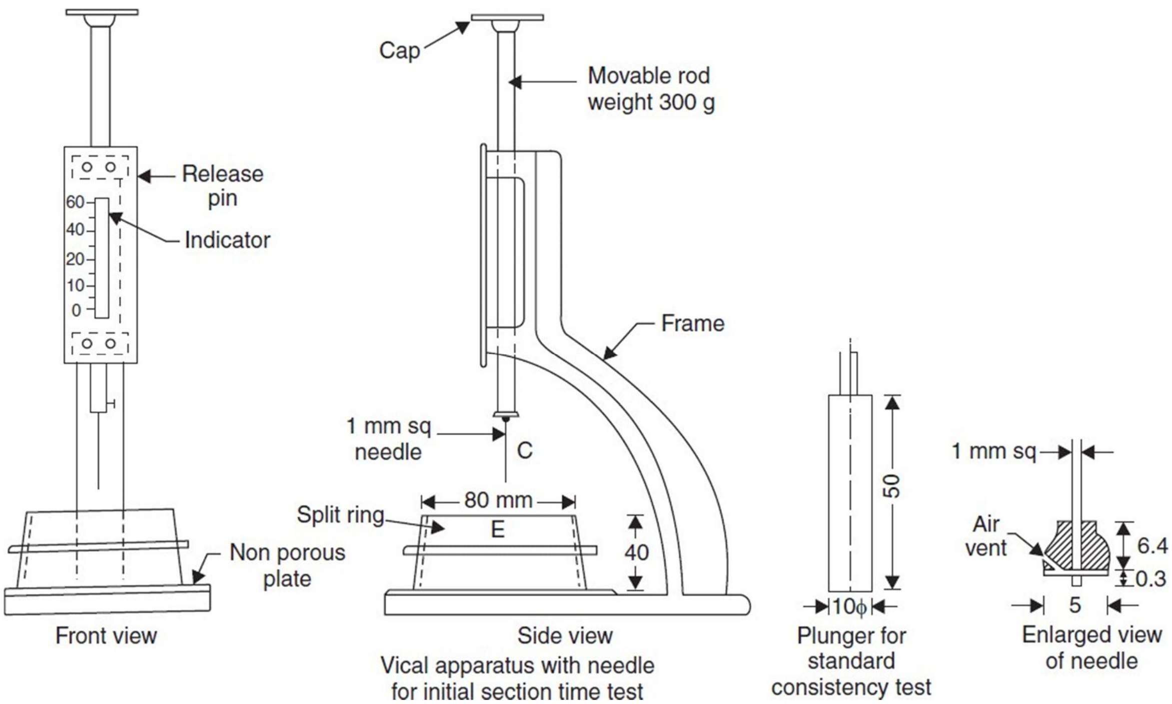

Fig. 4 Standard Consistency Apparatus

The standard in order carried out using this Vicat apparatus, which consists of a movable plunger, Vicat mould, and graduated scale arrangement. The apparatus is used to evaluate the amount of water required to prepare cement paste of standard consistency.

3.2.3 Determination of initial and final setting time of cement (IS: 4031–1988 Part V)

This setting time test is conducted to identify the time used in the preparation of cement paste to lose its plasticity and attain sufficient hardness. The test is performed using the Vicat apparatus under standard laboratory conditions.

The time required for Initial setting time is defined as the time at which begins to harden and lose workability. time elapsed within the range of the addition of water–cement proportion and the moment when this Vicat standard needle apparatus penetrates the cement paste only up Vicat.

This period indicates available for mixing, transporting, placing, and compacting concrete before the paste plastic nature.

Final Determination

Determination of final is defined as interval required at which cement paste completely hardens and ceases to be workable. time elapsed within the period addition and moment this circular ring form attachment related Vicat apparatus fails to make an mark on the external surface.

At this stage, this cement paste loses its plasticity completely and gains sufficient rigidity.

The setting time characteristics of cement are important in construction works because they influence handling, finishing, and strength development of concrete. Proper setting time ensures adequate workability during placement and satisfactory hardening after casting.

Fig. 5 Initial and Final Setting Time of Cement

Important parameters of cementitious material. tests are conducted with the help of the Vicat apparatus to examine process with the help of the Vicat apparatus. These tests help during evaluating the suitability of cement for construction activities including the mixing, placing, compacting, and finishing of concrete.

3.3.5 Determination of compressive strength of cement (IS: 4031 Part VI – 1989)

The calculated testing by testing cement cement mortar samples of standard proportion. The mortar is fabricated using cement standard sand in a 1:3 weight ratio

The standard sand used for testing must conform to the specifications provided in Bureau of Indian Standards IS 650:1955. Sand belonging to grading Zones I, II, and III is generally used for preparing the mortar specimens.

After casting, the mortar cubes are cured under standard conditions and tested for determination obtained different such as.

This compressive strength of cement represents typically characterized on the basis of strength achieved at 28 days related to curing.

The compressive strength is evaluated experimentally using the following relationship:

Axial strength under =LoadAreaCompressive\ Strength=\frac{L}{A}Compressive Strength=AreaLoad

where:

- Load = maximum load carried by the specimen
- Area = Loaded surface area of the cube specimen

The load-bearing compressive strength test is regarded as one of the key and widely used tests for assessing behavior of performance related to cement used in ement-based material construction.

Table 3.1 Physical behavior and characteristics (SAGAR)

The engineering properties of Sagar Ordinary Ordinary Portland Cementgrade 53Grade cement characteristics including specific gravity and fineness, standard consistency, and time of setting are key properties used to evaluate cement. and compressive strength are determined according to relevant Indian Standard specifications and are presented in

C. Aggregates

Aggregates are inert granular materials that, when combined with cement paste, form concrete. They occupy a constitutes a major part of the total concrete volume and significantly durability, and performance. Aggregates are obtained from natural rocks such as igneous, sedimentary, and metamorphic rocks, as well as from industrial by-products like slag and other suitable materials.

As the properties of concrete are mainly influenced are primarily influenced by the quality related to aggregates used, Aggregates are required to be hard, strong, durable, and free from deleterious materials. harmful substances such as clay, silt, organic matter, coal particles, lignite, and other impurities. The presence of such undesirable materials affects the interfacial interfacial bond between cement paste and aggregate particles surfaces, there fore reducing quality and mechanical cementitious material.

Based on particle size, Aggregates are broadly classified into:

- Finer fraction of aggregate
- Large-sized aggregates

3.3.0.1 FINE AGGREGATE

Fine particulate material refers to granular material having particle sizes smaller than 4.75 mm. Natural naturally occurring river sand and crushed stone Sand remains the most widely utilized a key component in concrete manufacturing.

Fine aggregates may be derived from natural sources such as rivers, pits, and lakes, or crushed rock sources. However, before use in concrete, the material must be properly cleaned and evaluated to ensure that the amount of silt, clay, salts, and naturally occurring organic matter impurities remains within permissible limits.

Both natural sand and Manufactured sand is appropriate for use as fine aggregate in concrete production.

Sea fine aggregate material is generally not recommended for reinforced cement concrete (RCC) works because the salts present in sea water may cause corrosion of reinforcement steel. River sand is widely preferred, although it often requires washing to remove impurities. Pit sand may also be used after eliminating unwanted organic and silty materials.

The shape characteristics of sand particles greatly influences the behavior of mortar and concrete. Angular sand particles provide better interlocking and bonding characteristics, resulting in stronger mortar and concrete compared to rounded particles.

3.3.0.2 Coarse aggregate as a constituent of concrete

For mass concrete works such as dams, larger aggregate sizes may be used, whereas for reinforced concrete construction, aggregates of nominal size 20 mm are commonly adopted.

Crushed stone, gravel, granite, gneiss, limestone, and sandstone are widely used as coarse aggregates in structural concrete. The aggregates should possess good mechanical strength and durability.

Flaky and elongated particles are generally avoided because they adversely affect the properties of workability, strength, and compaction of concrete. In low-cost construction process works, broken brick aggregates may sometimes be used for plain cement concrete applications.

3.3.0.3 GRADING OF AGGREGATES

Proper grading of Aggregates are crucial within achieving dense, workable, and durable concrete. Aggregate grading refers to the size distribution of fine and coarse aggregate particles

Well- Graded aggregates consist of a well-distributed range of particle sizes.. arranged in suitable proportions so hat smaller-sized particles fill the interstitial voids between larger particles. This reduces this volume of voids in concrete and minimizes the quantity of cement paste required.

Properly graded aggregates provide the following advantages:

- Improved workability of concrete
- Reduced void content
- Lower cement requirement

- Increased strength and durability
- Better compaction and impermeability

Therefore, aggregate grading is crucial in achieving economical as well as high-quality concrete.

D. Tests Conducted On Fine Aggregate

Testing experimental used used for determining the gradation of particles or grading of granular material materials such as sand and aggregates. This used in civil engineering to assess the performance of suitability of aggregates for concrete production.

In sieve analysis, the aggregate sample is passed hrough a sequence of standard sieves arranged in declining order of magnitudeThe quantity of material retained on each sieve is quantified, and this grading curve is prepared accordingly.

The particle size distribution significantly influences the behavior, ease of mixing and placing, strength, and resistance of concrete to deterioration. Proper size distribution ensures efficient packing of particles and reduces voids in the concrete mix.

Sieve analysis can be applied to various granular materials including sand, crushed stone, gravel, soil, coal, powders, and other construction materials. Due to its simplicity and effectiveness, it is one of the most commonly used methods for determining aggregate grading.

Fig.15. Set of Sieves for fine aggregate

Fig.16. Set of Sieves for coarse aggregate

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3.5.2 BULK DENSITY (IS: 2386–1963 Part III)

The voids present between them. Determination of Bulk density is the weight per unit volume of important during concrete mix design because it helps in understanding the packing characteristics and void content of aggregates.

Knowledge of voids between aggregate particles is essential to determine the quantity of cement paste or fine aggregate necessary to fill the voids, resulting in dense concrete.Bulk density depends upon several factors such as:

- Size and sieve analysis of aggregates
- Shape and surface properties of particles
- Moisture condition
- Degree of compaction

Bulk density is generally expressed in kg/m³.

Bulk Density=Mass of AggregateTotal VolumeBulk\ Density=\frac{Mass\ of\ Aggregate}{Total\ Volume}Bulk Density=Total VolumeMass of Aggregate

where:

- Mass of Aggregate = Weight of aggregate filling the container
- Total Volume = Volume occupied by aggregates including voids

The test is conducted by filling a standard container with aggregate under specified conditions and measuring its mass. Bulk density values are useful for proportioning aggregates in concrete mix design and for evaluating material quality.

called the Bulk thickness.

Fig.7. Bulk Density apparatus

Fineness modulus:

The Fineness Modulus (FM) is a measurement of how The aggregate gradation is commonly evaluated by means of the fineness modulus. coarseness or fineness of an aggregate. It's an arbitrary number that measures the aggregate's fineness.

FINE AGGREGATE	Aggregate fineness modulus
Fine Sand	2.2-2.6
Medium Sand	2.6-2.9
Coarse Sand	2.9-3.2

For coarse aggregates, having a fineness modulus of generally is in the range of 6.5 and 8.5.

3.5.4 SPECIFIC GRAVITY

(IS: 2386–1963 Part III)

Key property used in order to evaluate this strength and quality of the constituent material It is widely used in concrete mix design calculations because it helps in converting the weight of aggregate into solid volume.

Specific gravity is defined as the ratio of the mass of aggregate to that of an equal volume of water.The specific gravity of fine aggregate is used for aggregates generally ranges from 2.0 to 2.7, while for coarse aggregates it usually varies between 2.6 and 3.0.

The specific gravity is computed using the following expression:

Or in proper equation form:

$$\text{Specific Gravity} = \frac{\text{Weight of Aggregate}}{\text{Weight of Equal Volume of Water}}$$

Determination of specific gravity
is an experimental procedure used for helps in:

- Determining aggregate quality and strength
- Calculating concrete mix proportions
- Estimating void ratio and water absorption
- Evaluating durability characteristics of aggregates

Aggregates having higher specific gravity generally possess greater strength and durability, making them more suitable for concrete production.

Gravity test is useful in determining the type of stone.

Fig.16. Specific Gravity apparatus

3.5.5 BULKING OF SAND

In the presence of water, a thin moisture film develops around granular sand particles. This film induces slight repulsion between particles, resulting in an increase in the total volume.

The extent of bulking is governed by:
• Moisture content present in sand
• Particle size distribution of sand
• Grading properties of the sand material sand fraction sand generally shows greater bulking compared to coarse sand.

Bulking of sand is an important consideration in concrete mix proportioning because moist sand occupies more volume than dry sand. If bulking is not considered during batching, the quantity of sand used in concrete may become insufficient, affecting workability and strength.

The bulking test is performed to determine the percentage expansion in the volume of sand caused by moisture content.

3.4.2 Test for water absorption of coarse aggregate

Moisture absorption of coarse aggregate indicates the quantity of moisture absorbed by the granular material particles when underwater exposure occurs under specified conditions. It provides information regarding the porosity and permeability of fine and coarse aggregates.

Mineral aggregates with high values of water absorption are generally having higher porosity and may adversely influence the durability and the strength of concrete, thereby leading to aggregates lower water absorption are usually preferred for concrete production.

The water absorption test helps in:

- Determining the porosity of aggregates
- Evaluating aggregate quality
- Adjusting water content in concrete mix design
- Assessing durability characteristics

Water absorption is represented percentage increase in the mass of the aggregate after soaking compared to its dry weight.

The water absorption is calculated using the following expression:

Water Absorption (%)

$$\text{Water Absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100$$

where:

- W1W_1W1 = Weight of aggregate
- W2W_2W2 = mass of saturated surface dry mixtures

Lower moisture absorption values generally indicate stronger and more durable aggregates suitable for concrete construction.

Fig.8. Water Absorption test apparatus

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3.4.2 Flakiness Index: (IS: 2386–1963 Part I)

The percentage of particles in it whose least-aspect (for example thickness) is under three-fifths of its mean aspect is known as the flakiness file. Sizes less than 6.3mm are not qualified for thistest.

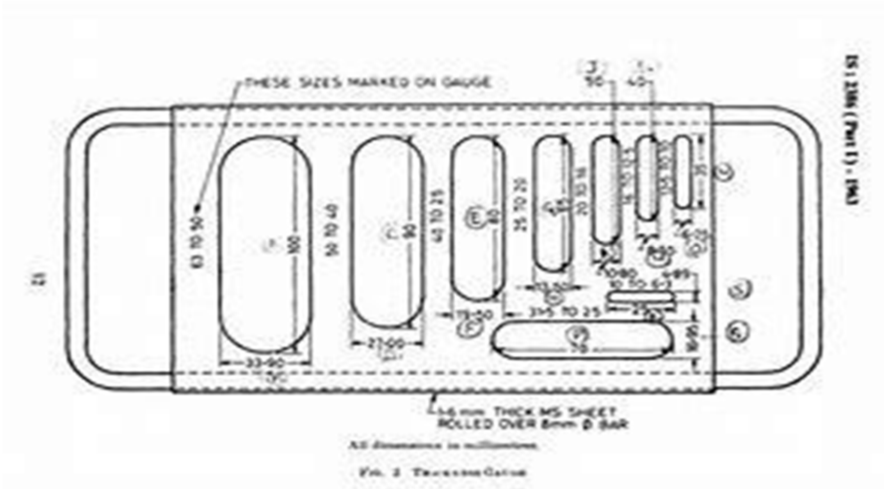

Fig.11. Flakiness index Thickness Gauge

3.4.3 Elongation Index: (IS: 2386-1963 Part I)

The fraction of particles in it whose biggest dimension (i.e. length) is if greater than 1.8 times their average size, is known as the Elongation Index. For diameters lower than 6.3mm, this test is not applicable.

Fig.12. Elongation index gauge

3.4.4 Crushing Value: (IS: 2386–1963 Part IV)

The total smashing worth is a proportion of how safe a material is to pounding when exposed to a continuously applied compressive pressure. To accomplish an elevated **degree** of substantial quality, all out with a low complete crushingvalue.Coarse all out crushing regard is the crushing rate expressed as weight percentage of material obtained in the test sums are presented to a foreordained weight under prescribed conditions

Fig.13. Crushing Value apparatus

Table 3.4 Physical Properties of Fine aggregate (Natural Sand):

S. No	Property	Value
1.	Grading of Sand	Zone II as per IS 383
2.	Specific Gravity	2.59
3.	Bulk Density • Loose State • Compacted State	1.63g/cc 1.73g/cc
4.	Fineness Modulus	2.40

Table 3.2 Physical Properties of coarse Aggregate

S.NO	Property	Value
1.	Specific Gravity	2.81
2.	Bulk Density • Loose state • Compacted state	1.55g/cc 1.75g/cc
3.	Water absorption	0.59%
4.	Flakiness Index	12.54%
5.	Elongation Index	23.07%
6.	Crushing Value	21.01%
7.	Fineness Modulus	6.8

Table 3.5 Sieve Analysis of Fine aggregate (Natural Sand)
Total Weight of Sample Taken = 1000 grams.

S. No	IS Sieve	Weight Retained(g)	Cumulative weight(g)	%Cumulative weight retained(g)	%Passing
1.	10mm	0	0	0	0
2.	4.75mm	14	14	1.4	98.60
3.	2.36mm	28	42	4.2	95.80
4.	1.18mm	116	158	15.8	84.20
5.	600µm	261	419	41.9	58.10
6.	300µm	356	775	77.5	22.50
7.	150µm	221	996	99.6	0.4
Fineness modulus = ∑%Cumulative weight retained/100 = 2.40					

According to IS 383-1970:

Sieve	%Passing Zone I(%)	%Passing Zone II(%)	%Passing Zone III(%)	%Passing Zone IV(%)
10mm	100	100	100	100
4.72mm	90-100	90-100	90-100	90-100
2.38mm	65-95	75-100	85-100	95-100
1.18 µm	30-70	55-90	75-100	90-100
600µm	15-34	35-59	60-79	80-100
300µm	5-20	8-30	12-40	15-50
150 µm	0-10	0-10	0-10	0-10

Thus, in accordance with IS 383:1970, the sand falls under Zone II.

Table 3.5 Sieve Analysis of Fine aggregate (Manufactured Sand):
Total Weight of Sample Taken = 1000 grams.

S. No	IS Sieve	Weight Retained(g)	Cumulative weight(g)	%Cumulative weight retained(g)	%Passing
1.	10mm	0	0	0	100
2.	4.75mm	4	4	0.4	99.6
3.	2.36mm	174	178	17.8	82.2
4.	1.18mm	253	431	43.1	56.9
5.	600µm	106	537	53.7	46.3
6.	300µm	192	729	72.9	27.1
7.	150µm	194	923	92.3	7.7
Fineness modulus= ∑%Cumulative weight retained/100 = 2.80					

Hence according to IS 383-1970 specifications this sand confirms to Zone II

Table 3.3 Sieve Analysis of coarse aggregate
Total weight of sample taken = 5 Kg

S. No	IS Sieve	Weight Retained(g)	Cumulative weight(g)	%Cumulative weight retained(g)	%Passing
1.	80mm	0	0	0	100%
2.	40mm	0	0	0	100%
3.	20mm	453	453	9.06	90.94%
4.	10mm	3117	3570	71.4	28.6%
5.	4.75mm	1419	4989	99.78	0.22%
6.	2.36mm	10	4999	99.98	0.2%
7.	1.18mm	1	5000	100	0%
8.	600µm	0	5000	100	0%
9.	300µm	0	5000	100	0%
10	150µm	0	5000	100	0%
Fineness modulus= ∑%Cumulative weight retained/100= 680.22/100= 6.802					

E. Water

Water plays a significant role in the preparation and performance of concrete. It is required for mixing, hydration, placing, compaction, curing, and hardening of concrete. The quality and quantity of water used significantly affect influence the strength, durability, and ease of workability of concrete

Mixing water with cement leads to a chemical reaction known as hydration takes place. This reaction forms a cement hydrated cement paste that binds the fine and large-sized aggregates together, resulting in a hard and durable mass. Adequate water content also improves the workability of concrete and facilitates proper compaction and finishing.

Concrete is generally prepared using clean potable water. The Water used in concrete mixing and curing should not contain harmful materials such as oils, acids, alkalis, salts, sugars, and organic matter. and other impurities that may weaken the concrete properties and reinforcement steel.

Water is considered commonly measured in litres per bag of cement. Proper adjustments should be adjusted based on the moisture content present in fine and coarse aggregates while calculating the total water requirement of concrete.

Requirements of Water Used in Concrete

The water used for concrete should satisfy the following conditions:

- It should be free from excessive quantities of oils and grease.
- It should not contain harmful amounts of acids, alkalis, or other chemical impurities.
- It should be free from organic matter, iron compounds, and substances that may affect the quality of concrete or reinforcement steel.

Functions of Water in Concrete

The important functions of water in concrete are:

- It functions as a lubricating medium for fine and coarse aggregates.
- It undergoes a chemical reaction with cement to form cement paste.
- It assists in coating the aggregate particles with cement paste.
- It prevents aggregates from absorbing water required for hydration.
- It improves the flow and workability of concrete during placement.

3.3.1 WATER–CEMENT RATIO

The water–cement ratio refers to the proportion of water to cement by weight in concrete.

Water-Cement Ratio=Weight of WaterWeight of CementWater\text{-}Cement\ Ratio=\frac{Weight\ of\ Water}{Weight\ of\ Cement}Water-Cement Ratio=Weight of CementWeight of Water

The water–cement ratio is among the most important parameters affecting the strength and durability of concrete. Experimental studies have shown that for a given mix proportion, there exists an optimum quantity of water that produces maximum strength.

If insufficient water is used:

- Concrete becomes less plastic and difficult to place properly Proper compaction becomes difficult.
- Complete hydration of cement may not occur.
- Strength development is reduced.

If excessive water is used:

- Concrete becomes weak and porous.
- Segregation and bleeding may occur.
- Durability decreases.

Therefore, maintaining an appropriate water–cement ratio is essential for achieving the required strength, workability, and the long-term performance of concrete.

IV. EXPERIMENTAL INVESTIGATION OF CONCRETE

A. General

The primary objective of the experimental assessment is to compare the workability and strength characteristics of conventional concrete with concrete containing manufactured sand along with Ground Granulated Blast Furnace Slag (GGBS).

The study focuses on evaluating the performance of concrete by partially using manufactured sand as a replacement for natural sand and replacing cement with GGBS. Experimental tests were performed on both fresh and hardened concrete specimens. to determine the optimum replacement levels and to assess the overall behavior of modified concrete mixes.

B. Mixing And Casting Of Test Specimens

n the present research work, M30 the selected concrete grade was because it is widely used in structural construction works.

The experimental program was carried out in two phases:

Phase I

During the initial stage of the study,natural sand was partially substituted by manufactured sand at varying proportions of

- 0%
- 20%
- 40%
- 60%
- 80%
- 100%

The purpose of this phase was to identify the optimum percentage replacement of natural sand that provides maximum compressive strength and satisfactory workability.

Phase II

Based on the optimum percentage of M-sand obtained in Phase I, cement was partially replaced with GGBS at replacement levels of:

- 10%
- 20%
- 30%
- 40%

The mix design calculations and details are provided in Appendix-I.

Casting Procedure

Casting is the process of placing freshly mixed concrete into moulds of required dimensions and allowing it to harden into the desired shape.

Before casting, the moulds were thoroughly cleaned and their inner surfaces were coated with mould oil to prevent adhesion of concrete transferred to the mould surfaces. The moulds were firmly assembled using bolts or clamps and placed on a level base plate to avoid leakage during casting.

The concrete mix ingredients were uniformly mixed to achieve uniform consistency. Fresh concrete was then placed into the moulds in stages and compacted properly to air voids and ensure dense concrete specimens.

Following casting, the specimens were allowed to remain undisturbed for 24 hours and were then demoulded and water-cured up to the required testing age.

Fig: Casting of specimens

CASTING OF CUBES

To study the resistance of concrete to compressive loads 9 blocks of (150mm x 150mm x 150mm) size were projected for each cluster of substantial blend. Oil was applied to the 3D shape form and is loaded up with concrete. The substantial filled solid shape molds were put on table vibrator and were vibrated for 1 moment. Once compaction was completed,abundance concrete was taken out with scoop and the top surface is evened out.

Fig.17. Casting of Cubes

4.1.5.2 CASTING OF CYLINDERS

For each concrete mix, nine cylindrical specimens of size Cylindrical concrete specimens of 150 mm diameter and 300 mm height were cast for split tensile strength testing.

Before casting, the inner surfaces of the cylinder moulds were thoroughly cleaned and coated with mould oil to facilitate easy removal of specimens after hardening. Freshly prepared concrete was then placed into the moulds in suitable layers.

The moulds filled with concrete were compacted using a table vibrator for approximately one minute to remove entrained air and achieve adequate consolidation. After vibration, the excess concrete on the top surface was removed using a trowel, and the surface was finished smoothly and levelled properly.

The specimens were allowed to set for 24 hours before demoulding and subsequently cured in water until the required testing period.

Fig.18. Casting of Cylinders

4.1.5.3 CASTING OF PRISMS

For each batch of concrete mix, prism specimens were produced to measure determine the flexural strength of concrete. Standard prism moulds of suitable dimensions were used for casting the specimens.

Before placing concrete, the mould surfaces were cleaned before casting properly and coated with mould oil to prevent adhesion of concrete to the mould surface. Fresh concrete was then placed into the moulds in layers and compacted thoroughly using a table vibrator to remove air voids and achieve proper densification.

After compaction, the extra concrete was removed using a trowel, and the top surface was made smooth and even finished smoothly.

The cast specimens were kept undisturbed for 24 hours. After demoulding, the prisms were cured in clean water until the required testing ages for flexural strength evaluation.

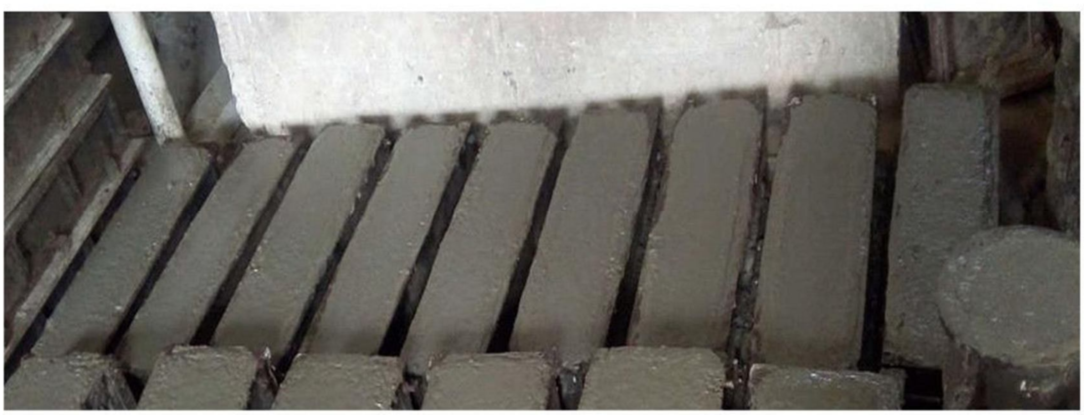

Fig.19. Casting of Prisms

4.1.6 CURING OF SPECIMENS

Curing involves maintaining sufficient moisture and temperature conditions for a specific period after placing and finishing concrete to facilitate adequate hydration of cement. Proper Curing significantly contributes to the strength, durability, and impermeability of concrete.

In the hydration process, cement combines with water to form cementitious compounds that contribute to the hardening and strength gain of concrete. If sufficient moisture is not maintained, hydration may stop prematurely, resulting in reduced strength and durability.

Curing also helps in:

- Preventing rapid moisture loss from concrete surfaces
- Reducing plastic shrinkage cracks
- Minimizing thermal cracks due to temperature variations
- Improving durability and long-term performance of concrete

To achieve satisfactory concrete properties, curing should begin immediately after finishing operations and continue for the recommended duration.

4.1.6.1 STANDARD CURING

After casting, all specimens were kept kept undisturbed at room temperature for approximately 24 hours. The specimens were then carefully stripped from the moulds and immediately immersed in a curing tank containing clean fresh water.

The cube, cylinder, and prism specimens were cured in accordance with the recommendations of Bureau of Indian Standards IS: 516–1959.

The specimens were cured for different periods such as:

- 3 days
- 7 days
- 28 days
- 56 days
- 91 days

After completion of the required curing period, the specimens were removed from water curing and allowed to dry under shade before testing.

Proper curing ensured adequate hydration of cement and helped the specimens attain after water curing, the specimens were removed and characteristics.

Fig : Curing of Specimens

C. Tests On Fresh Concrete

4.2.1 WORKABILITY

Ease of placement is one of the most important properties of fresh concrete, as it directly influences the ease of mixing, placing, compaction, finishing, strength and durability characteristics of concrete. It further affects labour requirements and the quality of the finished concrete exterior surface.

Workability may be described as the property that allows concrete to be easily mixed, handled, placed, compacted, and finished without segregation or bleeding.

Concrete is considered workable when it can be compacted properly with minimum effort and without causing separation of aggregates from the cement paste. Poorly workable concrete may lead to difficulties during placement and compaction, resulting in honeycombing and voids in hardened concrete.

Definition of Workability

Workability is defined as the useful internal energy necessary for complete compaction of concrete without segregation and surface water accumulation.

Good workability ensures:

- Proper compaction
- Uniform distribution of aggregates
- Reduced honeycombing
- Improved surface finish
- Better strength and durability

4.2.2 SLUMP CONE TEST(IS: 1199–1959)

The slump test is considered one of the most important commonly used methods for determining the consistency and workability of fresh concrete.

The test indicates the relative stiffness or fluidity of the concrete mix, which mainly is governed by the amount of water present in the mix. Proper consistency is essential to achieve satisfactory compaction and strength.

The slump test is a simple and widely adopted field test used to evaluate the workability of unhardened concrete.

Apparatus

The slump test apparatus consists of a metallic mould in the shape of a frustum of a cone having:

- Top diameter = 10 cm
- Bottom diameter = 20 cm
- Height = 30 cm

The mould is commonly known as the slump cone.

Procedure

- The inner face of the slump cone is cleaned carefully before testing.
- The cone is placed on a smooth, horizontal, non-absorbent surface.
- Fresh concrete is filled into the mould in three equal layers.
- Every layer is compacted carefully properly using a tamping rod with standard strokes.
- After filling and compacting the final layer, the top surface is levelled.
- The cone is then lifted vertically upward slowly and carefully.
- The concrete subsides due to its own weight.

The difference between the original cone height and the reduced height after slump is known as slump.

The slump value is expressed as:

Slump=Original Height−Final Height of ConcreteSlump=Original\ Height-Final\ Height\ of\ ConcreteSlump=Original Height−Final Height of Concrete

Importance of Slump Test

The slump test helps in:

- Determining workability of fresh concrete
- Checking uniformity between batches
- Controlling water content in concrete
- Ensuring proper consistency for placement

Higher slump values indicate higher workability, while lower slump values indicate stiffer concrete mixes.

Fig.20. Slump cone apparatus

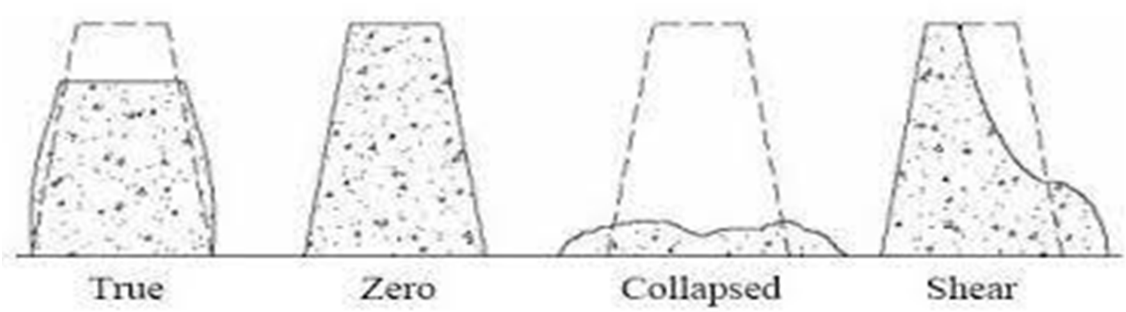

Fig.21. Types of Slump

Fig.22. Slump Cone Test

4.3.2 VEE–BEE CONSISTOMETER TEST(IS: 1199–1959)

The Vee–Bee workability test consistometer test is used to determine the handling properties of concrete and consistency of concrete mixes having very low workability, for which the The slump test cannot be used.

This test is particularly useful for stiff concrete mixes prepared with low water–cement or water–binder ratios. Such mixes generally show very little slump, making it difficult to evaluate their consistency using the slump cone test.

The Vee–Bee consistometer measures the duration needed for concrete to change from a cone shape to a cylindrical shape under the effect of vibration. The time measured is known as the Vee–Bee time and is expressed in seconds.

Principle of the Test

Fresh concrete placed in a slump cone is subjected to vibration inside a cylindrical container. Due to vibration, the concrete gradually remoulds itself from the cone configuration into the cylindrical shape of the container.

Concrete with lower workability requires more time for remoulding, whereas highly workable concrete requires less time.

Apparatus

The Vee–Bee consistometer apparatus mainly consists of:

- Vibrating table
- Cylindrical container
- Slump cone
- Transparent disc
- Stopwatch

Procedure

- The slump cone is placed inside the cylindrical container.
- Fresh concrete is filled into the cone in layers and compacted properly.
- The slump cone is carefully lifted.
- A transparent disc is placed on the concrete surface.
- Vibration is applied through the vibrating table.
- The time required for the concrete to completely remould into a cylindrical shape is recorded.

Interpretation of Results

- Lower Vee–Bee time indicates higher workability.
- Higher Vee–Bee time indicates lower workability.

The Vee–Bee consistometer test is highly suitable for dry and stiff concrete mixes commonly used in pavement construction, precast concrete works, and high-strength concrete applications.

Fig.24. Vee-Bee Consistometer apparatus

Fig: Vee-Bee Consistometer Test Procedure for Vee–Bee Consistometer Test

The workability of freshly mixed concrete using the Vee–Bee workability testing device is determined by the following procedure:

- A standard slump test is first conducted by positioning the slump cone within the cylindrical mould container of the Vee–Bee consistometer.
- This transparent glass disc fitted to the swivel arm is rotated and gently placed on the top surface of the concrete.
- The electrical vibrator is operated, and, and the stopwatch is started simultaneously.
- Vibration is continued until the cone configuration of the concrete completely disappears and the concrete takes the cylindrical shape of the container.
- As soon as the concrete is fully remoulded into a cylindrical shape, the stopwatch is stopped and the time is recorded.
- The recorded time in seconds is known as the Vee–Bee time or Vee–Bee degree.

The Vee–Bee time represents the workability of concrete:

- Lower Vee–Bee time → Higher workability
- Higher Vee–Bee time → Lower workability

4.3.3 COMPACTION FACTOR TEST(IS: 1199–1959)

The compaction factor test is used to evaluate the workability of fresh concrete, particularly in low-workability mixes where the slump test cannot be applied. may not provide accurate results.

The test is based on the principle of determining the degree of compaction achieved by allowing concrete to fall through a standard height under its own weight.

The compaction factor is defined as the ratio of the weight of partially compacted concrete to the weight of fully compacted concrete.

The compaction factor is expressed as:

Compaction Factor=Weight of Partially Compacted ConcreteWeight of Fully Compacted ConcreteCompaction\ Factor=\frac{Weight\ of\ Partially\ Compacted\ Concrete}{Weight\ of\ Fully\ Compacted\ Concrete}Compaction Factor=Weight of Fully Compacted ConcreteWeight of Partially Compacted Concrete

Apparatus

The compaction factor apparatus mainly consists of:

- Upper hopper
- Lower hopper
- Cylindrical container
- Trap doors

Procedure

- The upper hopper is filled completely with fresh concrete.
- The trap door of the upper hopper is opened, allowing the concrete to fall into the lower hopper.
- Immediately, the trap door of the lower hopper is opened so that the concrete falls into the cylindrical container.
- Excess the concrete is taken out, and the mass of partially compacted concrete is recorded is determined.
- The container is then placed again in layers using the same concrete and compacted completely manually or mechanically to determine the weight of well-compacted concrete.
- The compaction factor of concrete is obtained as the ratio of partially compacted concrete weight to fully compacted concrete weight.

Significance of the Test

The compaction factor test is highly suitable for:

- Low-workability concrete mixes
- Road concrete
- Pavement concrete
- Heavily reinforced concrete sections

Higher compaction factor values indicate greater workability, while lower values indicate stiffer concrete mixes.

Fig.25. Compaction Factor Apparatus

Table 4.1: Aspects of Compaction Factor contraption:

Upper Hopper	Dimensions(mm)
Top Internal Diameter	25.4
Base Internal Diameter	12.7
Inward Height	27.9
Lower Hopper	Dimensions(mm)
Top Internal Diameter	22.9
Base Internal Diameter	12.7
Inward Height	22.9
Chamber	Dimensions(mm)
Inward Diameter	15.2
Inward Height	30.5
Distance between lower part of upper container and top of lower container	20.3
Distance between lower part of lower container and top of chamber	20.3

D. Tests On Hardened Concrete

4.4.1 COMPRESSIVE STRENGTH TEST(IS: 516–1959)

The compressive strength test is a fundamental test conducted on hardened concrete. to evaluate its load-carrying capacity and overall quality.

During this test, standard cementitious material cube specimens are subjected to testing under compressive loading using a compression testing machine up to the point of failure. The maximum load carried by the specimen before failure is measured and used to evaluate the compressive strength of concrete.The compressive strength test setup consists of a compression testing machine of suitable capacity. The cube specimen is placed centrally on the testing platform so that the load is applied uniformly over the entire surface.

Procedure

- Concrete cube specimens with dimensions of 150 mm × 150 mm × 150 mm are used for testing.
- After curing for the required period, the specimens are removed from water and allowed to dry.
- The specimen is placed carefully in the compression testing machine.
- Load is applied gradually and continuously at a uniform rate without shock.
- The loading is continued until the specimen fails.
- The maximum load at failure is recorded for the specimen.

The resistance of concrete to compression of concrete is calculated using the relation:

Resistance to compressive loading =PA (N/mm2)Compressive\ Strength=\frac{P}{A}\;(N/mm^2)Compressive Strength=AP (N/mm2)

Where:

- PPP = Highest load applied during testing of the specimen (N or kN)
- AAA = Cross-sectional area of the cube specimen over whi load is applied

For a standard cube:

A=150×150 mm2A=150\times150\;mm^2A=150×150mm2

The test was conducted on cube specimens after curing periods of:

- 7 days
- 28 days
- 56 days
- 91 days

The average compressive strength of the specimens at each age was calculated and compared for different concrete mixes.

Fig.27. Testing of cube in compressive strength testing machine

Fig: Failure of Specimen

4.4.2 SPLIT TENSILE STRENGTH TEST(IS: 5816–1999)

The split tensile strength test is performed to determine the tensile strength of concrete. indirectly. Since concrete possesses low tensile resistance, this test helps in evaluating its resistance to cracking under tensile stresses.

The test is carried out using a compression testing machine by subjecting to compressive load along the vertical diameter of a concrete cylinder. The external load applied compressive applied force induces with the help of a compression testing machine by applying cylinder to split vertically.

Specimen Details

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Standard concrete cylinders of:

- Diameter = 150 mm
- Height = 300 mm

were used for the test.

Procedure

- Following curing, the cylinder specimens are removed from water curing and allowed to dry.
- The weight of each specimen is noted.
- Diametrical lines are drawn on both ends of the cylinder to ensure proper alignment during testing.
- The cylindrical specimen is positioned horizontally between the compression plates of the testing machine.
- The specimen is aligned such that the marked lines remain vertical.
- Load is applied uniformly and continuously without shock until failure occurs.
- The maximum load sustained at failure is recorded..

The cylinder splits along its vertical diameter due to tensile stresses developed inside the specimen.
The split tensile strength is calculated using the following equation:
Ft=2PπDLF_t=\frac{2P}{\pi DL}Ft=πDL2P
Where:

- FtF_tFt = Split tensile strength of concrete (N/mm2)(N/mm^2)(N/mm2)
- PPP = Maximum applied load at failure (N)
- DDD = Diameter of cylinder specimen (mm)
- LLL = Length of cylinder specimen (mm)

Importance of the Test
The split tensile strength test is carried out useful for:

- Evaluating cracking resistance of concrete
- Assessing tensile behavior of concrete
- Comparing performance of different concrete mixes
- Studying the effect of admixtures and replacement materials on tensile strength

The test was performed at different curing periods such as:

- 7 days
- 28 days
- 56 days
- 91 days

and the results were compared for various concrete mixes containing M-sand and GGBS.

Fig.28.Testing of cylinder in Compressive strength testing machine

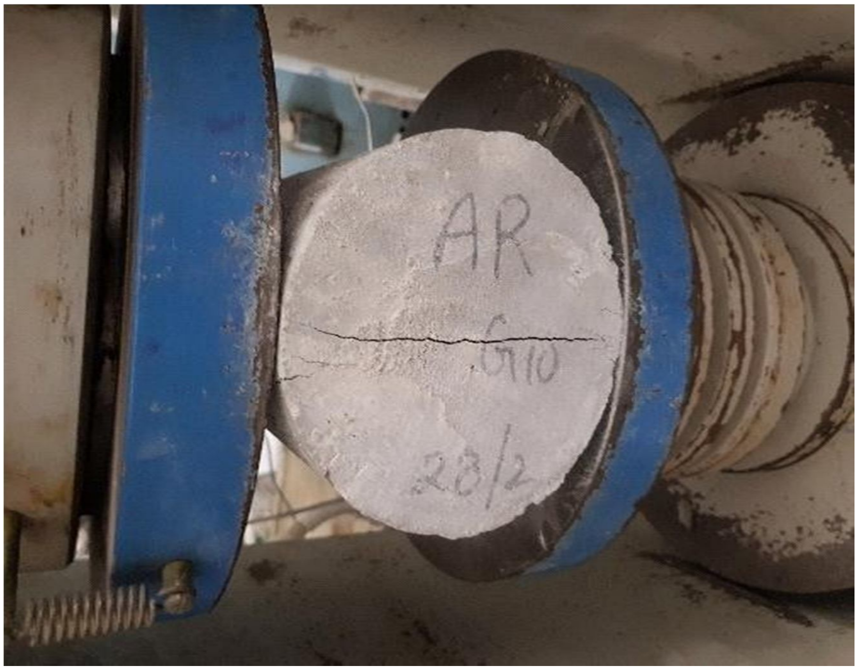

Fig: Failure of Specimen

4.4.3 FLEXURAL STRENGTH TEST(IS: 516–1959)

The flexural strength test is conducted to determine the bending strength or modulus of rupture of concrete. This test indicates the ability of concrete to resist failure under bending stresses.

The test was performed using a 10-ton mechanical testing machine (UTM)Concrete beam specimens were evaluated under two-point loading conditions conditions.

Specimen Details

Standard beam specimens of suitable dimensions were used for the flexural strength test.

Test Setup

The beam specimen is used to determine flexural strength.n was supported on two simple supports steel rollers. The loading arrangement was provided using two loading rollers positioned symmetrically at one-third points of the span.

For 100 mm specimens:

- Effective span = 400 mm
- Distance between loading points = 133 mm

All rollers were arranged such that the load was applied axially without inducing torsional stresses in the specimen.

Procedure

- After curing, the beam specimens were extracted from water and allowed to dry.
- The specimen was mounted on the bearing rollers with the cast surface facing upward.
- The axis of the specimen was positioned correctly properly with applied load arrangement.
- Load was applied gradually and uniformly without shock.
- The loading was continued up to specimen failure
- The failure load was recorded.
- The distance of the crack from the nearest support was also measured.

Calculation of Flexural Strength

When the crack takes place within the middle third of the span, the flexural strength is calculated as:

fb=PLbd2f_b=\frac{PL}{bd^2}fb=bd2PL

When the crack occurs outside the middle third but within permissible limits:

fb=3Pabd2f_b=\frac{3Pa}{bd^2}fb=bd23Pa

Where:

- fbf_bfb = Bending strength or modulus of rupture (N/mm2)(N/mm^2)(N/mm2)
- PPP = Failure load (maximum applied load)
- LLL = Effective span length of specimen (mm)
- bbb = Measured width of specimen (mm)
- ddd = Measured depth of specimen (mm)
- aaa = Distance of crack from nearest support (mm)

Significance over theTest

The bending strength testhelps in:

- Evaluating the bending resistance of concrete
- Assessing pavement and slab performance
- Studying crack resistance characteristics
- Comparing the behavior of conventional and modified concrete mixes

The flexural compressive strength of concrete specimens was evaluated at different curing periods and compared for various percentages of M-sand and GGBS replacement.

Fig.29. Testing of prism for flexural strength

E. Tests On Durability Of Concrete

4.5.1 ACID ATTACK TEST

This durability performance of cement-based composite specimens was evaluated by exposing them to dilute sulphuric acid solutions after the required period of water curing.

Concrete cube, cylinder, and beam specimens were immersed in sulphuric acid (H2SO4)(H_2SO_4)(H2SO4) solutions of different concentrations such as:

- 0.3%
- 1%
- 3%

The specimens were periodically inspected to investigate the effect of acid attack concerning concrete mechanical properties such as strength and surface deterioration.

During the testing period, the acid concentration was checked at regular intervals. Whenever the acid strength decreased due to reaction with concrete, fresh acid solution was added to maintain the required concentration.
Volumetric analysis was undertaken to assess the strength of the acid solution.

4.5.1.1 PROCEDURE FOR VOLUMETRIC ANALYSIS

In the volumetric analysis, Sodium Hydroxide (NaOH)(NaOH)(NaOH) solution was used as the standard alkali to find the concentration of sulphuric acid present in the aqueous solution.
Methyl Orange indicator was used during the titration process. The indicator changes colour:

- Pink in acidic medium
- Pale yellow in alkaline medium

The sodium hydroxide solution concentration selected was approximately equal to the concentration of aqueous sulphuric acid solution.

Procedure

- 20 ml of sulphuric acid solution was measured and taken in a conical flask.
- Two drops of methyl orange indicator were added.
- Sodium hydroxide solution was added slowly from a burette drop by drop.
- The solution was continuously stirred during titration.
- The endpoint was identified when the observed colour changed from pink to pale yellow.
- The volume of sodium hydroxide consumed was recorded.

Let:

- N1N_1N1 = Normality of the sodium hydroxide solution
- VbV_bVb = Volume of Sodium Hydroxide consumed
- N2N_2N2 = Normality of Sulphuric Acid solution
- VaV_aVa = Volume of acid solution taken

The normality relation used is:
N1Vb=N2VaN_1V_b=N_2V_aN1Vb=N2Va
Therefore, the normality of sulphuric acid is calculated as:
N2=N1VbVaN_2=\frac{N_1V_b}{V_a}N2=VaN1Vb
This procedure was repeated periodically to maintain the required acid concentration throughout the durability study.

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Fig: Effect of 1% of Sulphuric acid on M30 grade concrete cylinders

Fig: Effect of 1% of Sulphuric acid on M30 grade concrete cubes

Fig: Effect of 1% of Sulphuric acid on M30 grade concrete prisms

V. RESULTS AND DISCUSSIONS

The outcomes of investigational study are given in tables and analysed in this chapter. Experimental data, comprising compressive strength and split tensile strength rigidity, flexural strength, and solidness tests, are tabulated.

A. Phase 1(Fine Aggregate supplanted with Manufactured Sand):

1) Workability

Droop cone, compaction factor, and Vee-Bee tests are utilized to gauge the functionality of cement, and these tests are likewise relevant to low serviceable blends. Functionality is just surveyed during the projecting of examples; on the off chance that a blend doesn't have the expected rut of 25-75mm, it will be changed with plasticizer. The tests were completed on cement of the M30 grade. The level of admixture necessary for low workable mixtures to achieve a slump of 25-75mm is likewise decided based on workability. The results of the slump cone test are listed in table
For M30 grade concrete, the results are visually illustrated in fig.31.

a) Workability concerning Slump

With the use of admixture, a slump research is done. For in the case of M30 grade concrete, the results of the slump cone test are listed in table 5.1. Because manufactured sand has a higher water absorption capacity than river sand, the slump diminishes as the fraction of fine aggregate replaced with manufactured sand increases.

Table: 5.1 Variation of slump for M30 grade concrete with various substitution rates of fine total by manufactured sand.

Grade of concrete	M30					
Percentage of admixture required for the slump (25mm-75mm)	0.4%					
Percentage replacement of manufactured sand	0% (Ce)	20%	40%	60%	80%	100%
Slump (mm)	59	56	44	38	35	32

Fig. 31 Slump Variation for **M30 grade concrete with different replacement levels of** Manufactured Sand Replacement.

b) Workability With Respect To Compaction Factor

The compaction factor test was conducted to evaluate the workability of M30 grade concrete mixes containing different percentages of manufactured sand as replacement for natural fine aggregate.

The compaction factor values obtained from the experimental investigation are displayed in Table 5.2.

From the observed results, it was found that he measured compaction factor gradually decreased with an increase in the percentage replacement of natural sand by manufactured sand.

This reduction in compaction factor indicates a decrease in workability of the concrete mixes. The loss in workability may be explained by:

- Angular and rough surface texture of M-sand particles
- Higher water absorption capacity of manufactured sand
- Increased surface area requiring more water for lubrication

Due to these properties, concrete mixes containing higher percentages of manufactured sand required greater effort for compaction compared to conventional concrete mixes.

However, the use of suitable admixtures helped in maintaining acceptable workability for all concrete mixes.

Study on Compaction Factor Variation of M30 Grade Concrete with Different Percentage Replacement Levels of Manufactured Sand Replacement Using Admixture.

Grade of Concrete	M30					
Percentage replacement of Manufactured Sand	0%(Cc)	20%	40%	60%	80%	100%
Compaction Factor	0.96	0.94	0.93	0.92	0.90	0.88

Fig. 32 Compaction Factor Variation for M30 Grade Concrete with Different Percentages of Manufactured Sand Replacement.

c) Workability With Respect To Vee–Bee Time

The Vee–Bee consistometer test was performed to evaluate the workability of concrete mixes containing different percentages of manufactured sand as replacement for natural fine aggregate.

The Vee–Bee time values obtained during the experimental investigation are summarized in Table 5.3. From the results of the test, it was observed that the Vee–Bee time increased gradually with an increase in manufactured sand content in the concrete mixture mix.

An increase in Vee–Bee time indicates a reduction in workability and an increase in stiffness of the concrete mix. This behavior may be attributed to:

- Higher water absorption capacity of manufactured sand
- The angular particle shape and coarse surface texture of manufactured sand particles
- Increased internal friction between aggregate particles

As the quantity of manufactured sand increased, the concrete mix became stiffer and required more time for complete remoulding under vibration.

However, the addition of suitable admixtures improved the consistency and helped in achieving the required workability for all concrete mixes.

Effect of Different Percentages on Vee–Bee Time of M30 Grade Concrete Manufactured Sand Replacement Using Admixture.

Grade of Concrete	M30					
Percentage replacement of Manufactured Sand	0%	20%	40%	60%	80%	100%
Vee-Bee Time (sec)	3.25	3.37	4.18	6.5	6.75	8.18

Fig. 33 Variation of Vee–Bee Time for M30 Grade Concrete with Different Percentages of Manufactured Sand Replacement.

2) *Compressive Strength*

The compressive strength test was undertaken on concrete cube specimens using a compression testing machine.

Prior to testing, the bearing surfaces of the machine were cleaned properly, and any loose particles or debris present over the outer surfaces of the specimen were removed.

The cube specimen was positioned carefully in the testing machine in such a way that the applied load was applied on the opposite side faces of the cube and not on the top and bottom cast surfaces. The axis of the specimen was aligned accurately with the centre of the loading frame to ensure uniform loading.

Loading was applied continuously and gradually at a constant rate without shock until the specimen failed. The maximum load carried by the specimen at failure was recorded.

Concrete cube specimens of size:

150 mm×150 mm×150 mm150\ mm\times150\ mm\times150\ mm150 mm×150 mm×150 mm

were tested for different percentages of manufactured sand replacement.

The compressive strength tests were undertaken at curing ages of:

- 7 days
- 28 days
- 56 days
- 91 days

The compressive strength values obtained for concrete of M30 grade mixes with different percentages of manufactured sand replacement are presented in Table 5.4 and graphically represented in Fig. 34 and Fig. 35.

Table 5.4

Compressive Strength f M30 grade concrete with different proportions of Percentages of Manufactured Sand Replacement.

Compressive strength at the age (days)	M30+ 0% M-sand (MPa)	M30+20% M-sand (MPa)	M30+40% M-sand (MPa)	M30+60% M-sand (MPa)	M30+80% M-sand (MPa)	M30+100% M-sand (MPa)
7	25.77	26.66	28	29.33	28.44	28
28	39.11	40.88	42.22	44	41.77	40.44
56	41.77	43.11	44	46.22	44.44	42.66
91	42.66	44	44.44	47.11	44.88	43.55

a) *Variation of 28-Day Compressive Strength*

The change in compressive strength after 28 days of curing with increasing percentages of manufactured sand replacement for M30 grade concrete is discussed below.

Variation of Compressive Strength for M30 Grade Concrete at 28 Days with Different Percentages of Manufactured Sand Replacement.

From the graph, it can be observed that the compressive strength of concrete increased gradually with the increase in percentage replacement of natural sand with manufactured sand up to 60% replacement

The maximum compressive strength was achieved at 60% replacement of natural sand with manufactured sand. Beyond this level, the compressive strength started decreasing.

For M30 grade concrete at 28 days, the percentage improvement in compressive strength was observed to be approximately:

- 0% replacement → Reference mix
- 20% replacement → 4.52% increase
- 40% replacement → 7.95% increase
- 60% replacement → 12.50% increase
- 80% replacement → 6.80% increase
- 100% replacement → 3.40% increase

The improvement in compressive strength up to a certain percentage of 60% replacement may be attributed to:
- Better particle packing
- Angular shape of manufactured sand
- Improved cement paste–aggregate bond
- Reduction in voids within concrete

However, at higher replacement levels such as 80% and 100%, the strength decreased due to:
- Increased water demand
- Higher surface area of manufactured sand
- Reduced workability
- Improper compaction caused by stiff mixes

Analysis of Compressive Strength Variation in M30 Grade Concrete at 7, 28, 56, and 91 Days with Different Proportions of Manufactured Sand Replacement.

b) Effect of Manufactured Sand on Compressive Strength

From the experimental results, it was determined that concrete mixes containing manufactured sand presented higher compressive strength than conventional concrete at all curing ages.
An increase in compressive strength was observed continuously up to 60% replacement of fine aggregate with manufactured sand. Beyond this optimum level, the compressive strength gradually decreased.
Thus, it can be concluded that:
- Manufactured sand improves the strength characteristics of concrete when used in optimum proportions.
- The optimum replacement level of natural sand by manufactured sand for M30 grade concrete was found to be 60%.

3) Split Tensile Strength

The split tensile strength test was carried out for cylindrical concrete specimens using a compression testing machine.
Prior to testing, the machine bearing surfaces and the specimen surfaces were cleaned properly to remove dust and loose particles.
The cylinder specimens were positioned carefully in the testing machine so that the load is distributed uniformly along the diametrical plane. Load was applied continuously at a constant rate until the specimen failed.
The maximum load carried by the specimen at failure was recorded.
Standard cylinder specimens of:
Diameter=150 mm, Length=300 mmDiameter=150\ mm,\ Length=300\ mmDiameter=150 mm, Length=300 mm
were tested for different percentages of manufactured sand replacement.
The split tensile strength tests were conducted at various curing ages such as:
- 7 days
- 28 days
- 56 days
- 91 days

The obtained split tensile strength values obtained for M30 grade concrete with various percentages of manufactured sand replacement are presented in Table 5.5 and graphically represented in Fig. 36 and Fig. 37.

Split Tensile Strength at the age (days)	M30+0% M-sand (MPa)	M30+20% M-sand (MPa)	M30+40% M-sand (MPa)	M30+60% M-sand (MPa)	M30+80% M-sand (MPa)	M30+100% M-sand (MPa)
7	2.42	2.78	3.05	3.21	2.91	2.62
28	3.15	3.29	3.38	3.62	3.41	3.19
56	3.22	3.40	3.56	3.72	3.52	3.36
91	3.30	3.51	3.65	3.79	3.41	3.43

a) Variation of Split tensile strength of concrete at 28 days

The variation in split tensile strength at 28 days for M30 grade concrete with different percentages of manufactured sand replacement is discussed below.

Variation in splitting tensile strength of concrete for M30 Grade Concrete at 28 Days with Different Percentages of Manufactured Sand Replacement.

From the graph, it can be observed that the split tensile strength was found to increase gradually as the percentage of manufactured sand replacement increased up to 60%.

The maximum split tensile strength was determined at 60% replacement of natural sand using manufactured sand.Beyond this optimum level, the split tensile strength decreased.

For M30 grade concrete, the percentage increase in split tensile strength at 28 days was approximately:

- 0% replacement → Reference mix
- 20% replacement → 4.44% increase
- 40% replacement → 7.30% increase
- 60% replacement → 14.92% increase
- 80% replacement → 8.25% increase
- 100% replacement → 1.26% increase

The gain in split tensile strength up to 60% replacement of material may be attributed to:

- Better interlocking of angular manufactured sand particles
- Improved adhesion between cement paste and aggregates
- Reduction in internal voids
- Denser concrete matrix

However, when the replacement ratio exceeded 60%, the split tensile strength decreased due to:

- Increased water demand
- Lower workability
- Difficulty in compaction
- Increased fines content in manufactured sand

Study on Split Tensile Strength Variation of M30 Grade Concrete at Different Curing Ages with Varying Percentages of Manufactured Sand Replacement.

b) Effect of Manufactured Sand on Split Tensile Strength

Based on the experimental investigation, it was observed that the split tensile strength of concrete containing manufactured sand was higher than that of conventional concrete at all curing ages.

The split tensile strength increased continuously up to 60% replacement of natural sand with manufactured sand and then decreased for higher replacement levels of 80% and 100%.

Thus, it can be concluded that:

- Manufactured sand improves the tensile characteristics of concrete when used in optimum proportions.
- The optimum replacement level for achieving maximum splitting tensile strength was found as 60%.

E. Flexural Strength

Beam specimens were subjected to flexural strength testing using a UTM under two-point loading condition conditions to simulate pure bending.

Before testing, the bearing surfaces of the machine and the specimen surfaces were cleaned properly to remove dust and loose particles.

The beam specimen was positioned accurately on the supporting rollers, and the load was applied via two symmetrically placed loading points over the span.

The load was increased gradually and continuously at a uniform loading rate until the specimen failed. The maximum load carried by the specimen at failure was recorded.

Beam specimens of size:

500 mm×100 mm×100 mm500\ mm\times100\ mm\times100\ mm500 mm×100 mm×100 mm

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were tested for all concrete mixes.

The flexural strength tests were undertaken at different curing ages such as:

- 7 days
- 28 days
- 56 days
- 91 days

The flexural strength values obtained for M30 grade concrete containing different proportions of manufactured sand replacement are presented in Table 5.6 and graphically represented in Fig. 38 and Fig. 39.

Split Flexural strength at the age (days)	M30+0% M-sand (MPa)	M30+20% M-sand (MPa)	M30+40% M-sand (MPa)	M30+60% M-sand (MPa)	M30+80% M-sand (MPa)	M30+100% M-sand (MPa)
7	5.22	5.37	5.42	5.65	5.53	5.29
28	6.55	6.84	6.99	7.47	7.28	6.92
56	6.73	7.01	7.32	7.79	7.41	7.20
91	6.83	7.18	7.45	7.96	7.53	7.16

a) Flexural strength variation behavior at 28 Days for M30 Grade Concrete

Flexural strength variation of M30 grade concrete with different percentage levels of manufactured sand replacement is discussed below.

Fig.34 shows the variation of flexural strength at 28 days for different replacement levels of fine aggregate with manufactured sand. From the graph, it is observed that the flexural strength increases with an increase in the percentage of manufactured sand up to 60% replacement. The concrete mix containing 60% manufactured sand exhibited the maximum flexural strength compared to all other mixes.

The percentage increase in flexural strength at 28 days for M30 grade concrete was approximately:

- 0% replacement – 0%
- 20% replacement – 4.42%
- 40% replacement – 6.71%
- 60% replacement – 14.04%
- 80% replacement – 11.14%
- 100% replacement – 5.64%

The improvement in flexural strength may be associated with enhanced particle packing, angular shape, and improved bonding characteristics of manufactured sand.

Fig.35 illustrates the variation of flexural strength at 7, 28, 56, and 91 days for different percentages of manufactured sand replacement.

b) Effect of Addition of Manufactured Sand

The experimental results indicate that the flexural strength of concrete containing manufactured sand is higher than that of conventional concrete at all curing ages. Flexural strength increased gradually when natural sand was replaced with manufactured sand up to a 60% proportion However, beyond 60% replacement, the flexural strength showed a decreasing trend for 80% and 100% replacement levels.

The decrease in strength at higher replacement levels may be due to reduced workability and improper compaction caused by the higher water absorption capacity of manufactured sand.

F. Acid Attack

After the specimens were properly water cured, the concrete specimens were immersed in a 1 percent dilute sulphuric acid solution (H_2SO_4) solution to study the durability characteristics of concrete under acidic conditions. The acid concentration was checked periodically, and the depleted acid solution was replaced at regular intervals to maintain a constant concentration throughout the testing period. The acid exposure test was conducted to evaluate the durability of concrete specimens against chemical exposure deterioration caused by sulphuric acid exposure.

Table: Effect of 1% H_2SO_4 on Concrete Cubes

S. No	Type of Concrete	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	% Weight Loss	Average % Weight Loss	Average Strength (MPa)
1.	M30+ 0%MS	9272	9210	62	0.66	0.63	
		9080	9014	66	0.72		
		9122	9075	47	0.51		
2.	M30+ 20%MS	9272	9215	57	0.61		
		9282	9209	73	0.78	0.70	
		9314	9247	67	0.71		
3.	M30+ 40%MS	9287	9216	71	0.76		
		9290	9226	64	0.68	0.71	
		9211	9145	66	0.71		
4.	M30+ 60%MS	9314	9255	59	0.63		
		9288	9212	76	0.81	0.83	
		9199	9101	98	1.06		
5.	M30+ 80%MS	8824	8801	23	0.26		
		9222	9169	53	0.57	0.46	
		9192	9140	52	0.56		
6.	M30+ 100%MS	9456	9390	136	1.43		
		9276	9201	75	0.80	0.99	
		9290	9221	69	0.74		

Table: Effect of 1% H_2SO_4 on concrete Cylinders

S. No	Type of Concrete	Initial Weight (kg)	Final Weight (kg)	Weight Loss (kg)	% Weight Loss	Average % Weight Loss	Average Strength (MPa)
1.	M30+ 0%MS	13.85	13.63	0.22	1.58	1.15	
		13.63	13.47	0.16	1.17		
		13.94	13.84	0.10	0.71		
2.	M30+ 20%MS	13.94	13.79	0.14	1.0	0.90	
		14.07	13.97	0.10	0.71		
		13.99	13.85	0.14	1.0		
3.	M30+ 40%MS	14.03	13.95	0.08	0.57	0.85	
		13.89	13.75	0.14	1.01		
		14.01	13.88	0.13	0.99		
4.	M30+ 60%MS	13.99	13.86	0.13	0.92	0.78	
		13.99	13.90	0.09	0.64		
		13.92	13.81	0.11	0.79		
5.	M30+ 80%MS	13.99	13.72	0.17	1.21		
		13.84	13.51	0.53	3.82	1.98	
		14.06	13.93	0.13	0.92		
6.	M30+ 100%MS	13.88	13.72	0.16	1.15		
		14.06	13.94	0.12	0.85	1.14	
		13.89	13.69	0.20	1.43		

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Table: Effect of 1% H_2SO_4 on concrete Prisms

S. No	Type of Concrete	Initial Weight (kg)	Final Weight (kg)	Weight Loss (kg)	% Weight Loss	Average % Weight Loss	Average Strength (MPa)
1.	M30+ 0%MS	13.20	13.07	0.13	0.98	1.03	
		13.18	12.99	0.19	1.44		
		13.20	13.11	0.09	0.68		
2.	M30+ 20%MS	13.40	13.26	0.14	1.04	1.19	
		13.40	13.20	0.20	1.49		
		13.37	13.23	0.14	1.04		
3.	M30+ 40%MS	13.08	12.94	0.14	1.07	1.83	
		13.45	13.29	0.16	3.44		
		13.25	13.12	0.13	0.98		
4.	M30+ 60%MS	13.52	13.35	0.18	1.33	1.20	
		13.57	13.42	0.15	1.10		
		13.46	13.30	0.16	1.18		
5.	M30+ 80%MS	13.94	12.83	0.11	0.78	0.89	
		13.60	13.45	0.15	1.10		
		13.62	13.51	0.11	0.80		
6.	M30+ 100%MS	13.97	13.79	0.18	1.28	1.29	
		13.71	13.55	0.16	1.16		
		13.87	13.67	0.20	1.44		

B. Phase 2: Cement Replacement with GGBS

After determining the optimum replacement level of manufactured sand as 60%, the second phase of the investigation was carried out by partially substituting cement with GGBS (Ground Granulated Blast Furnace Slag)in different proportions. The concrete mixes were prepared using maintaining the optimum 60% percentage of natural sand replaced with manufactured sand sand while varying the percentage of GGBS replacement.

1) Workability determined using slump value

Slump tests were conducted both with and without inclusion of the use of admixtures to evaluate the workability characteristics of M30 grade concrete containing GGBS. The results obtained from the slump cone test are presented in Table 5.1.

The experimental observations indicate that the slump value gradually decreases as the percentage of GGBS replacement increases. This reduction in slump value shows a decrease in the workability of concrete mixes at higher levels of GGBS replacement.

The decrease in workability may be attributed to the finer particle size and larger surface area of GGBS, which increases the water demand of the concrete mix.

Table 5.1: Variation of slump in M30 grade concrete with varying percentages of Cement Replacement by GGBS

Grade of concrete	M30			
Percentage of admixture required for the slump (25mm-75mm)	0.3%			
Percentage of manufactured sand used as a replacement	60%			
Percentage replacement of GGBS	10%	20%	30%	40%
Slump(mm)	65	50	37	29

Fig.31 shows the change in slump values for M30 grade concrete with different proportion of cement replacement by GGBS.

The graph indicates that a decrease in slump value is observed gradually with an increase in proportion of GGBS replacement. This reduction in slump confirms that the workability of concrete decreases with an increase in the amount of GGBS increases. The finer particles of GGBS absorb more water and increase the surface area of the mix, resulting in reduced flowability of concrete.

a) Compaction factor-based workability of concrete

The compaction factor values obtained for various percentages of cement replacement with GGBS are presented in Table 5.2.
From the experimental results, it was observed that the compaction factor decreases as the percentage of GGBS replacement increases. The reduction in compaction factor indicates a decrease in workability of the concrete mix concrete mix.
This behavior may be attributed to the finer particle size and higher surface area of GGBS, which demand additional water for lubrication and proper compaction of the mix.
Therefore, it can be concluded that increasing the percentage of GGBS replacement reduces the workability of M30 grade concrete.

Table 5.2: Effect of Different Percentages on Compaction Factor of M30 Grade Concrete Cement Replacement by GGBS Using Admixture

Grade of concrete	M30			
Percentage of manufactured sand used as a replacement	60%			
Percentage replacement of GGBS	10%	20%	30%	40%
Compaction Factor	0.94	0.93	0.90	0.87

illustrates the effect of different percentages on compaction factor of M30 grade concrete cement replacement by GGBS.
From the graph, it is evident that the compaction factor decreases gradually as the percentage of GGBS replacement increases. This indicates a reduction in the workability of concrete mixes containing higher amounts of GGBS.
The decrease in workability is mainly due to the finer particles and larger surface area of GGBS, which require additional water for proper lubrication and compaction of the concrete mix.

b) Vee-Bee time-based workability of concrete

The Vee-Bee consistometer test was conducted to evaluate the consistency and workability of M30 grade concrete with different percentages of cement replacement by GGBS. The obtained Vee-Bee time values are summarized in Table 5.3.
It is observed from the results that Vee-Bee time increases as the percentage increases of GGBS replacement. Higher Vee-Bee time values indicate that the concrete mix becomes stiffer and less workable.
This increase in stiffness may be attributed to the finer particle size and higher water demand of GGBS-containing concrete mixes.

Table 5.3: Effect of Different Percentages on Vee-Bee Time of M30 Grade Concrete Cement Replacement by GGBS Using Admixture

Grade of concrete	M30			
Percentage of manufactured sand used as a replacement	60%			
Percentage replacement of GGBS	10%	20%	30%	40%
Vee Bee time(s)	3.5	4.28	4.81	8.7

Fig.33 shows the influence of different percentages on Vee-Bee time of M30 grade concrete cement replacement by GGBS.

From the graph, it can be concluded that observed that the Vee-Bee time improves as the percentage of increases GGBS the level of replacement increases. The increase in Vee-Bee time indicates that the concrete used in the study mix shows reduced workability and increased stiffness with higher GGBS content.

This behavior is mainly due to the finer particles and increased surface area of GGBS, which result in increased water demand of the fresh concrete mix.

2) Compressive Strength

The concrete compressive strength tests were carried out on cube specimens at curing ages of 7, 28, 56, and 91 days using a compression testing machine.

The results from the experimental study indicate that the compressive strength of concrete containing GGBS is higher than that of conventional concrete at all curing ages. The obtained compressive strength gradually increased with the substitution of cement with GGBS showed an increase up to an optimum level followed by a decrease at higher substituted material percentages.

The observed increase in strength may be attributed attributed to the pozzolanic reaction and improved particle packing characteristics of GGBS, which result in a denser concrete microstructure.

Behavior of 28-day compressive strength variation for M30 grade concrete incorporating different percentages of GGBS replacement is discussed below.

The compressive strength increased progressively for cement replaced at 10%, 20%, and 30% levels with GGBS. However, beyond the optimum replacement level, the compressive strength started decreasing for higher percentages of GGBS replacement.

This reduction in strength at increased proportion of replacement may be due to the lower availability of cementitious compounds required for early hydration.

Table 5.4: The compressive strength of M30 Grade Concrete with different percentage levels of Cement Replacement by GGBS

Compressive strength at the age (days)	M30 + 0%MS +G 0% (MPa)	M30+60% MS +G10% (MPa)	M30+60% MS +G 20% (MPa)	M30+60% MS +G 30% (MPa)	M30+60% MS +G 40% (MPa)
7	25.77	27.11	28.44	27.55	26.22
28	39.11	40.44	42.22	40.88	40
56	41.77	42.22	44.44	41.77	40.44
91	42.66	40	42.22	40.88	39.11

Based on the experimental results,it can be observed that the replacement of cement with GGBS improves the compressive strength of concrete up to an optimum replacement level of 20%.

The peak compressive strength strength was achieved at 20% GGBS replacement of cement. The increase in compressive strength value at 28 days for M30 grade concrete was approximately:

- 10% GGBS replacement – 3.40%
- 20% GGBS replacement – 7.95%
- 30% GGBS replacement – 4.52%
- 40% GGBS replacement – 2.27%

The increase in compressive strength is mainly attributed to the pozzolanic activity and filler effect of GGBS, which enhance the density and microstructure of concrete. However, beyond 20% replacement, the strength gradually decreases attributed to the reduction in cement content and slower hydration process.

illustrates the behavior of compressive strength for concrete of M30 grade at 28 days with different percentages of cement replacement by GGBS.

shows the variation of measured compressive strength for M30 strength grade concrete a curing ages of 7, 28, 56, and 91 days with different percentages of GGBS replacement.

3) Splitting strength of concrete

Concrete tensile strength obtained by indirect method containing GGBS was found to be higher than that of in all conventional concrete mixes curing ages.

The tensile strength by splitting method increased gradually with 10% and 20% replacement of cement by GGBS. However, beyond in the case of 20% replacement, the split tensile strength started decreasing for for 30% and 40% replacement proportions

The increase in split tensile strength may be attributed to the improved bonding at the cement paste–aggregate interface due to the finer particle size and pozzolanic reaction of GGBS.

The variation in 28-day split tensile strength for M30 grade concrete with different percentages of GGBS replacement is discussed below.

Table 5.4: Indirect tensile strength of M30 grade concrete with Different Percentages of Cement Replacement by GGBS

Split tensile strength at the age (days)	M30+0%MS+G 0% (MPa)	M30+ 60% MS + G10% (MPa)	M30+ 60% MS + G 20% (MPa)	M30+ 60% MS + G 30% (MPa)	M30+ 60% MS + G 40% (MPa)
7	2.42	2.65	2.83	2.72	2.50
28	3.15	3.29	3.52	3.44	3.35
56	3.22	3.37	3.66	3.51	3.42
91	3.30	3.49	3.81	3.64	3.58

Based on the graphical results, it can be concluded that the concrete mix containing cement replaced with 20% GGBS content achieved the peak split tensile strength among all the mixes tested.

The percentage enhancement in split tensile strength at 28 days for M30 grade concrete was approximately:

- 10% GGBS replacement – 4.44%
- 20% GGBS replacement – 11.74%
- 30% GGBS replacement – 9.20%
- 40% GGBS replacement – 6.34%

The improvement in split tensile strength is mainly attributed to the enhanced bonding between aggregate cement paste with particles caused by the pozzolanic reaction and filler effect of GGBS. However, beyond 20% replacement, the tensile strength gradually decreases due to reduced cementitious content and slower hydration.

illustrates the variation in splitting tensile strength for M30 grade concrete at 28 days with different percentages of cement replacement by GGBS.

shows the variation of split tensile strength for M30 grade concrete at curing ages of 7, 28, 56, and 91 days with varying percentages of GGBS replacement.

4) Flexural Strength

The flexural strength of concrete prepared with GGBS was found to be superior to that of conventional concrete at all curing ages.

The flexural strength gradually increased with 10% and 20% replacement of cement by GGBS. However, beyond 20% replacement, a decrease in flexural strength was observed at 30% and 40% replacement levels.

The development in flexural strength may be linked to improved microstructure and better bonding characteristics produced by the addition of GGBS.

Behavior of 28-day flexural strength for M30 grade concrete containing different proportions of GGBS replacement is discussed below.

Table 5.4: Flexural strength of M30 grade concrete prepared with different percentages of Cement Replacement by GGBS

Flexural strength at the age (days)	M30+0%MS+G 0% (MPa)	M30+60%MS+G10% GGBS (MPa)	M30+60%MS+G20% GGBS (MPa)	M30+60%MS+G30% GGBS (MPa)	M30+60%MS+G40% GGBS (MPa)
7	5.22	5.63	6.30	5.76	5.54
28	6.55	6.69	6.98	6.77	6.58
56	6.73	6.85	7.14	6.94	6.81
91	6.83	7.01	7.36	6.98	6.89

We can see from the graphs that replacing natural sand with artificial sand by 60% provides more strength than any other alternative. For 10%, 20%, 30%, and 40% replacement of GGBS at 28 days, the Flexural is in the range of 2.13 percent, 6.56 percent, 3.35 percent, and 0.45 percent for M30 grade concrete.

Table: 5.7 Percentage variation of the compressive, split tensile, and flexural strengths of M30 grade concrete (both phases) for 28 day

Percentage replacement	Compressive strength variation in %	Compressive strength variation in %	Flexural strength variation in %
CC	0	0	0
20% M-sand	4.52	4.44	4.42
40% M-sand	7.95	7.30	6.71
60% M-sand	12.50	14.92	14.04
80% M-sand	6.80	8.25	11.14
100% M-sand	3.40	1.26	5.64
M30 + 60% MS + 10%GGBS	3.40	4.44	2.13
M30 + 60% MS + 20%GGBS	7.95	11.74	6.56
M30 + 60% MS + 30%GGBS	4.52	9.20	3.35
M30 + 60% MS + 40%GGBS	2.27	6.34	0.45

5) Acid Attack

After the required period of water curing, the concrete concrete specimens were immersed in a 1% sulphuric acid solution (H_2SO_4) solution to evaluate The performance of concrete in terms of durability under various environmental conditions acidic conditions.

The acid concentration was monitored periodically, and the depleted acid solution was replaced regularly to maintain a constant concentration throughout the testing period.

An acid attack test was carried out to evaluate the resistance of concrete. against chemical material degradation under sulphuric acid attack exposure. The specimens were observed for changes in strength, surface condition, and weight loss after exposure to the acidic environment.

Concrete mixes containing manufactured sand and GGBS exhibited better resistance to acid attack relative to conventional concrete, this improved performance may be attributed to the denser microstructure, reduced permeability, and improved bonding characteristics of the modified concrete mixes.

Table: Effect of 1% H_2SO_4 on Concrete Cubes

S. No	Type of Concrete	Initial Weight (kg)	Final Weight (kg)	Weight Loss (kg)	% Weight Loss	Average % Weight Loss	Average Strength (MPa)

1.	M30+ 0%MS+ G10%	8.79	8.62	0.17	1.93	1.35	
		8.88	8.75	0.13	1.46		
		8.82	8.76	0.06	0.68		
2.	M30 + 60% MS + 20%GGBS	8.61	8.45	0.16	1.85	1.67	
		8.74	8.63	0.11	1.25		
		8.80	8.63	0.17	1.93		
3.	M30 + 60% MS + 30%GGBS	8.85	8.72	0.13	1.46		
		9.11	8.99	0.12	1.31	1.18	
		9.03	8.96	0.07	0.77		
4.	M30 + 60% MS + 40%GGBS	9.25	9.10	0.15	1.62		
		9.14	9.03	0.11	1.20	1.37	
		9.19	9.07	0.12	1.31		

Table: Effect of 1% H_2SO_4 on concrete Cylinders

S. No	Type of Concrete	Initial Weight (kg)	Final Weight (kg)	Weight Loss (kg)	% Weight Loss	Average % Weight Loss	Average Strength (MPa)
1.	M30 + 60% MS + 10%GGBS	13.53	13.41	0.12	0.88		
		13.68	13.61	0.07	0.51	0.68	
		13.59	13.50	0.09	0.66		
2.	M30 + 60% MS + 20%GGBS	13.42	13.26	0.16	1.19		
		13.20	13.07	0.13	0.98	0.99	
		13.33	13.22	0.11	0.82		
3.	M30 + 60% MS + 30%GGBS	13.52	13.41	0.11	0.81		
		13.52	13.46	0.06	0.44	0.85	
		13.63	13.45	0.18	1.32		
4.	M30 + 60% MS + 40%GGBS	14.17	14.05	0.12	0.84		
		14.07	14.01	0.06	0.42	0.63	
		14.12	14.03	0.09	0.63		

Table: Effect of 1% H_2SO_4 on concrete Prisms

S. No	Type of Concrete	Initial Weight (kg)	Final Weight (kg)	Weight Loss (kg)	% Weight Loss	Average % Weight Loss	Average Strength (MPa)
1.	M30 + 60% MS + 10%GGBS	13.34	13.11	0.23	1.72	1.41	
		13.10	12.97	0.13	0.99		
		13.12	12.92	0.20	1.52		
2.	M30 + 60% MS + 20%GGBS	13.18	13.04	0.14	1.06	0.93	
		13.23	13.13	0.10	0.75		
		13.23	13.10	0.13	0.98		
3.	M30 + 60% MS + 30%GGBS	13.55	13.42	0.13	0.95	0.73	
		13.34	13.26	0.08	0.59		
		13.44	13.35	0.09	0.67		
4.	M30 + 60% MS + 40%GGBS	13.63	13.52	0.11	0.80	0.73	
		13.68	13.59	0.09	0.65		
		13.64	13.54	0.10	0.73		

VI. CONCLUSION

According to the results obtained from the experimental investigation on M30 grade concrete containing manufactured sand (M-sand) and Ground Granulated Blast Furnace Slag (GGBS), the following conclusions were drawn:

1) The study evaluated the performance of concrete in terms of workability, compressive strength, and durability characteristics by replacing natural sand with manufactured sand and partially replacing cement with GGBS.
2) Manufactured sand was found to be an effective and sustainable alternative to natural river sand in concrete production.
3) The strength characteristics of concrete, including compressive strength, split tensile strength, and flexural strength improved significantly with the incorporation of M-sand and GGBS.
4) The the workability of concrete was found to be reduced gradually with an increase in the percentage of M-sand and GGBS due to their higher water absorption capacity and finer particle size.
5) Among all the mixes tested, M30 grade concrete containing manufactured sand showed superior strength performance when evaluated against conventional concrete systems.
6) at any stage curing at different ages of curing, the replacement of fine aggregate with manufactured sand up to 60% showed significant improvement in compressive, split tensile, and flexural strength properties.
7) The most effective replacement proportion of natural fine sand fraction by manufactured sand was was established at 60%.
8) The partial incorporation of cement with GGBS improved the mechanical properties and the durability characteristics of concrete up to an optimum level.
9) The most effective percentage substitution of cement by GGBS was determined to be 20%.
10) Concrete containing M-sand and GGBS exhibited better resistance to acid attack compared to normal concrete due to its denser microstructure and lower permeability.
11) The adoption of manufactured sand as a fine aggregate and GGBS in cement-based concrete systems reduces the consumption of natural resources and supports environmentally sustainable construction practices.
12) Therefore, it can be the investigation revealed that combined use of 60% crushed fine aggregate produced from hard rock and 20% GGBS in M30 grade concrete provides optimum strength, durability, and economical benefits.

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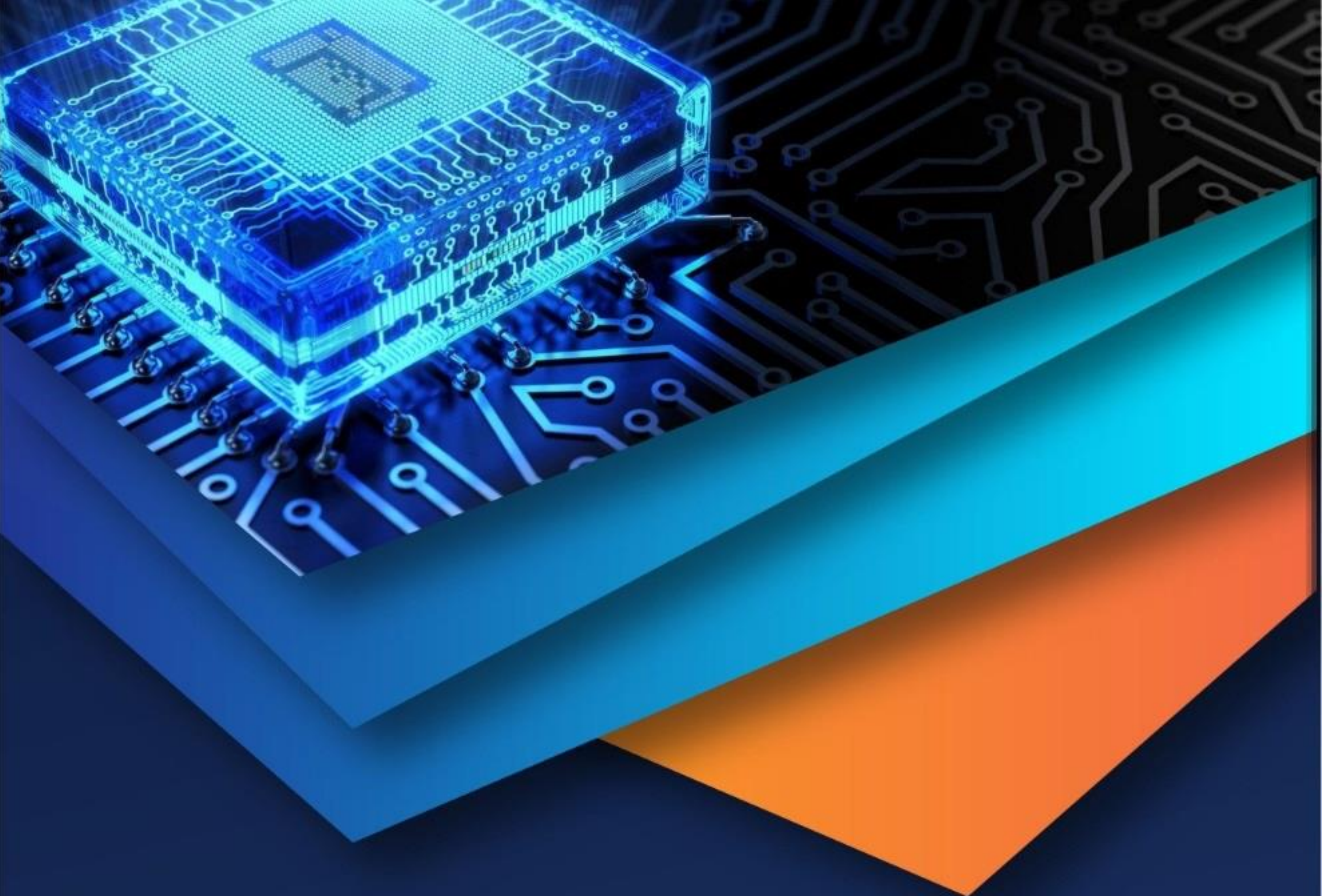

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