

Study on the Cement Concrete Incorporated with Ground Granulated Blast Furnace Slag and M-Sand

*Jayakumar V¹ and Prabaghar A²

¹Research Scholar, Department of Civil & Structural Engineering, Annamalai University, Annamalai Nagar -Tamilnadu, India.

²Associate Professor, Department of Civil & Structural Engineering, Annamalai University, Annamalai Nagar -Tamilnadu, India.

erjayaphd61@yahoo.com, aprabaghar@gmail.com

Abstract

The search for an alternative material for the traditional construction materials are wide open and many researches have been on progress to find the suitability replacement material for construction in the modern era. The continuous use of the traditional materials such as ordinary Portland cement, river sand lead to major issues related to environmental imbalance. The continuous production of cement leads to contribute equal amount of carbon dioxide emission into the atmosphere which in return traps the heat energy below the atmosphere and increase the temperature of the planet. Carbon dioxide is one among the green house gases which is a main contributor for global warming. The use of natural sand resulted in unavailability of river sand and on the other hand the level of the water table gets decreased. So, to reduce the negative effects of cement and river sand, this research focussed on using Ground Granulated Blast Furnace Slag (GGBS) and Manufactured Sand (M-Sand) in concrete as partial replacement for cement and full replacement for river sand respectively. The percentage of GGBS as replacement for cement is used in the range of 0%, 30%, 40%, 50% and 60%. River sand is completely replaced with M-Sand. To determine the properties of GGBS and M-Sand incorporated concrete, concrete cubes, cylinders and prisms of sizes 150 x 150 mm, 150 mm diameter and 300 mm height and 500 x 100 x 100 mm respectively. The compressive strength is determined using concrete cubes and cylinder specimens. The concrete cylinder and prisms specimens are used to determine the tensile strength of the concrete. From the results, it is clearly observed that the concrete with 40% of GGBS and 100% M-Sand showed higher strength compare to all other specimens. The increase in the percentage of GGBS beyond 50% reduces the strength of the concrete. The M-Sand contributed to strength of the concrete is slightly higher and similar to the river sand in concrete. The early age strength of GGBS concrete is lower than control concrete but with increase in curing period (28 days) the strength is higher than control concrete. It is concluded that the usage of GGBS up to 40% and M-Sand can reduce the carbon emission and the degradation of river sand without affecting the strength of the concrete.

Keywords: Ground Granulated Blast Furnace Slag, M Sand, Portland Cement, Substitution, Carbon Footprint, Compressive Strength, Strength Properties

*Jayakumar.V and Prabaghar. A

1. Introduction

Concrete is one of the most celebrated material till date. The material which is widely in the application of construction field is concrete due to its low cost compared to other structural materials and it can be obtained in all the required shape. Concrete is a versatile material formed from the combination of binder material, filler material and solution for mixing. The potable water is most probably used for mixing binder and filler materials to form the matrix of concrete. Ordinary Portland Cement (OPC) is commonly used binder for concrete and for filler material river sand and crushed stone. River sand is used as fine aggregate and crushed stone is used as coarse aggregate. Concrete is a most demanding material since it is the most used materials next to water [1][2]. Concrete matrix is divided into two parts such as the paste and aggregates. The paste is composed of cement and water and the aggregates are composed of sand and crushed stone. Due to the high demand for concrete, the need for the materials is also in great demand. Cement paste occupies 10 to 15 percentage of volume in the concrete matrix which binds the all other filler materials. The increase in the production of cement produces large quantity of carbon dioxide gas into the atmosphere which is the main source for increasing global warming and a high energy efficiency is required during the calcination process of cement. Another issue with the cement production is it consumes more natural raw materials in production process. On the other hand, the availability of river sand is becoming scarce due to the continuous digging of sand from the riverbed. Due to the drastic excavation of sand from river sand, the availability of river sand is very rare and due to its rare availability, the price of river sand is kept on increasing day by day. The degradation of riverbed leads to the dramatic drop in the water table [3]. To reduce the problems such as carbon emission and degradation of river sand, suitable alternative materials must be found. The focus of this study is to find the suitability of GGBS as partial replacement for OPC and M-Sand as an alternative material for river sand. At present situation, utilisation of GGBS and M-Sand can be more cost effective since the price of cement and river sand are increasing day by day especially the rate of river sand increased drastically in recent days. Also, the availability of standard quality river sand is restricted. The utilisation of GGBS as partial replacement for cement and M-Sand as full replacement for river sand will reduce the cost of construction and time of construction.

2. Review of Literature

Many researches were conducted to find the suitable alternative material for river sand and GGBS and most of the research studies concluded that M-Sand and GGBS can be used as a suitable alternative material as a partial replacement for river sand and cement. The workability of concrete incorporated with M-Sand was low compared to control mix and at the same time the workability can be improved by adding admixtures and the concrete with 60% of M-Sand as a replacement for river sand improved the concrete with grades such as M 20 and M 30 [4][5][6]. Contrast to the above statement, the optimum percentage of M-Sand as partial replacement for river sand was 60% and there was no need for any

admixtures to improve the workability [7]. Studies were conducted on 50% replacement of M-Sand for river and the results showed increase in strength properties [8][9][10]. It was confirmed that the 60% of M-Sand as replacement for river sand greatly influence the compressive strength of high-performance concrete [11]. The crushed stone sand was used as replacement for river sand and found that, compressive strength of concrete achieved maximum with 60% of crushed stone [12]. Another report showed that the mechanical strength of concrete increased at 55% of replacement of river sand by M-Sand [13]. The use of M-Sand as partial replacement for river sand increased the compressive strength of concrete [14][15]. The use of stone dust was tried and found that the 40% of stone dust as replacement for river sand improved the mechanical properties of concrete. it was concluded that the stone dust was suitable for using as a filler material [16]. The replacement of river sand with 10% of rock dust increased the compressive strength and flexural strength of the concrete [17]. Crushed stone powder is suitable for all kind of concrete such as normal concrete, standard concrete and high strength concrete as a partial replacement for river sand [18]. The hardened properties of concrete increased due to the use of stone dust as replacement for river sand but at the same time, there was a negative effect on the fresh concrete properties, and it can be overcome by adding admixtures [19]. The compressive strength of concrete with GGBS is influenced by the percentage of GGBS and the age of concrete [20]. The hydraulic activity of GGBS is greatly influenced by its composition. The presence of magnesium oxide, aluminium oxide and calcium oxide increases the hydraulic activity of GGBS and at the same time the increase in the percentage of silicon dioxide. The concrete with GGBS rich in calcium oxide, aluminium oxide improves the compressive strength and absorption of water and loss of mass are minimised [21]. GGBS is considered as one of the most proper suitable partial replacement material for cement and the concrete with 25% of M-Sand and 50% GGBS achieved higher compressive strength and can be used for practical applications [22]. The compressive strength and the durability of the concrete is mainly depending upon the density of Interfacial Transition Zone (ITZ) of concrete matrix. The addition of GGBS increase the density of ITZ making concrete with denser ITZ which decreases the carbonation depth, chloride diffusion and other permeable substance into concrete. the compressive strength also gets increased [23]. The workability of the concrete with GGBS increased when compared to control concrete and at the same time the early age strength of GGBS concrete was lower than control concrete but the strength was higher at later ages [24]. The high volume GGBS concrete performed well and it greatly reduce the carbon footprint. The concrete with 80% GGBS and 20% OPC were considered as economical mix even though the concrete with different percentage of GGBS such as 10%, 50% and 60% meets the strength and durability standards of normal concrete [25].

3. Binder Material for Concrete

Binder material is an important factor which holds the concrete matrix together as a hard material. The properties and types of binder materials influence the strength and durability of the concrete. The binder plays a significant role in enhancing the

Interfacial Transition Zone (ITZ) of concrete. Denser the ITZ will increase the strength durability characteristics of concrete. OPC is the most common material used as a binder for concrete. Due to the carbon emission issues of cement production, the need for an alternative binder material is emerging vastly. In this research, the suitability of GGBS as an alternative binder material for concrete is investigated. The binder materials used in the research are cement and GGBS. GGBS is used as partial replacement for cement.

3.1 Ordinary Portland Cement (OPC)

Ordinary Portland Cement is a kind of hydraulic cement and it is used to make conventional concrete. Portland is the origin where cement was originated, and the name was given to cement and it is termed as Ordinary Portland Cement. In recent days the cement manufactures given several brand names according to their standards. The specific gravity of cement used in this research is 3.14 and the cement is conforming to IS 12269: 1987[26]. The grade of cement used is 53 grade and the compressive strength of the cement paste is 53.19 N/mm² at 28 days.

3.2 Ground Granulated Blast Furnace Slag (GGBS)

GGBS used in this research work is obtained from ASTRAA Chemicals located in Tamilnadu. The specific gravity of GGBS is found as 2.85 and with a fineness below 350 m²/kg which is lesser than OPC. The density of GGBS is found as 1200 kg/m³. The colour of GGBS is white and has possesses chemical properties compared to cement. So, in this study GGBS is chosen as partial replacement for cement. GGBS is made from molten slag, an industrial waste that is created as a by-product of the steel making process. To achieve GGBS, the molten slag is cooled. The GGBS's response is influenced greatly by the process of cooling or quenching. A fast cooling or quenching is necessary to achieve highly reactive or hydraulic GGBS. It was subsequently turned into particles of less than 5 mm, which were subsequently grinded into powder which is known as GGBS after the molten slag was cooled or cooled down. Rapid freezing is achieved through the throwing of high flows of water jets and melting of the fused slag under 800 degree Celsius is achieved by quenching. The hydraulic activity of the GGBS is mainly depends upon two factors namely, quenching temperature and chemical compositions. High reactive GGBS will be obtained when the quenching process is conducted with temperature higher than 800 degree Celsius. At the same time the presence of higher percentage of aluminium oxide, calcium oxide and magnesium oxide will increase the hydraulic activity of GGBS whereas, the higher percentage of silicon dioxide will reduce the reactivity of GGBS [27][28][29]. The glassy and crystalline phases are primarily responsible for GGBFS binding and hydration [30][31]. Figures 1 and 2 show the Ordinary Portland Cement and GGBS which are used for casting concrete specimens.



Fig 1 Cement



Fig 2 GGBS

4. Filler Materials for Concrete

Filler materials are the major constituent of the concrete matrix as it occupies more than 75 % of the volume of concrete. In other words, the filler materials are acting as a body of the concrete. The filler materials generally used in concrete are fine and coarse aggregates. River sand is used as fine aggregate and crushed stone aggregate are used as coarse aggregate. Due to demand and non-availability of river sand, in this study M-Sand is tried as fine aggregate to find the suitability of replacing it to river sand.

4.1 River Sand

River sand is widely used popular material as fine aggregate and it originates naturally due to the weathering of rocks. As the river sand is used unanimously as fine aggregate, the demand for river sand is high and its availability is also getting scarce. Due to this, the search for the alternative material for river sand is emerged and in this study M-Sand is tried as fine aggregate. To compare the results of concrete with M Sand, control concrete is cast with river sand. Locally available river sand with specific gravity 2.65 is used in this study. River sand with Zone II category is used and confirming the IS 2386: 1963 and IS 383:1970 [32][33]. Figure 3 shows the river sand used in this study.

4.2 M - Sand

The use of M-Sand is emerging in India and many researches have been on progress to determine its effects on concrete. M-Sand is more advantageous than river sand in many ways. The shape and size of M-Sand can be controlled since it is manufactured artificially using Vertical Shaft impact crusher (VSI). The grading M-Sand can be ideal compared to river sand which is not ideal since the shape and size of the river sand particles are not same. The quality of M-Sand is improved in recent days due to advanced crushing equipment are employed. By using the advanced crushers like VSI crushers cubic shaped and well graded M-Sand is manufacturing in India. The impurities such as clay and silt content are lesser in M-Sand when compared to that of river sand. The lesser impurities in M-Sand improves the properties of concrete and due to its smooth and angular surface the water absorption capacity is slightly higher than river sand [33]. The properties of M-Sand such as specific gravity, fineness modulus, bulk density are found as 2.68, 2.87 and 1825 kg/m³ respectively. Confirming to IS 2386: 1963 and IS 383: 1970 [32][33], the M-Sand used falls under the category of Zone II. The voids and porosity are reduced due to the proper gradation of M-Sand and hence the durability properties are also increased, and the bleeding and segregation of fresh concrete are reduced [34]. The cubical shape of M Sand improves the strength and durability of concrete and the proper gradation reduces the voids, bleeding and segregation in the concrete [35]. Figure 4 shows the M-Sand used in this study.

4.3 Coarse Aggregate

Coarse aggregate is a filler ingredient that provides concrete its body and strength, as well as being an inactive ingredient. The size, shape, and texture of coarse aggregate have a significant impact on the strength and durability of concrete. Crushed stone having a specific gravity of 2.83 is utilised as coarse aggregate. The coarse aggregate is 20 mm in size and it complies to IS 2386: 1963 and IS 383: 1970 [32][33]. Figure 5 shows the coarse aggregate used in this study.



Fig. 3 River Sand



Fig. 4 M-Sand



Fig. 5 Coarse Aggregate

5. Concrete Mix Proportioning

5.1 Mix Ratios

GGBS is gradually replaced with cement to establish the appropriate proportion of GGBS to replace cement. GGBS replaces 0 percent, 30 percent, 40 percent, 50 percent, and 60 percent to cement and M-Sand is replaced river sand entirely. IS 10262:2009 [34] is used to calculate the mix proportions for M 20 grade conventional concrete and concrete incorporated with GGBS and M Sand. Control concrete with a mix ratio of 1:2.01:3.65 and concrete with GGBS and M Sand with a mix proportion of 1:2.03:3.65 are designed for M 20 grade of concrete. For both concretes, the water-to-cement ratio is kept as 0.55. Tables 1 and 2 provide the precise mix proportions for conventional concrete and concrete with GGBS and M Sand, as well as the percentages of GGBS replacement.

Table 1 Mix Proportioning of Concrete (M 20)

Sl. No.	Type of Concrete	Binder (kg/m ³)	River Sand (kg/m ³)	M Sand (kg/m ³)	Coarse Aggregate (kg/m ³)	Water (kg/m ³)
1	Control Concrete (CC)	340	682.13	---	1240.36	186
1	GGBFS Concrete (CCISRS)	340	682.13	---	1240.36	186
3	GGBFS Concrete (CCISMS)	340	---	689.86	1240.36	186

*CC – Control Concrete; CCISRS – Control Concrete Incorporated with GGBS and River Sand; CCISMS – Control Concrete Incorporated with GGBS and M Sand.

Table 2 Quantity of GGBS as Partial Replacement for Cement

Sl. No.	GGBFS (%)	Cement (%)	GGBFS (kg/m ³)	Cement (kg/m ³)	Total Volume (kg/m ³)
1	0	100	0	340	340
2	30	70	92.60	238.04	330.64
3	40	60	123.46	203.79	327.25
4	50	50	154.32	170.03	324.35
5	60	40	185.19	136.46	321.65

5.2 Process of Production of Concrete Specimens

Moulds such as cubes, cylinders, and prisms are cleaned and readied for casting concrete specimens. Cube moulds with dimensions of 100 x 100 x 100 mm and 150 x 150 x 150 mm are used to create mortar and concrete cubes.

Concrete cylinder specimens are formed in cylinder moulds measuring 150 mm in diameter and 300 mm in length, while concrete prism specimens are formed in prism moulds measuring 500 x 100 x 100 mm. The raw components are first combined in a dry state, then water is added and completely mixed until a consistent combination is achieved in order to get uniformly mixed concrete. In laboratory, fresh concrete is poured into corresponding moulds and completely compacted using a vibrator table. For all mixtures, the virgin concrete mix had a slump value of 50 mm. Concrete specimens are kept for 24 hours without interruption, then the moulds are thoroughly removed such that concrete specimens are not damaged. The concrete samples are maintained underwater for curing process for a period of 28 days. However, the early age strength of concrete specimens is being investigated through seventh-day compressive strength. The concrete specimens are evaluated after 28 days to assess the strength characteristics of the concrete specimens. Figure 6 depicts the casting of concrete specimens and hardened concrete specimens.



Fig. 6 Concrete specimens in Fresh and Hardened State

6. Investigation Results of Control Concrete and Concrete with GGBS and M-Sand

6.1 Compressive Strength

The compression tests are performed according to the Indian standards – IS 516: 1959[35]. The mechanical performance (compressive strength) of conventional concrete and concrete incorporated with GGBS and M-Sand is assessed using a compression testing equipment in laboratory, by testing 150 x 150 x 150 mm concrete cube specimens and cylinder specimens with a diameter of 150 mm and 300 mm in height. The concrete cubes cover an area of 22500 mm². Figure 7 illustrates the compression tests on a concrete cube and cylinder. The load is gradually applied perpendicular to the direction of compaction on the face of the concrete cube. The compressive strength of the concrete cubes is evaluated by using ultimate load at the ultimate failure point. Tables 3 and 4 provide the compression strength results of the concrete cubes and cylinders.



Fig. 7 Testing of Concrete Specimens

Table 3 Compressive Strength of GGBS and River Sand Incorporated Concrete Cubes

Sl. No.	Specimen Designation	7 th Day Compressive Strength (N/mm ²)	14 th Day Compressive Strength (N/mm ²)	28 th Day Compressive Strength (N/mm ²)
1	CCRS	22.42	25.60	30.00
2	CCISRS30	22.93	29.23	31.12
3	CCISRS40	21.56	30.56	33.23
4	CCISRS50	18.20	22.65	25.58
5	CCISRS60	21.13	23.60	24.50

* CCRS – Cement Concrete with River Sand; CCISRS30 – Cement concrete incorporated with 30% of GGBS and 100% of River Sand; CCISRS40 – Cement concrete incorporated with 40% of GGBS and 100% of River Sand; CCISRS50 – Cement concrete incorporated with 50% of GGBS and 100% of River Sand; CCISRS60 – Cement concrete incorporated with 60% of GGBS and 100% of River Sand.

Table 4 Compressive Strength of GGBS and M-Sand Incorporated Concrete Cubes

Sl. No.	Specimen Designation	7 th Day Compressive Strength (N/mm ²)	14 th Day Compressive Strength (N/mm ²)	28 th Day Compressive Strength (N/mm ²)
1	CCMS	18.47	23.45	31.00
2	CCISMS30	22.31	28.52	32.10
3	CCISMS40	19.32	25.12	33.86
4	CCISMS50	18.20	23.45	27.65
5	CCISMS60	17.95	22.25	26.40

* CCMS – Cement concrete with M-Sand; CCISMS30 – Cement concrete incorporated with 30% of GGBS and 100% of M-Sand; CCISMS40 – Cement concrete incorporated with 40% of GGBS and 100% of M-Sand; CCISMS50 – Cement concrete incorporated with 50% of GGBS and 100% of M-Sand; CCISMS60 – Cement concrete incorporated with 60% of GGBS and 100% of M-Sand.

Table 5 Strength of M 20 Concrete Cylinder with GGBFS and River Sand

Sl. No.	Specimen Designation	7 th Day Compressive Strength (N/mm ²)	14 th Day Compressive Strength (N/mm ²)	28 th Day Compressive Strength (N/mm ²)
1	CCRS	16.30	18.03	22.60
2	CCISRS30	14.69	17.45	21.20
3	CCISRS40	16.45	18.45	22.45
4	CCISRS50	15.63	18.23	21.00
5	CCISRS60	15.02	17.63	20.12

Table 6 Compressive Strength of M 20 Concrete Cylinder with GGBFS and M Sand

Sl. No.	Specimen Designation	7 th Day Compressive Strength (N/mm ²)	14 th Day Compressive Strength (N/mm ²)	28 ^h Day Compressive Strength (N/mm ²)
1	CCMS	15.71	16.62	22.02
2	CCISMS30	15.84	19.07	22.01
3	CCISMS40	16.03	20.02	24.02
4	CCISMS50	15.03	19.02	23.06
5	CCISMS60	14.42	18.06	20.00

6.2 Split Tension Test

The traction or tensile strength of a concrete is a tensile stress resistance of the concrete and is expressed as force per cross-sectional area. The amount of concrete tensile strength may be measured by testing the concrete cylinder specimens in our laboratory under the compression testing machine. The cylinders are horizontally positioned, and the stress is gradually increased until it reaches the split point of the cylinders, via the axis diameter, the fractures occur. In laboratory, the split tensile strength of the cylinder specimen with a diameter of 150 mm and a height of 300 mm is evaluated using a compression testing equipment in accordance with IS 5816: 1999 [36]. The tension test for concrete is illustrated in Figure 8. Table 9 shows the tensile strength of M 20 concrete with GGBS as a partial substitute for OPC and M Sand as a full substitute for river sand.

6.3 Modulus of Elasticity Test

The elastic modulus of concrete is a measure of the resistance of concrete to stress. Elastic modulus is one of the key parameters for defining concrete strength. In laboratory, according to IS 516: 1959 the elastic modulus is estimated by testing the 150 mm diameter cylinder specimen with a height of 300 mm is tested under the compression test machine [35]. The concrete cylinder specimens are linked to an extensometer to measure the stress in concrete under the steady rise of the load. Test of the concrete elastic modulus is shown in Figure 9. Table 11 provides the M 20 concrete elastic modulus using GGBS, river sand and M-sand.

6.4 Flexural Strength Test

The flexural strength is also known as a rupture module and is a technique of measuring the concrete's tensile strength. Concrete prism dimension 500 x 100 x 100 mm conforming IS 516: 1959 [35] is used to determine the bending strength. The specimens are stored under water at room temperature for two days after 28 days of treatment. The sample is evaluated in moist state as soon as feasible. The sample of prism is supported and is kept simple using roller supports. For testing the concrete prism specimen, a 3-point loading technique is applied, and a gap of 400 mm between roller supports is maintained. The load is given gradually up to failure of specimen. Figure 10 illustrates the flexural resistance tests for the concrete prism specimen. In Tables 11, the flexural strength of conventional concrete and concrete incorporated with GGBS and M Sand are given.

Table 11 Elastic Modulus of Concrete Specimens

Sl. No.	Specimen Designation	Modulus of Elasticity (N/mm ²)	Split Tensile Strength (N/mm ²)	Flexural Strength (N/mm ²)
1	CCRS	25300	2.43	3.20
2	CCISRS30	26000	2.61	3.60
3	CCISRS40	26400	2.75	3.89
4	CCISRS50	24600	2.58	2.60
5	CCISRS60	24200	2.12	2.26
6	CCMS	26800	2.61	3.40
7	CCISMS30	27100	2.69	3.90
8	CCISMS40	27600	3.17	4.20
9	CCISMS50	26200	2.51	2.90
10	CCISMS60	25900	2.10	2.80

**Fig. 8 Tension Test****Fig. 9 Elastic Modulus Test****Fig. 10 Flexural Test on Concrete Prism**

7. Results and Discussions

The role of GGBS plays a vital role in the strength of cement concrete. As the percentage of GGBS is increased the strength of the concrete is also increased upto 40 % replacement of cement. Above 40% of replacement of cement with GGBS, the strength of concrete such as compressive strength, tensile strength and modulus of elasticity are decreased. The presence of M Sand in the concrete specimens slightly increased the compressive strength, tensile strength and modulus of elasticity than that of the concrete specimens with river sand. The comparison of concrete specimens is shown in Figures 13 and 14

and the compressive strength of concrete cube and cylinder specimen with 40 % replacement of cement by GGBS and 100 % replacement of river sand by M Sand higher than all other concrete specimens. All the concrete cube specimen with M-Sand achieved strength higher than nominal strength of M 20 grade, The concrete specimens with M-Sand achieved higher compressive strength than the target strength of M 20 grade, i.e. 26.6 N/mm^2 . The compressive strength, tensile strength and modulus of elasticity of control concrete, concrete with GGBS and river sand and concrete with M-Sand are plotted and given in Figures 11 to 15. From the results, it is conveyed that the mechanical properties of concrete with 40% GGBS and 100% M-Sand is better than all other types of concrete specimens cast. The difference between the concrete with M-Sand in mechanical properties are not significant but the concrete with M-Sand achieved slightly higher mechanical properties. The addition of GGBS percentage beyond 40% decreases the mechanical properties of the concrete, this is due to the presence of higher percentage of unreacted composition in GGBS. The early age strength of GGBS is lower when compared to concrete without GGBS but at 28 days the strength achieved by GGBS concrete is higher than control concrete and at the same time the mechanical properties of GGBS concrete with M-Sand are higher than the GGBS concrete with river sand. The delay in the development of early age strength of GGBS concrete is due to the lower fineness of GGBS than OPC. The reduction in the mechanical properties of GGBS concrete beyond 40% is also due to the insufficient cementitious material. As the percentage of GGBS increased, the total cementitious content get reduced compared to that of control concrete mix. Due to this, the strength of high volume GGBS concrete is reduced. To overcome this additional 10 to 20 percent of cementitious material to total cementitious content could be added [37][38].

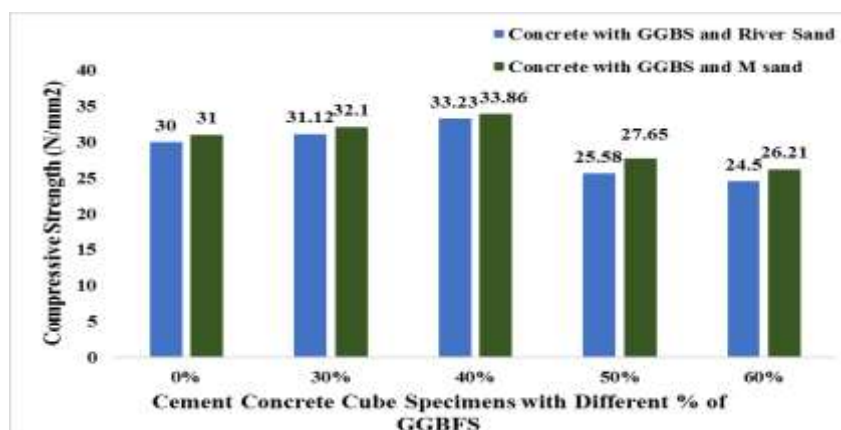


Fig. 11 Compressive Strength of Concrete Cube Specimens

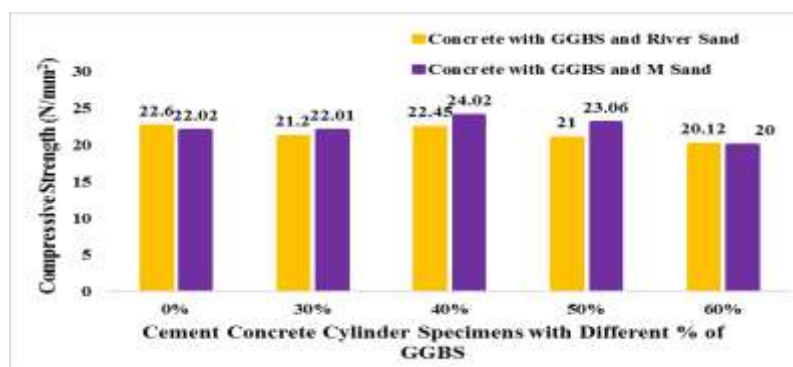


Fig. 12 Compressive Strength of Concrete Cylinder Specimens

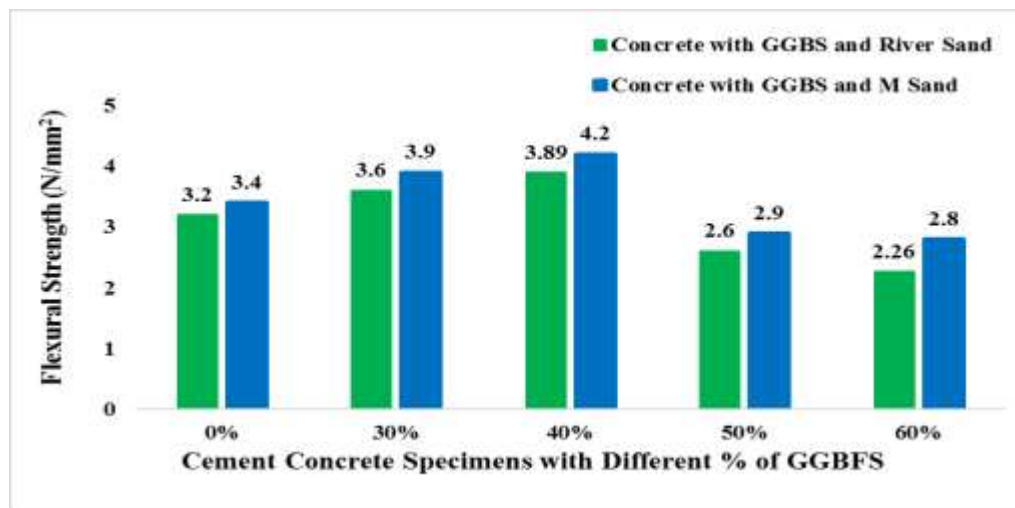


Fig. 13 Flexural Strength of Concrete Specimens

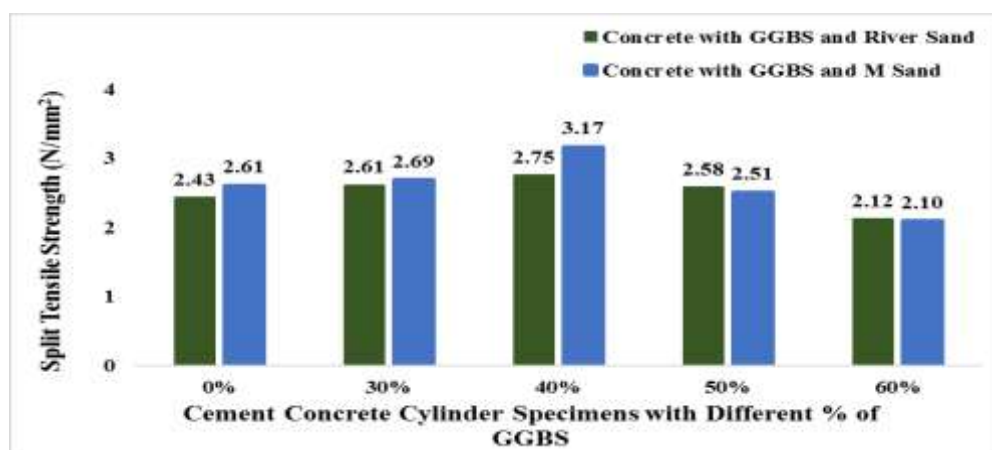


Fig. 14 Split Tensile Strength of Concrete Specimens

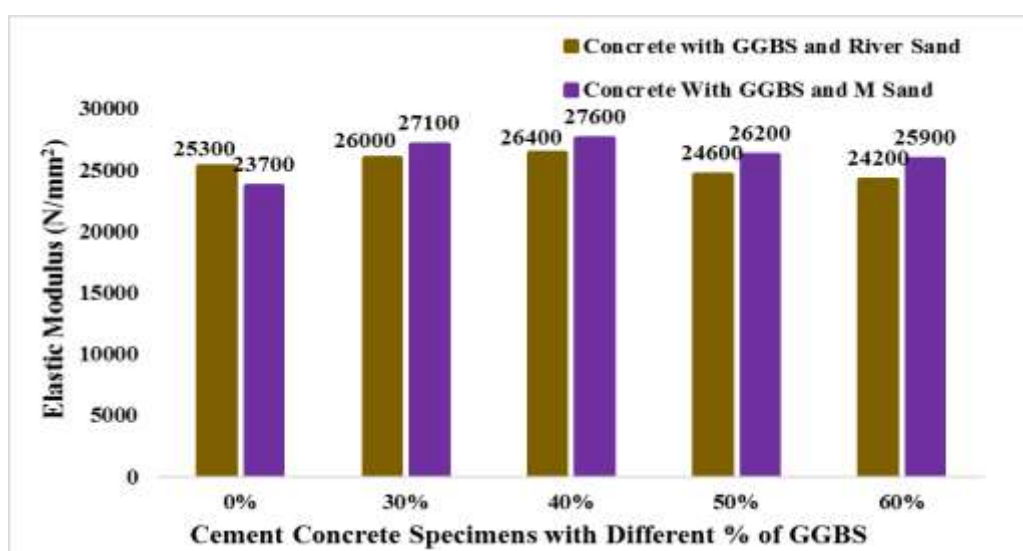


Fig. 15 Elastic Modulus of Concrete Specimens

8. Conclusions

The compressive strength, tensile strength, and elastic modulus of concrete with GGBS and M Sand are determined and compared to conventional concrete and concrete with GGBS and river sand by an experimental study. The following conclusions are drawn:

1. Optimum percentage of GGBS as partial replacement for OPC is 40%.
2. M-Sand is effective as suitable alternative to river sand since the concrete with M-Sand performed better than concrete with river sand.
3. Concrete with GGBS and M-Sand showed higher compressive strength, tensile strength, flexural strength and elastic modulus than that of the concrete with GGBS and river sand.
4. All the concrete specimens with M-Sand achieved higher strength than the target strength of M 20 grade.
5. The increase in the percentage of GGBS higher than 40% results in the decrease in mechanical properties of the GGBS concrete.
6. The use of GGBS as partial replacement for OPC can reduce the carbon footprint to the atmosphere.

References

- [1] Gagg, C.R., (2014), "Cement and Concrete as an Engineering Material: An Historic Appraisal and Case Study Analysis", *Engineering Failure Analysis*, Vol. 40, pp. 114-140, May. doi: 10.1016/j.engfailanal.2014.02.004
- [2] Hendrik Van Oss, G., (2007), "Mineral Commodity Summaries", Prepared for the US Geological Survey.
- [3] Pitchaiah Podila Sankara (2017), "Impacts of Sand Mining on Environment – A Review", *SSRG International Journal of Geo Informatics and Geological Science (SSRG-IJGGS)*, Vol. 4, Issue 1, January – April, pp. 2393 – 9206.
- [4] Yajurved Reddy, M., Swetha, D.V., and Dhani, S.K., (2015), "Study on Properties of Concrete with Manufactured Sand as Replacement to Natural Sand", *International Journal of Civil Engineering and Technology (IJCET)*, Vol. 16, pp. 29-42.
- [5] Rameshwar S. Ingalkar, Shrikant M. Harle, (2017), "Replacement of Natural Sand by Crushed Sand in the Concrete", *Landscape Architecture and Regional Planning*, Vol. 2, No. 1, pp. 13-22.
- [6] Boobalan, S.C., Nikeath, D., and Pragadesh, M., (2019), "Experimental Study on Concrete by Using Manufactured Sand – A General Review", *International Journal of Engineering and Advanced Technology (IJEAT)*, Vol. 8, No. 3, February, pp. 91-93.
- [7] Boopathi, Y. and Doraikkannan, J. (2016), "Study on M-Sand as a Partial Replacement of Fine Aggregate in Concrete", *International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)*, Vol. 3, Special Issue 2,

March, pp. 746-749.

- [8] Adams Joe, M., Maria Rajesh, A., Brightson, P., Prem Anand, M., (2013), “Experimental Investigation on the Effect of M-Sand in High Performance Concrete”, *American Journal of Engineering Research (AJER)*, Vol. 02, Issue 12, pp. 46-51.
- [9] Manjunatha, M., Akshay, N.K., Jeevan, H., (2016), “Durability Studies on Concrete by Replacing Natural Sand with M-Sand – A Review”, *International Journal of Emerging Technology and Advanced Engineering*, Vol.6, Issue.3, March, pp. 293-296.
- [10] Sabarish, K.V., Pratheeba Paul, Mohammed Aslam Khan, Gowtham, S., Hariharan, R., (2018), “Utilization of M-Sand as a Partial Replacement for Fine Aggregate in Concrete Elements”, *International Journal of Civil Engineering and Technology (IJCIET)*, Vol. 9, Issue 10, October, pp. 422 -426.
- [11] Somasekharaiah, H.M., Basavaprabhu, M.S., Basavalingappa, Nandishkumar Sajjan, (2016), “An Experimental Investigation on Strength Properties of Concrete Replacing Natural Sand by M-Sand using Silica Fume as an Admixture”, *International Research Journal of Engineering and Technology (IRJET)*, Vol. 3, Issue 08, August, pp. 1952 – 1958.
- [12] Naga Prashanth, p., and Shiva Sankar Reddy, N., (2017), “Performance of High Strength Concrete – Partially Replacing Fine Aggregate with Manufactured Sand”, *International Research Journal of Engineering and Technology (IRJET)*, Vol. 04, November, pp. 2079 – 2087.
- [13] Altamashuddinkhan Nadimalla, Siti Aliyyah Binti Masjuki, Sher Afghan Khan and Akshatha, B.A., (2018), “The Effect of Replacement of Natural Sand by Manufactured Sand on the Properties of the Concrete”, *2018 IEEE 5th International Conference on Engineering Technologies & Applied Sciences*, November, pp. 22 – 23, Bangkok, Thailand.
- [14] Shewaferaw Dinku Belay, “The Use of Manufactured Sand in Concrete Production”, *M.Sc. Thesis*, Addis Ababa University, July 2006.
- [15] Crouch, L.K. and Jason Philips (2009), “Lean, Green and Mean Concrete”, *2009 World of Coal Ash Conference (WOCA)*, pp. 1-17.
- [16] Shukla, M., Sahu, A.K., Srivastava, A.K., and Sachan, A.K., (2000), “Studies on Strength and Behaviour of Concrete by Using Stone Dust as Fine Aggregate”, *Proceedings of National Seminar on Advances in Cement and Concrete*, pp. 38 - 43.
- [17] Celik, T., and Marar, K., (1996), “Effects of Crushed Stone Dust on Some Properties of Concrete”, *Cement and Concrete Research*, Vol. 26, pp. 1121-1130.
- [18] Pofale, A.D., and Kulkarni, S.S., (1998), “Comparative Study of Strength Properties of Concrete Mixes with Natural Sand Replaced Fully or Partially by Crushed Stone Powder from Aggregate Crushing Plant Waste”, *Indian Concrete Institute*, Bangalore, pp. 227 – 240.
- [19] Sahu, A.K., Sunil Kumar and Sachan, A.K., (2003), “Crushed Stone Waste as

Fine Aggregate for Concrete”, *The Indian Concrete Journal*, pp. 845-848.

- [20] Babu Ganesh, K and Kumar Sree Rama, V (2000), “Efficiency of GGBS in Concrete”, *Cement and Concrete Research*, Vol. 30, pp. 1033 – 1036.
- [21] Pavia, S. and Condren, E, (2018), “Study of the Durability of OPC Versus GGBS Concrete on Exposure to Silage Effluent”, *Journal of Materials in Civil Engineering*, Vol. 20, No. 4, April, pp 313 – 320. DOI: 10. 1061/(ASCE)0899-1561(2008)20:4(313)
- [22] Malagavelli Venu and Rao, P.N., (2010), High Performance Concrete with GGBS and ROBO Sand, *International Journal of Engineering Science and Technology*, Vol. 2, No. 2, pp. 5107 – 5113.
- [23] Duan Ping, Shui Zhonghe, Chen Wei and Shen Chunhua (2013), Enhancing Microstructure and Durability of Concrete from Ground Granulated Blast Furnace Slag and Metakaolin as Cement Replacement Materials, *Journal of Materials Research and Technology*, Vol. 2, No. 1, pp. 52 - 59.
- [24] Arivalagan, S (2014), Sustainable Studies on Concrete with GGBS as a Replacement Material in Cement, *Jordan Journal of Civil Engineering*, Vol. 8, No. 3, February, pp. 263- 270.
- [25] Elchalakani Mohamed, Aly Tarek and Abu-Aisheh Emad (2014), Sustainable Concrete with High Volume GGBFS to Build Masdar City in UAE, *Case Studies in Construction Materials*, Vol. 1, pp. 10 - 24.
- [26] IS 12269: 2013, Ordinary Portland Cement, 53 Grade - Specification. Bureau of Indian standards, New Delhi, India.
- [27] Grist, E.R., Paine, K.A., Health, A., Norman, J. and Pinder, H. (2015), “The Environmental Credentials of Hydraulic Lime-Pozzolan Concretes”, *The Journal of Cleaner Production*, Vol. 93, pp. 26 – 37.
- [28] Kumar, S., Kumar, R., Bandopadhyay, A., Alex, T.C., Kumar, B.R., Das, S.K., and Mehrotra, S.P., (2008), “ Mechanical Activation of Granulated Blast Furnace Slag and its Effect on the Properties and Structure of Portland Slag Cement”, *Cement and Concrete Composites*, Vol. 30, No. 8, pp. 679 – 685. DOI: 10. 1016/j.cemcocomp.2008.05.005
- [29] Bellmann, F and Stark, J (2009), “Activation of Blast Furnace Slag by a New Method”, *Cement and Concrete Research*, Vol.39, No. 8, pp. 644 – 650. DOI: 10. 1016/j.cemconres.2009. 05. 012
- [30] Oner, A and Akyuz, S (2015), “An Experimental Study on Optimum Usage of GGBS for the Compressive Strength of Concrete, *Cement and Concrete Composites*, Vol. 29, No. 6, pp. 505 – 514.
- [31] Nagaratnam, B.H., Rahman, M.E., Mirasa, A.K., Mannan, M.A., Lame, S.O., (2015), “Workability and Heat of Hydration of Self-Compacting Concrete Incorporating Agro-Industrial Waste”, *The Journal of Clear Production*, Vol. 112,

No. 1, pp. 882 – 894.

- [32] IS 2386: 1963, Methods of Test for Aggregates for Concrete, Part IV Mechanical Properties. Bureau of Indian standards, New Delhi, India.
- [33] IS 383: 1970, Specification for Coarse and Fine Aggregates from Natural Sources for Concrete. Bureau of Indian standards Reaffirmed 2002, New Delhi, India.
- [34] IS 10262: 2009, Concrete Mix Proportioning – Guidelines, Bureau of Indian standards, New Delhi, India.
- [35] IS 516: 1959, Methods of Test for Strength of Concrete, Bureau of Indian standards, New Delhi, India.
- [36] IS 5816: 1999, Splitting Tensile Strength of Concrete – Methods of Test, Bureau of Indian standards, New Delhi, India.
- [37] Krunal Rajput, “Difference Between M Sand Vs River Sand| What is M sand & River Sand”, *CivilJungle*, 2021, civiljungle.com, <https://civiljungle.com/difference-between-m-sand-vs-river-sand/>
- [38] Vani Paspula, “ M Sand [Manufactured Sand] – A Substitute to River Sand”, *BuildersMART*, 6th July 2019, <https://www.buildersmart.in/blogs/M-sand/>