Development of Ternary Blended Concrete using Industrial Waste with Manufactured Sand as a Partial Replacement

Dhaval Patel[1]*, Chetankumar Modhera[2], Jagad Gaurav[3], Dr. Vimalkumar N Patel[4], Mayank Bose[5]

Abstract

Concrete is a building material composed of hard, chemically inert particles known as aggregates bound together by cement and water. As a result of its employment in buildings, concrete is extensively utilized around the globe. As cement and aggregate are essential components of concrete, they must be produced in a high quantity. Cement production releases a substantial amount of CO_2 into the atmosphere, which is a key contributor to global warming. On the other side, overusing aggregates (sand) creates environmental difficulties such as groundwater depletion, destruction of natural habitats, soil erosion, etc. This research examines the efficient exploitation of waste material in manufacturing concrete as a partial substitute for cement and sand. This research used two types of concrete, i.e., cement concrete and concrete with 30% GGBS and 20% microfine of M20 and M30 grade mixes. In both types of concrete, natural sand was replaced with manufactured sand at 20% intervals up to 100% replacement. The compressive strength of hardened concrete was evaluated. It was discovered that partial substitution of natural sand with manufactured sand significantly improved the concrete's strength compared to standard mix concrete. At 60% replacement of sand, the compressive strength of all the types of concrete shows maximum results. Therefore, 60% replacement was set as an optimum replacement of sand with manufactured sand. Further mechanical properties were evaluated at 60% replacement of natural sand with manufactured sand for cement concrete and concrete with GGBS and microfine. Results showed that concrete with 60% manufactured sand as fine aggregate with GGBS and microfine shows quite good results compared to cement concrete with the same amount of manufactured sand as fine aggregate. With mechanical properties, this concrete is also evaluated for global warming potential. The test results showed that concrete with industrial waste and manufactured sand could reduce environmental stress.

Keywords: Ground granulated blast-furnace slag, Microfine, Manufactured Sand, Mechanical Properties, Global Warming Potential

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1. Introduction

After China, India is the world's second-largest cement manufacturer. Approximately 545 million tonnes (MT) of cement were produced in India in FY2020, accounting for nearly 8 percent of the worldwide installed capacity (REPORT 2021). Compared to February 2020, India's cement output in February 2021 grew by 7.8 percent. In FY2021, India produced 262 million tonnes (MT) of cement (Till February 2021). For the financial year 2022, cement output is predicted to rise by 10% to 12%, with utilization hovering around 65% (REPORT 2021). We can conclude from the above statistics that concrete

***Corresponding Author:** Dhaval Patel
Address:[1*,3]Research Scholar, Civil Engineering Department, S V National Institute of Technology, Surat, India.
[1]Email: dhavalkumarmpatel@gmail.com, [3]Email: jagadgaurav@gmail.com
[2]Professor (HAG), Civil Engineering Department, S V National Institute of Technology, Surat, India.
Email: cdm@amd.svnit.ac.in
[4]Professor, Civil Engineering Department, G H Gardi college of Engineering and Technology, Rajkot, India.
Email: vimalccet1@gmail.com
[5]M.Tech Students, Civil Engineering Department, S V National Institute of Technology, Surat, India.
Email: bosemy712@gmail.com
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is one of the longest-lasting construction materials available. Because of the environmental toll of using natural resources to make cement and concrete, more and more people are turning to non-traditional sources for their cement and concrete needs. Direct replacement of waste products from various industries is one of the most successful strategies for sustainable growth (Gadpalliwar, Deotale, and R. Narde 2014). Research into the use of alternative materials in concrete has recently gained momentum. Numerous environmental benefits come with using these materials, including reducing landfill expenses, saving energy, and protecting the environment from contamination. The best option to reduce the impact of the cement industry on the environment is to use industrial waste products such as GGBS, Fly Ash (FA), Silica Fume (SF), and Metakaolin (MK) as supplementary cementing materials (Kim et al. 2018). GGBFS and Microfine are used in place of cement in this current study to address these issues. Besides using supplementary cementing materials as a partial replacement for cement, conventional sand can also be replaced with other alternative materials to produce more environmentally friendly concrete. The surplus use of conventional sand causes environmental issues such as reducing the groundwater level, damaging natural habitats, soil erosion, etc. (Shen et al. 2018). It also increases the cost of the project. These worries drive the need for more reliable sand in supply, better under control in terms of quality, and friendlier to the environment. Researchers have investigated using recycled sand derived from demolished buildings (Vijaya n.d.). One of the recycled sands used in our research is manufacturing sand (MS). Vijiya et al. (2013**)** (Vijaya n.d.) discussed the manufactured sand, which can be used as an alternative for river sand while manufacturing concrete. In this experiment, the well-processed manufacturing sand is used to replace river sand fully. The complete replacement of river sand with manufacturing sand showed good workability and compressive strength results. Workability increases due to the higher fineness modulus, particle grading, shape, and texture properties of manufacturing sand, while compressive strength increases due to the reduced surface area and better particle packing. Shen et al. (2018)(Shen et al. 2018) discussed the influence of manufacturing sand characteristics on concrete performance. They carried out a series of experiments on manufacturing sand and its concrete. The result showed that the particle shape of manufacturing sand had little effect on the performance of concrete. Still, the powder of manufactured sand significantly impacts concrete performance. The gradation of manufacturing sand positively affects the concrete strength, and its value can reach its peak when the stone powder content is 7.5%. This positive effect is due to the ability to manufacture sand powder which can wrap the aggregate, reduce the pore and make concrete denser. The manufacturing sand has higher strength than river sand concrete. Mo et al. (2016)(Mo et al. 2016) explore the durability of sustainable concrete by using the oil palm shell, a waste material from the oil palm industry. The lightweight coarse aggregate and manufactured sand are used in this concrete instead of conventional concrete material. The GGBS was used with 20%, 40%, and 60% cement replacement to reduce the cement consumption in ordinary Portland cement concrete. Sorptivity, water absorption, and long-term free shrinkage were the main area that the researchers used for evaluating the GGBS concrete. With this, they found that GGBS benefits the long-term compressive strength gain compared to ordinary Portland cement without GGBS. Kuo et al. (2013)(Kuo et al. 2013) used the GGBS and Piezoelectric powder to replace cement and fine aggregate partially, respectively, to check their effect on cement mortar's mechanical and electrical properties. In this study, the volumetric method was employed in which the GGBS replaced the cement as 0%, 10%, 20%, and 30%, as well as 5% of fine aggregate, is replaced with piezoelectric powder. The mix of mechanical and electrical properties was tested to assess the compressive strength and electricity at 50V and 100V. The result showed that at the curing age of 28 days, the control group exhibited higher compressive strength in the electrical property test than Piezoelectric material concrete. The compressive strength also decreases as the replacement of GGBS increases. Thus, they suggested that piezoelectric material cannot be effectively mixed with fine aggregate and cement. Suthar et al. (2013)(Patel, Shah, and Patel 2013) used

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alccofine, fly ash, and silica fume to partially replace cement for high-strength concrete. The results of the above material concrete show excellent fresh and hardened properties. It was observed that the compressive strength of concrete formed with Portland cement with flyash-Alccofine concrete was higher than that made with Portland cement-fly ash-silica fume. Dordi et al. (2013) (Dordi, Vyasa Rao, and Santhanam 2013) used microfine ground granulated blast furnace slag (MFGGBS) for high-performance concrete, i.e., M60. Implementing MFGGBS into concrete resulted in better workability and improved cohesiveness property of concrete.
The long-term strength and permeability results also show how valuable this MFGGBS is.

2. Experimental Proggramme

2.1 Materials

2.1.1 Cement

As per IS 12269-2013 (IS 12269 2013) 53-grade of ordinary Portland cement is used in this experimental studies. Chemical properties of cement are shown in Table 1.

2.1.2 Ground Granulated Blast-Furnace Slag (GGBS)

The manufacturing of iron creates a by-product known as GGBS (ground granulated blast furnace slag), which improves concrete's workability, strength, and durability(Kim et al. 2018). Blast furnaces operate at temperatures more than 1,500 °C by a mixture of iron ore, coke, and limestone that act as carefully calibrated fuel(Narender Reddy and Meena 2018). Iron is extracted from the iron ore, while the remaining components float to the surface of the iron, where they are transformed into slag. This slag is frequently extracted as a molten liquid and rapidly cooled in significant volumes of water, which are further employed in manufacturing GGBS. Cementitious properties are enhanced during quenching, and coarse granules resembling sand are produced. Slag is granulated, dried, and finally powdered to create a fine powder (reddy.s. and Rao 2016). An essential environmental strategy will be recycling waste from these mines. Many industries now utilize slag from the iron and steel industry instead of the waste product it was originally intended to become. This has been a result of decades of study and development. Lime (CaO) and silica (SiO2) are the major components of slag(Vijaya Bhaskar Reddy and Srinivasa Rao 2020). These elements can also be found in Portland cement. Meanwhile, with the steel sector's rise, waste disposal is a concern that can cause serious environmental hazards.

2.1.3 Microfine

Microfine is a low-calcium silicate mineral-based additive with a particle size distribution that is carefully managed to produce high levels of reactivity(Srin Ivasan 2020). Microfine fineness and high responsiveness contribute to a faster hydration process. Using Microfine enhances the particle packing of paste components, resulting in stronger and more durable concrete(Patel, Shah, and Patel 2013). To achieve an ultra-fine consistency, a rigorous milling process is utilized. A strictly controlled classification process is being used to produce material with uniformly distributed particle sizes. During this procedure, regular GGBS is milled into an extremely fine powder of GGBS(Reddy and Naqash 2019). The features of conventional GGBS, such as high surface area, increased penetrating properties, and high resistivity to chemical assault, is improved when the particles are ultrafine(Reddy and Naqash 2019). Table 1 shows chemical properties of the microfine.

Table 1 Chemical Properties of OPC, GGBS and Micro Fine

Particulars	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	Na_2O	K_2O	SO_3
Cement	63	20	6	3	1.5	0.5	0.5	2
GGBS	38.09	32.19	8.59	2.8	5.5	0.26	0.4	8.89
Micro Fine	36.7	35.1	17.58	1.62	7.75	------	------	0.65

2.1.4 Manufacturing Sand

In the production of concrete, manufactured sand, often known as M-Sand, can be used in place of river sand. Crushing tough granite stone is the first step in the production of manufactured sand(Vijaya n.d.). As a building material, the crushed sand has been given a cube-like shape with grounded edges, and it has also been washed and graded. Typically, the fine aggregates or sand come from natural sources, particularly river beds or riverbanks. The natural sand supply is being depleted at an alarming rate these days due to the continuous mining of sand(Shen et al. 2018). The removal of sand from river beds has resulted in several problems for the ecosystem. The dragging of sand from rivers has been made illegal by the government as a response to numerous environmental concerns(Mo et al. 2016). Because of this, natural sand is becoming increasingly difficult to come by, which has caused its price to jump. It is essential to locate a suitable replacement for river sand. Manufactured sand is the only material that can effectively replace sand over the long term.

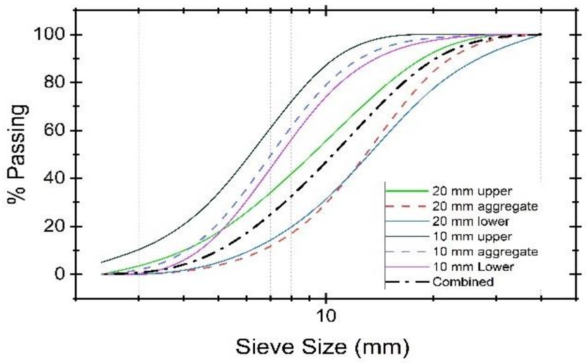

Figure 1 Sieve analysis of Coarse Aggregate (20mm and 10mm)

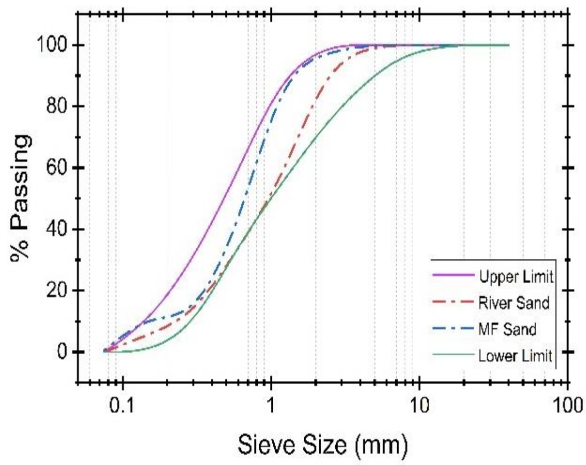

Figure 2 Sieve Analysis of River sand and MS

2.1.5 Coarse aggregate and Fine aggregate

Regular crushed stones of 20mm and 10mm are used as a coarse aggregate as per IS 383:2016 (Bureau of Indian Standards 2016). The basic properties of course aggregate. Coarse aggregate is locally available in Surat is used in this experimental work. Natural sand or River sand of size below 4.75mm, confirming Zone-II grading as per IS383:2016(Bureau of Indian Standards 2016), is used as fine aggregate. Manufactured sand is locally available form chikhli is used in this study. Physical properties of Fine and Coarse aggregate are shown in Table 2. Sieve analysis of coarse and fine aggregate is shown in Fig. 2. and Fig. 3.

Table 2 Physical parameter of CA and FA

Sr. No.	Tests	River Sand	MS	C.A. (20 mm)	C.A. (10 mm)
1	Fineness Modulus	2.8	2.9	7.84	6.15
2	Specific Gravity	2.66	2.536	2.84	2.79
3	Water Absorption (%)	1.8	5.544	2.07	2.54
4	Bulk Density Loose (kg/m^3)	1.70	1.71	1.42	1.45
5	Bulk Density Rodded (kg/m^3)	1.83	1.84	1.61	1.65
6	Grading Zone	Zone II	Zone II	—	—
7	Percentage Voids (%)	37.12	32.45	49.88	48.29
8	Moisture Content (%)	1.9	0.15	0.4	0.4

3. Concrete Mix proportion and Sample Preparation

In this research, the M20 and M30 concrete grades were used throughout the study, with river sand being partially replaced with manufacturing sand. The w/c ratios for M20 and M30 were set to 0.50 and 0.45, respectively, and the target slump value was set to 80 and100 mm respectively, with the rest of the mix design method following the IS 10262:2019 (Standard 2019) criteria. Initially, the concrete mix proportion was tested with river sand for the trial study and then for the rest of the specimens, after river sand was partially eliminated by the MS at the rate of 20%. The first batch was made with river sand as a fine aggregate and cement partially substituted with GGBS and microfine at 30% and 20%, respectively. After that, only river sand was partially replaced with MS sand at a rate of 0%, 20%, 40%, 40%, 80%, and 100% (shown in Table 3). For concrete casting, a laboratory pan mixer was utilized to mix the concrete. The concrete production process began with the addition of all dry materials to a running concrete pan mixer for a set amount of time. The appropriate water was gradually added in accordance with the design mix's requirements. The fresh concrete was then poured in three layers in a suitable mould, each layer being compacted with 25 blows with a compaction rod in accordance with IS 3558. The table vibrator was used for 90 seconds after proper compaction to eliminate entrapped air. For the above-mentioned concrete mixes, different specimens were prepared to evaluate different mechanical and durable properties of concrete, such as Cube, Cylinder, and Beam specimens with sizes of 150 x 150 x 150 mm, 150 mm diameter and 300 mm depth, and 150 x 150 x 700 mm, and for 28, 56, 90, and 180 days, respectively. After the concrete was cast, the specimens were left at room temperature for 24 hours before being demolded. The concrete specimens were then placed in a water curing tank for the duration of the curing process. To guarantee consistent dispersion of the concrete mixture, the wet and dry densities of concrete were measured. After inspecting the uniform distribution of the concrete mix, the specimen is evaluated for mechanical characteristics. At the same time, few of the samples are cured under specified conditions, such as salt and acid exposure. They are dried and cleaned with a wire brush after finishing their exposure duration in the appropriate conditions to remove the deteriorated material. They are then weighed and put to the test. Cube, Cylinder, Beam, and L-shaped specimens with dimensions of 150 x 150 x 150 mm, 150 mm diameter and 300 mm depth, 150 x 150 x 700 mm, and 150 x 150 x 90 mm were prepared to evaluate the different mechanical properties of concrete for the above-mentioned concrete mixes at 7 and 28 days. After being cast with concrete, specimens were left at room temperature for 24 hours before being demolded. The concrete samples were then stored in a tank of water until the mechanical test was conducted.

Table 3 Mix Proportions of M20 and M30 grade of concrete

Sr. No.	Sample Designation	Binder (%)			Binder (kg/m³)			Water (kg/m³)	FA (kg/m³)		CA (kg/m³)
		Cement	GGBS	Micro Fine	Cement	GGBS	Micro Fine		MS	RIVER SAND	
					M20 Grade						
1	C1	100	0	0	430	0	0	212	0	663	1134
2	C2	100	0	0	430	0	0	212	132.6	530.4	1134
3	C3	100	0	0	430	0	0	212	265.2	397.8	1134
4	C4	100	0	0	430	0	0	212	397.8	265.2	1134
5	C5	100	0	0	430	0	0	212	530.4	132.6	1134
6	C6	100	0	0	430	0	0	212	663	0	1134
7	A1	50	30	20	215	129	86	212	0	657	1122
8	A2	50	30	20	215	129	86	212	131.4	525.6	1122
9	A3	50	30	20	215	129	86	212	262.8	394.2	1122
10	A4	50	30	20	215	129	86	212	394.2	262.8	1122
11	A5	50	30	20	215	129	86	212	525.6	131.4	1122
12	A6	50	30	20	215	129	86	212	657	0	1122
					M30 Grade						
13	**C1**	100	0	0	410	0	0	191	0	671	1113
14	**C2**	100	0	0	410	0	0	191	134.2	536.8	1113
15	**C3**	100	0	0	410	0	0	191	268.4	402.6	1113
16	**C4**	100	0	0	410	0	0	191	402.6	268.4	1113
17	**C5**	100	0	0	410	0	0	191	536.8	134.2	1113
18	**C6**	100	0	0	410	0	0	191	663	8	1113
19	**A1**	50	30	20	205	123	82	191	0	664	1103
20	**A2**	50	30	20	205	123	82	191	132.8	531.2	1103
21	**A3**	50	30	20	205	123	82	191	265.6	398.4	1103
22	**A4**	50	30	20	205	123	82	191	398.4	265.6	1103
23	**A5**	50	30	20	205	123	82	191	531.2	132.8	1103
24	**A6**	50	30	20	205	123	82	191	664	0	1103

4. Results and Discussions

4.1 To find optimum replacement of Manufactured Sand replacement

The primary factor in determining the strength of concrete, compressive strength, was used to determine the optimal replacement of manufactured sand with river sand in both conventional concrete and concrete with GGBS and microfine. As shown in the graph, the compressive strength of concrete was measured at 7 and 28 days of age.

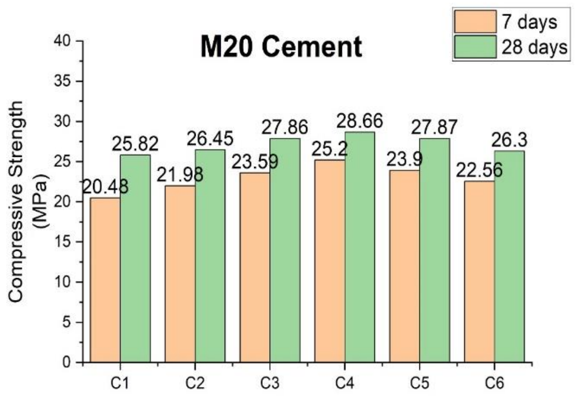

Figure 3 Compressive Strength of M20 containing cement with Partial replacement of MS with RS

The above Fig. 3. represents the compressive strength of M20 grade concrete with cement as a binding material and partial replacement of natural sand by manufactured sand as 0%, 20%,40%,60%,80%, and 100%. It was observed that compressive strength at 7 days and 28 days increases up to 60% replacement after it decreases. The compressive strength of concrete with 100% replacement and without any replacement shows a 10.15% increase in compressive strength.

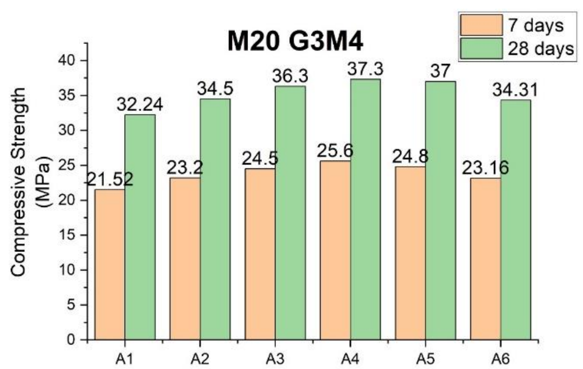

Figure 4 Compressive Strength of M20 containing SCMs with Partial replacement of MS with RS

The above Fig. 4. represents the compressive strength of M20 grade concrete with partial replacement of cement with 30% GGBS and 20% microfine as binding material and partial replacement of natural sand by manufactured sand as 0%, 20%,40%,60%,80%, and 100%. It was observed that compressive strength at 7 days and 28 days increases up to 60% replacement after it decreases. The compressive strength of concrete with 100% replacement and without any replacement shows a 7.62% increase in compressive strength.

Figure 5 Compressive Strength of M30 containing cement with Partial replacement of MS with RS

The above Fig. 5. represents the compressive strength of M20 grade concrete with cement as a binding material and partial replacement of natural sand by manufactured sand as 0%, 20%,40%,60%,80%, and 100%. It was observed that compressive strength at 7 days and 28 days increases up to 60% replacement. After that, it decreases. The compressive strength of concrete with 100% replacement and without any replacement shows a 7.87% increase in compressive strength.

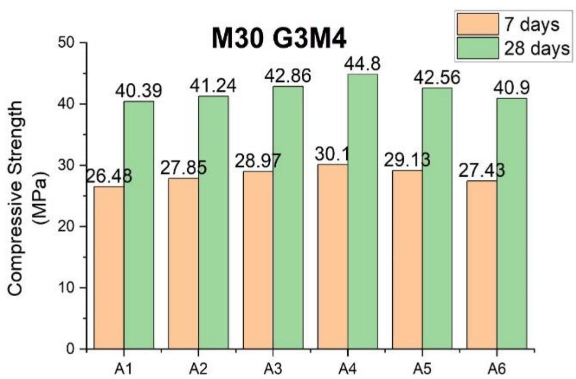

Figure 6 Compressive Strength of M30 containing SCMs with Partial replacement of MS with RS

The above Fig. 6. represents the compressive strength of M30 grade concrete with partial replacement of cement with 30% GGBS and 20% microfine as binding material and partial replacement of natural sand by manufactured sand as 0%, 20%,40%,60%,80%, and 100%. It was observed that compressive strength at 7 days and 28 days increases up to 60% replacement. After that, it decreases. The compressive strength of concrete with 100% replacement and without any replacement shows a 7.42% increase in compressive strength.

From the above results, it was clear that the compressive strength of cubes at 60% replacement of river sand with manufactured sand shows higher results in conventional concrete and concrete with GGBS and microfine for both grades. Hence, it was concluded that the optimum percentage of replacement of river sand with manufactured sand could be taken as 60%.

4.2 Mechanical Properties of Control and Optimized concrete with Manufactured Sand

The below Table 4. shows the compressive strength of the C4 and A4 concrete mix

4.2.1 Compressive Strength

Table 4 Compressive Strength of Optimized mix with Cement and SCMs for M20 and M30

Concrete mix	Compressive Strength in MPa (M20)			Compressive Strength in MPa (M30)		
	7 days	28 days	56 days	7 days	28 days	56 days
C4	24.9	36.2	40.5	28.24	40.86	42.6
A4	25.1	37.9	43.6	30.4	45.1	49.9

The above Table 4. shows the compressive strength of the C4 and A4 mix for M20 and M30 grade concrete for 7, 28, and 56 days. From the Table 4., it was clear that concrete containing GGBS and Microfine as a partial replacement for cement showed better results. The compressive strength of the A4 mix for M20 and M30 shows 2%, 4.69%, 7.65 % and 7.64%, 10.37%, 17.14 % increase compared to the C4 mix for 7, 28, and 56 days respectively.

4.2.2 Split tensile strength

Table 5 Split Tensile Strength of Optimized mix with Cement and SCMs for M20 and M30

Concrete mix	Split tensile strength in MPa (M20)		Split tensile strength in MPa (M30)	
	7 days	28 days	7 days	28 days
C4	2.63	4.48	2.79	4.8
A4	3.17	4.84	3.32	5.19

The above Table 5. shows the Split tensile strength of the C4 and A4 mix for M20 and M30 grade concrete for 7 and 28 days. From the Table 5., it was clear that concrete containing GGBS and Microfine as a partial replacement for cement showed better results. The Split tensile strength of the A4 mix showed 20.53%, 8.035% and 18.99%, 8.125% increments compared to the C4 mix for 7 and 28 days, respectively.

4.2.3 Shear strength

Table 6 Shear Strength of Optimized mix with Cement and SCMs for M20 and M30

Concrete mix	Shear Strength in MPa (M20)		Shear Strength in MPa (M30)	
	7 days	28 days	7 days	28 days
C4	4.85	5.42	5.12	5.87
A4	5.34	5.86	5.74	6.1

The above Table 6. shows the shear strength of the C4 and A4 mix for M20 and M30 grade concrete for 7 and 28 days. From the Table 6., it was clear that concrete containing GGBS and Microfine as a partial replacement for cement showed better results. The shear strength of the A4 mix showed 10.10%, 8.11% and 12.11%, 3.92% increments compared to the C4 mix for 7 and 28 days, respectively.

4.2.4 Flexural strength

Table 7 Flexural Strength of Optimized mix with Cement and SCMs for M20

Concrete mix	Flexural strength in MPa (M20)	Flexural strength in MPa (M30)
	28 days	28 days
C4	9.38	9.73
A4	9.86	10.16

The above Table 7. shows the flexural strength of the C4 and A4 mix for M20 and M30 grade concrete for 28 days. From the Table 7., it was clear that concrete containing GGBS and Microfine as a partial replacement for cement showed better results. The flexural strength of the A4 mix showed 5.12% and 4.12%

increments compared to the C4 mix for 28 days respectively.

5. Global Warming Potential

In the lower atmosphere, greenhouse gases (GHG) absorb heat. Approximately 3 percent of global greenhouse gas emissions result from the production of cement (Van Den Heede and De Belie 2012). Consequently, slag-containing concretes should be examined for this effect (Akbar and Liew 2020). Using the Eco-Invent database, the GWP (Global Warming Potential) of each mixture in this study was calculated. The type of binder used has a significant effect on the GWP of concrete, according to a recent study. Carbon emissions are compared for Control and Optimized concrete. The mixture containing 100 percent OPC emits the most CO_2 (386.02 kg CO_2 eq/m^3), while the mixture containing 50% OPC, 30% GGBS, and 20% MF emits the least CO_2 (199.22 kg CO_2 eq/m^3). A reduction in CO_2 emissions of 44% was found when GGBS and MF were substituted for 50% of the OPC. Switching from natural river sand to manufactured sand had little impact on CO_2 emissions, according to research. Fig. 7. depicts the mixture's carbon emissions.

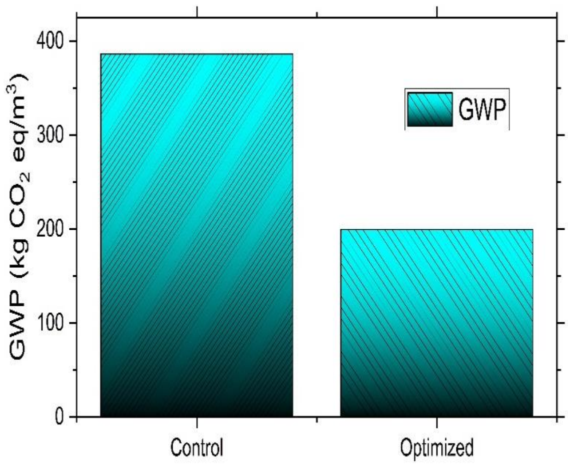

Figure 7 Carbon Emission of Control and Optimized mixtures

6. Conclusions

The results of the research led us to the following conclusion:

- The compressive strength of the concrete was increased with the substitution of manufactured sand as a partial replacement of natural sand in cement and SCMs concrete for both M20 and M30 grades of concrete containing. Concrete mix with 60% natural sand replacement level had a maximum compressive strength at all ages in cement and SCMs concrete beyond which it starts to decrease. For the M20 grade, the compressive strength of cement concrete increased by 23% and 10.99% at 7 and 28 days, while for SCMs concrete, it was increased by 18.95% and 15.69% at 7 and 28 days for optimized concrete. Similarly, for the M30 grade, the compressive strength of cement concrete increased by 10.99% and 10.31% at 7 and 28 days, while for SCMs concrete, it was increased by 13.67% and 10.90% at 7 and 28 days for optimized concrete Yet, the compressive strength of 100% replacement is still higher than the control mix. After analyzing all mixes, 60% substitution of natural sand with manufactured sand was considered the optimum mix. The compressive strength also increased when cement was replaced with the SCMs at the same level of substitution of manufactured sand, i.e., 60%. For M20, increases in compressive strength were 2%, 4.69%, and 7.65% at 7, 28, and 56 days respectively. While for M30, increases in strength were 7.64%, 10.37%, and 17.14% at 7, 28, and 56 days respectively. This increase in compressive strength of concrete is mainly due to the fineness of fine aggregate (i.e., manufactured sand) and binding material (cement, GGBS, and microfine), which results in a better hydration process. After analyzing all mixes, 60% substitution of natural sand with manufactured sand was considered the optimum mix.
- Split tensile strength of concrete was increased with the substitution of SCMs as a partial replacement of cement for 60% substitution of natural sand when compared to cement concrete for the same level of substitution of natural sand. For M20, it was 20.53% and 8% at 7 days and 28 days, respectively. While for M30, it was 18.99% and 8.12% at 7 and 28 days, respectively. This increase in the split tensile strength of concrete is mainly due to the fineness of fine aggregate (i.e., manufactured sand) and binding material (cement, GGBS, and

microfine), which results in a better condition for the hydration process, same as that of compressive strength.

- Flexural strength of concrete was increased with the substitution of SCMs as a partial replacement of cement for 60% substitution of natural sand compared to cement concrete for the same level of substitution of natural sand. For M20, it was 5.12% for 28 days, while for M30, it was 4.12% for 28 days. This increase in the flexural strength of concrete is mainly due to the fineness of fine aggregate (i.e., manufactured sand) and binding material (cement, GGBS, and microfine), which results in a better condition for the hydration process, same as that of compressive strength.
- Shear strength of concrete was increased with the substitution of SCMs as a partial replacement of cement for 60% substitution of natural sand compared to cement concrete for the same level of substitution of natural sand. For M20, it was 10.10% and 8.11% at 7 days and 28 days, respectively. While for M30, it was 12.11% and 3.92% at 7 and 28 days, respectively. This increase in the shear strength of concrete is mainly due to the fineness of fine aggregate (i.e., manufactured sand) and binding material (cement, GGBS, and microfine), which results in a better condition for the hydration process, same as that of compressive strength.
- Optimized concrete can be reduced 44% carbon foot print from the construction industry and also reduce 24% cost.

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