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Effect of Iron Ore Tailings and High Magnesium Nickel Slag on Flyash - Ggbs Based Geopolymer Concrete (GPC)

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Abstract: The cement industry is a major producer of carbon dioxide (CO_2), a powerful greenhouse gas which contaminate the environment by emitting massive volumes of CO_2. The building sector contributes both directly and indirectly to environmental degradation, natural resource depletion, and global warming. From a sustainability standpoint, it is critical that cement manufacturing be reduced. Geopolymer concrete (GPC) is a new material that does not require portland cement as a binder, instead, materials rich in Silicon (Si) and Aluminum (Al), such as Flyash (FA) and Ground granulated blast furnace slag (GGBS) are activated by alkaline liquids to produce the binder. The use of iron ore tailings (IOT) in place of traditional aggregates in concrete has been discovered to be feasible. Concrete made using IOT aggregate performed well with respect to strength and durable studies. GPC mix of 12M was prepared using FA, GGBS, aggregates, alkaline alkali activators such as Sodium hydroxide (NaOH) and Sodium silicate (Na_2SiO_3). A study on using iron ore tailings (IOT) in replacement of fine aggregates in percentages of 20, 30, 40 and 50 are studied in GPC. After achieving optimum strength in above mix then high magnesium nickel slag (HMNS) was replaced with varying percentages 5, 7.5, 10 and 12.5. As alkaline activators with 12M NaOH and Na_2SiO_3 solutions are used with a ratio of 2.5. Mechanical properties such as Compressive, Split tensile and Flexural strength are evaluated to determine the influence of IOT and HMNS replacement in GPC.
Keywords: Iron ore tailings (IOT), Geopolymer concrete (GPC), Fly ash (FA), Ground granulated blast furnace slag (GGBS).

I. INTRODUCTION

On our ecosystem, cement has a wide range of negative environmental effects. In cement industries carbon dioxide emissions are the main issues. CO_2 emissions worldwide a total of 23 billion tons per year from all sources have been determined, out 7% of the carbon dioxide emissions total come from this source.

Emissions are caused by the manufacturing of Ordinary Portland cement in industry. Carbon dioxide has negative consequences on both human health and wildlife. The sector that makes cement includes large-scale, possibly labour-intensive, and procedure of production that is risky.

The concrete made of geopolymer was implemented to decrease the environmental pollutants that resulting from Portland cement manufacturing. Geopolymers are mineral binders with an amorphous structure that were developed by professor Joseph Davidovits. In order to create binders, Davidovits suggested that an alkaline liquid may be utilized to react with the silicon (Si) and aluminium (Al) in byproduct materials like GGBS and rice husk ash.

He created the name "Geopolymer" to describe these binders since the chemical reaction that occurs in this instance is a polymerization process. This solid substance was created by the interaction of an alkaline liquid with an alumina silicate powder. Geopolymer concrete is a cutting-edge building material that will be created by the chemical reaction of inorganic molecules. In contrast, geopolymer is an inorganic aluminahydroxide polymer made primarily of silicon (Si) and geologically derived aluminium (Al) minerals as well as byproducts like GGBS. To describe the mineral polymers produced by geochemistry, the word "Geopolymer" was first used.

A chemical reaction is utilized in the procedure under very in amorphous Si-O-Al-O bonding, alkaline conditions are used. It is a superior building material for the future because of its great mechanical qualities paired with significant chemical resistance, minimal shrinkage and creep, and environmentally that produces very less carbon dioxide in contrast to ordinary concrete.

Mining activities usually occupy and degrade extensive tracts of land owing to the creation of a considerable quantity of waste rocks and tailing, which is deposited at the surface and becomes a continual source of metal pollution to the area's soil, air, and water resource.

Instead of disposing of these iron ore tailings, repurpose them as a replacement for fine aggregates. A study on using iron ore tailings (IOT) in replacement of fine aggregates in percentages of 20, 30, 40 and 50 are studied in GPC. After achieving optimum strength in above mix then high magnesium nickel slag (HMNS) was replaced with varying percentages 5, 7.5, 10 and 12.5. As alkaline activators with 12M NaOH and Na_2SiO_3 solutions are used with a ratio of 2.5.

II. REVIEW OF LITERATURE

Mohamed MoafakArbili et al. [1] investigated on concrete revealed that mechanical properties increases with IOT substitution up to a point due to pozzolanic reaction and micro-filling of voids. Various researchers suggest various optimal doses of IOT. The normal ideal IOT ranges from 30 to 40%. IOT doses higher than 40% have a negative impact on mechanical strengths. Concrete with 20% replaced IOT has a 14% higher compressive strength than standard concrete.

Finih et al. [2] studied that a 30% IOT mixture reduced bleeding capacity by 52% and bleeding rate by 48% at 30 minutes in concrete. When the IOT content was less than 30%, the bleeding rate increased after 30 minutes, according to the bleeding tests. The decrease in bleeding rate and bleeding capacity should be due on the finer size of IOT with a specific surface, which decreased the amount of free water in the mixture compared to natural river sand.

Kumar et al. [3] investigated on hardened concrete revealed that as the IOT percentages increases workability of mix reduces hence for better workability needs use of super plasticizer is recommended. Replacement of 40% IOT in concrete gives maximum compressive strength which is more than the reference mix.

Hou et al. [4] investigated that IOT improved the slump workability of concrete. Studies show that as iron waste ros, the downturn gradually and marginally diminished. This signifies that concrete has high durability and is workable within a suitable range.

Manjunatha MKatti et al. [5] investigation reveals that compressive strength and split tensile strength will rise when iron ore tailings as fine aggregate are replaced by 40% in GPC. Compressive strength and split tensile strength decrease from 60% to 100% replacement in GPC.

Krikar et al. [6] studied that the workability of the concrete is steadily reduced as the iron waste increases. While curing was extended, the strength of the concrete increases. By raising the iron waste ratio till 12%, the compressive and flexural tensile strength increased marginally. It should be noted that adding 12% iron waste in concrete resulted in a 15% increase in compressive strength in 28 days compared to normal concrete.

Shettima et al. [7] investigation revealed that incorporating IOT into the concrete mix raised the water requirement while decreasing the slump. This is thought to be influenced by the surface area and rough texture of the tailings. As a result, the workability of concrete containing IOT decreases as the amount of IOT increases. At all ages, concrete containing 25% IOT had consistently higher compressive strength than reference concrete.

Aissa Bouaissi et al. [8] investigations showed that the mechanical and microstructural features of FA-GGBS-HMNS-based geopolymer paste and concrete through experimental methods. Using GGBS and HNMS as partial replacements for FA affects compressive strength. The splitting tensile strength of mixed GP paste and GP concrete was assessed. Mixing GP paste and concrete with 70% FA, 20% GGBS, and 10% HNMS resulted in stronger mechanical qualities, including a compressive strength of 55.6 MPa and a splitting tensile strength of 4.57 MPa. Morphological and microstructural investigation revealed further crystalline phase occurrences. These minerals include magnesium, calcium, silicon, aluminum, and sodium. The XRD data revealed the development of C-S-H, C-A-S-H, and new gel phases, including magnesium vanadium molybdenum oxide and calcium beryllium praseodymium oxide. These phases are primarily supplied from GGBS and HMNS, respectively.

Oksri-Nelfia et al. [9] have studied that nickel slag powder (NSP) can be utilized as a substitute for OPC type 1 in concrete mixtures. It is expected to be used as an alternative construction material. The NSP with a size of 0.075 mm has finer characteristics and a lower water absorption rate than the OPC type 1. In general, the obtained affirmative results demonstrated that NSP may replace up to 20% of the cement in the concrete mixture without affecting the concrete's qualities, and it has a compressive strength of 30 MPa after 28 days. This nickel slag includes a high magnesium level, which was confirmed by XRF and SEM-EDS. However, it may need to undertake more studies of compressive strength at ages 56, 90, and 180 days to determine the pozzolanic activity of this material. Long-term conditions result in increased compressive strength compared to conventional concrete without NSP substitution.

III. MATERIALS AND ITS PROPERTIES

A. Materials

1) Fly ash

As a byproduct of the burning of the coal in the facilities plant's electronic precipitator, fly ash is produced. The combustible components of coal, such as carbon, hydrogen, oxygen, hydrocarbons, and non-combustible minerals impurities, chemically react and fuse at different stages in a power plant to produce crystalline molten ash. From the Rayalaseema Thermal Power Plant (RTPP) in Andhra Pradesh, fly ash has been collected. Fly ash has a 2.5 specific gravity.

2) GGBS

Ground granulated blast furnace slag (GGBS) is a byproduct of the iron-making blast furnace. These run at around 1500 degrees Celsius and are fed a precisely regulated mixture of iron ore that has been reduced to iron and the leftover elements from slag that floats on top of the iron. This slag is tapped off a molten liquid on a regular basis, and if it is to be employed in the production of GGBS, it must be swiftly quenched in increasing amounts of water. This quenching improves the cementitious characteristics and results in granules that resemble coarse sand. After drying, the granulated slag is crushed into a fine powder. It is also known as GGBS or slag cement. Specific gravity of GGBS is 2.8.

3) Fine Aggregate & Coarse Aggregate

Fine aggregate for the experimental program had been purchased locally and graded in compliance with IS: 383- 2016 [9]. Fine aggregate used in this work falls under zone ii as per the code. In this experiment, locally available coarse aggregate of the granite type of 20 mm down size were used. The results of laboratory tests on coarse aggregate that were carried out in accordance with IS: 2386 part (3)-1963 [10]. Properties of materials are shown in Table 1.

Table 1 Physical Properties of Coarse aggregate and Fine aggregate

S.No	Properties	Coarse Aggregate Values obtained	Fine Aggregate Values obtained
1	Type	Crushed	Uncrushed(natural)
2	Specific gravity	2.88	2.70
3	Fineness modulus	4.88	2.86

4) Iron Ore Tailings

Iron ore tailings are typically produced as a by-product of iron ore mining and processing. When ore is extracted from the earth, it is crushed and then separated from gangue minerals (unwanted and contaminants) using methods like grinding, magnetic separation and flotation. Iron ore tailings are left over waste materials, which contain a mixture of water and fine grained rock particles. Table 2. Physical properties of IOT.

Table 2. Physical properties of IOT

Properties	Results
1. Bulk density a) Loosely compacted b) Compacted	 1460.77 kg/m^3 1540.96 kg/m^3
2. Specific gravity	2.92
3. Fineness modulus	2.9
4. Water absorption	0.8

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5) High Magnesium Nickel Slag (HMNS)

High magnesium nickel slag is a by-product of nickel melting or refining processes. This slag is high in magnesium oxide (MgO). The composition and properties of high magnesium nickel slag vary depending on the nickel extraction procedure employed. Table 3 Physical properties of HMNS

Table 3. Physical properties of HMNS

Properties	Results
1. Specific gravity	2.6
2. Fineness modulus	3.0
3. Water absorption	1.1%

6) Alkaline Activator Solution

The alkaline activators like sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) has been used in this work and its ratio is 2.5.

7) Super Plasticizer

The superplasticizer in use is Conplast SP DIS. Conplast SP430 DIS, a brown liquid based on sulphonated naphthalene polymers, disperses quickly in water. Conplast SP430 DIS complies with ASTM-C-494 type "A" and type "G", IS: 9103, BS: 5075 and BS: 5075 depending on dosages. It has undergone rigorous development in order to produce high quality concrete with reduced permeability or to provide significant water savings without sacrificing workability. 1.20 is the specific gravity. According to BS: 5075 part 1, the chloride concentration is NIL.

IV. MIX PROPORTIONS

Mix proportions for GPC reference mix (M0) of 12 molarity was designed. It consists of 60% FA, 40% GGBS, NaOH, Na_2SiO_3, aggregates. Fine aggregate was replaced with iron ore tailings from 20% to 50%. After achieving optimum strength in above mix then high magnesium nickel slag (HMNS) was replaced with varying percentages 5, 7.5, 10 and 12.5. 2% of Super plasticizer (SP) used. Different mixes studied in this paper are shown in Table 4.

Table 4. Various mix proportions of GPC

Mixes Designation	Fly Ash kg/m^3	GGBS kg/m^3	Coarse Aggregate kg/m^3	Fine Aggregate kg/m^3	NaOH kg/m^3	Na_2SiO_3 kg/m^3	IOT kg/m^3	HMNS kg/m^3
M0 Reference mix	257.142	171.428	1080	720	48.98	122.45	-	-
M1 (20% of IOT)	257.142	171.428	1080	576	48.98	122.45	144	-
M2 (30% of IOT)	257.142	171.428	1080	504	48.98	122.45	216	-
M3 (40% of IOT)	257.142	171.428	1080	432	48.98	122.45	288	-
M4 (50% of IOT)	257.142	171.428	1080	360	48.98	122.45	360	-
M5 (30% of IOT + 5% of HMNS)	244.285	171.428	1080	504	48.98	122.45	216	12.85
M6 (30% of IOT + 7.5% of HMNS)	237.856	171.428	1080	504	48.98	122.45	216	19.28
M7 (30% of IOT + 10% of HMNS)	231.427	171.428	1080	504	48.98	122.45	216	25.71
M8 (30% of IOT + 12.5% of HMNS)	224.999	171.428	1080	504	48.98	122.45	216	32.14

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V. MECHANICAL PROPERTIES

To determine compressive strength, cube specimen of size 100mm x 100mm x 100mm, flexural strength, beams specimen of size 100mm x 100mm x 500mm and split tensile strength, cylinder of size 100mm x 200mm were cast and 28 days respective strength were analyzed. Results of compressive strength, flexural strength and split tensile strength of all mixes are shown in Table 5.

Mixes	Compressive strength	% Variation	Flexural strength	% Variation	Split tensile strength	% Variation
M0 (Reference mix)	42	-	5.15	-	4.11	-
M1 (20% of IOT)	77	83	7.17	39	5.72	39
M2 (30% of IOT)	80	90	7.43	44	6.21	51
M3 (40% of IOT)	74	76	7.29	41	5.84	42
M4 (50% of IOT)	53	26	5.65	9.7	5.03	22
M5 (30% of IOT + 5% of HMNS)	64	52	6.24	21	5.28	28
M6 (30% of IOT + 7.5% of HMNS)	66	57	6.27	22	5.43	32
M7 (30% of IOT + 10% of HMNS)	61	45	6.03	17	5.19	26
M8 (30% of IOT + 12.5% of HMNS)	57	35	5.95	16	5.10	24

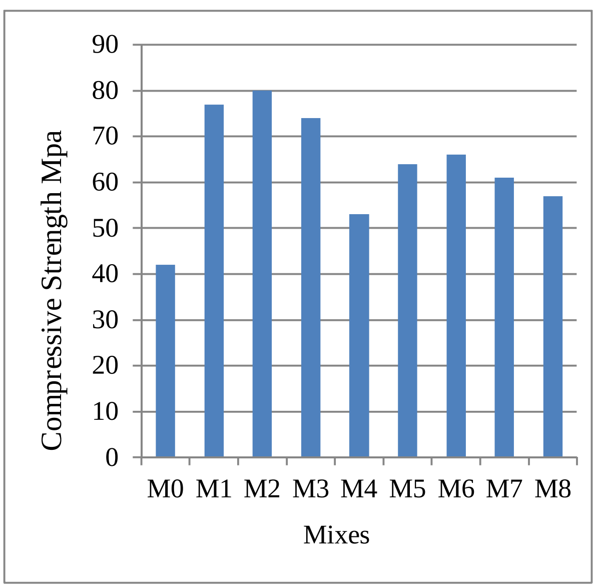

Figure 1. Compressive strength

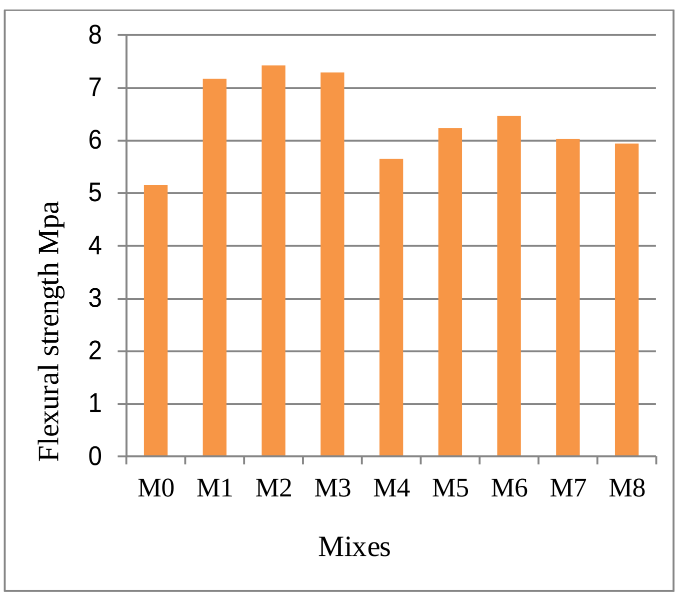

Figure 2. Flexural strength

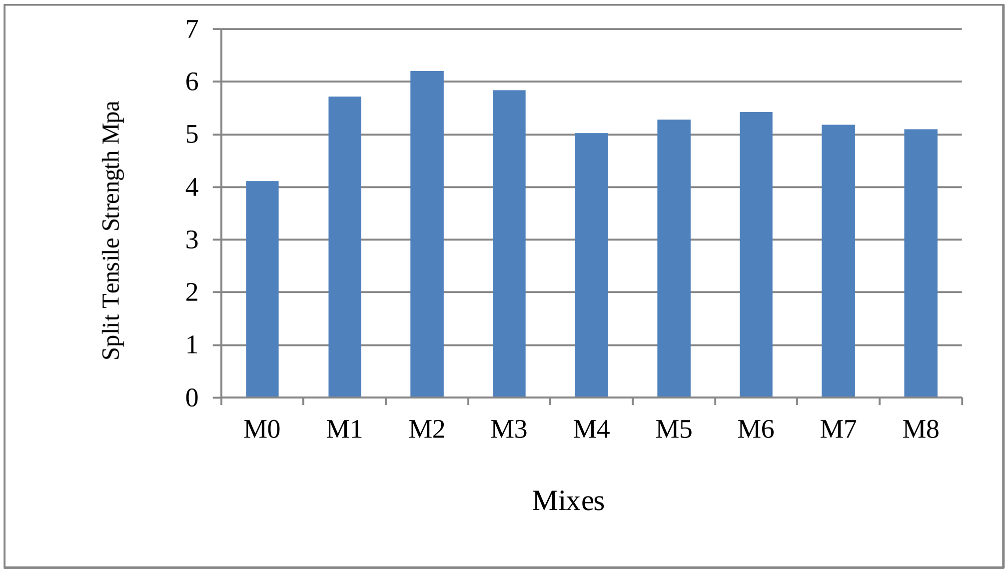

Figure 3 Split Tensile Strength

VI. CONCLUSIONS

The experimental investigation undertaken during the study led to the following conclusions:

1) In this present study, fine aggregate was replaced by IOT at different percentages from 20% to 50% in GPC (Fly ash & GGBS) of 12M. It was observed that optimum strength properties are obtained at 30% IOT replacement. At 30% IOT replacement compressive strength, flexural and split tensile strength are 80 Mpa, 7.43 Mpa and 6.21 Mpa and have been increased by 90%, 44% and 51% respectively over reference mix (M0).
2) After getting optimum strength then fly ash was replaced partially by HMNS at different percentages from 5 to 12.5 in GPC. It was observed that maximum strength properties obtained at 7.5% HMNS replacement in flyash. At 7.5% HMNS replacement compressive strength, flexural strength and split tensile strength are 66 Mpa, 6.27 Mpa and 5.43 Mpa and have been decreased by increased by 17.5%, 15.61% and 12.5% over reference mix (M0).
3) In this study, maximum strength attained at 30% replacement of IOT and strength goes on decrease with the increase in IOT up to 50%. After the replacement of HMNS in fly ash, the optimum strength attained at 7.5% replacement. This reveals that the strength increases when fine aggregate was replaced with IOT and later on strength decreases with partial replacement of HMNS in fly ash. Mixes with IOT and HMNS, compressive strengths are higher than that of reference mix.

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