Experimental study of low carbon emission alternative concrete

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Abstract. Urbanization and mass construction of housing will increase the consumption of cement and available natural resources such as sand and water. The production of cement generated from various industries leads to the emission of carbon dioxide gas in huge quantities into the atmosphere and creates serious problems in handling and disposal. So, the replacement of conventional materials with alternative materials for the preparation of concrete is needed. If the alternative cementitious and industrial waste materials are found suitable in replacing the ingredients of concrete then it can reduce the cost of construction. The present paper represents an experimental study of low carbon emission alternative concrete by replacing conventional concrete materials with alternative materials like geopolymer as binding material, copper and ferrous slag as fine aggregates, steel slag as coarse aggregates, and alkaline solution as an activator. Study made to examine the properties of low carbon emission alternative concrete proposed. The fresh and hardened state characteristics of low carbon emission alternative concrete are evaluated for both oven and ambient curing conditions. It is noticed that the time taken to achieve the strength by oven curing is less than ambient curing but had no major difference in load-carrying capacity and the results obtained are in good concurrence with conventional concrete.

Keywords: Geopolymers, copper slag, ferrous slag, steel slag, alkaline solution.

1. Introduction
Low carbon emission alternative concrete (LCEAC) is strong for the structural purpose of building components, which truncate the self-weight of structure. Moreover, it can also reduce deflections of individual structural components and improve stability at foundations. The present paper completely avoids the utilization of normal cement, natural sand in making the concrete. To reduce the self-weight of the structure, normal-weight aggregates and natural sand is replaced with light weight aggregates which improve fire resistance as well as noise absorption. Alkaline solutions were used for reaction in geopolymer concrete. Several solutions were prepared to estimate the rate of reaction [1]. The alkaline liquid which contains soluble silicates was proved to increase the rate of reaction compared to alkaline solutions that contain the only hydroxide [2]. It was observed that, for every one ton of copper production, 2.2 tons of copper slag has produced as waste. The copper slag can replace the aggregates without affecting the mechanical properties of concrete [3-4]. The experimental study carried out at CRRI, New Delhi has mentioned that up to 40% of copper slag increases 20% of flexural strength than conventional concrete [5]. The replacement of natural aggregates with steel slag in geopolymer concrete will significantly improve abrasion resistance [6]. The strength and durability characteristics of high-strength concrete is enhanced without affecting the property of workability with copper slag [7]. Study on microstructural characteristics of a class c fly ash geopolymer (CFAG) improves the characteristics of concrete by activating class c fly ash with NaOH solution [8]. The addition of reinforcement in geopolymer concrete will provide better results for precast concrete components which can be used in infrastructure developments [9]. The suitable mix design [9] for low carbon emission alternative concrete was obtained after testing many cubes. The proportions
obtained for Low carbon emission alternative concrete is represented. The water absorption rate decreases as copper slag increase up to 50%, beyond which surface water absorption increases. From experiments, it is suggested that 40% to 50% replacement of copper slag or iron slag improves strength and ductility [10-11]. The strength of the concrete increases at an early age. However, at a higher age, supplanting copper slag as fine aggregate is limited to 50% to improve strength characteristics [12]. The strength of wet mixed geopolymer concrete is enhanced with cementitious materials content [13], when the sand and the liquid-solid ratio remain constant. The torsion capacity, torsional resistance, and ductility of hybrid high-strength reinforced concrete beams can be improved [14] by adding pozzolanic and coal fly ash-based geopolymer. Alkaline ratio ranges between 0.2 to 0.3 reduces workability, compressive, and split tensile strength [15]. Moreover, the alkaline ratio of 0.4 increases workability. The specimens should be cured instantly by either oven or ambient curing. For oven curing, 60 to 100 degrees centigrade was maintained in oven for different specimens at different time periods varying from 6 hours to 48 hours.

| Material            | Mass (Kg/m³) | Proportions |
|---------------------|--------------|-------------|
| Binder content      | 450          | 1           |
| Fine aggregates     | 700          | 1.5         |
| Coarse aggregate    | 1050         | 2.3         |
| Alkaline solution   | 300          | 0.6         |
| Super plasticizer   | 4.5          | 0.01        |

2. Material properties

2.1. Geopolymer

The use of source materials depends on cost, application and availability. The alkaline liquid used for geopolymerization requires NaOH and sodium silicate. The water expelled during chemical reaction from the geopolymer matrix leaves behind discontinuous nano-pores in the matrix, which provide benefits to the performance of geopolymers. The water in a geopolymer mixture, therefore, plays no role in the chemical reaction. The specific gravity in accordance with IS:4031 (part 11) 1988 and fineness in accordance with IS:4031 (part 1) 1996 of geopolymer cement obtained are 2.46 and 5% respectively. The initial and final setting time in accordance with IS:4031 (part 5) 1988 obtained are 15 min and 100 min respectively. The geopolymer used for LCEAC is shown in figure 1.

2.2. Copper slag and ferrous slag

The addition of copper and ferrous slag in concrete is restricted for the strength characteristics. Excessive usage of copper and ferrous slag effects compressive strength of concrete and hence increases deflections. The fineness modulus, water absorption and specific gravity of copper slag obtained are 3.15, 1% and 3.2 respectively. The properties obtained for ferrous slag are similar to copper slag.
2.3. **Steel slag**

The addition of copper and ferrous slag in concrete should be limited to maintain the strength characteristics. Excessive usage of steel slag affects strength of concrete and the failure will occur by crushing of aggregates in concrete. The water absorption and specific gravity of steel slag obtained are 3% and 2.1 respectively.

![Figure 2. Copper Slag](image1)

![Figure 3. Ferrous Slag](image2)

![Figure 4. Steel Slag](image3)

2.4. **Alkaline solution**

The sodium silicate solution A53 with SiO$_2$ to Na$_2$O ratio by mass approximately 2, (Na$_2$O = 14.7%, SiO$_2$=29.4%, and water 55.9% by mass) was used. The sodium with 97-98% purity, in flake or pellet form, was used. The solids must be dissolved in water to make a solution with the required concentration. The sodium silicate to NaOH solution by mass was fixed as 2.

3. **Results and Discussions**

The different LCEAC specimens was casted by maintaining steel slag as constant and copper and ferrous slag as variables. The following graph 1 and graph 2, mention the results of mechanical properties for 30 % steel slag which is constant for all specimens. Moreover, proportions of copper along with ferrous slag were added as fine aggregate shown in graph 1 and graph 2.
Graph 1. Compression Strength of Ambient and Oven Cured Low Carbon Emission Alternative Concrete with 30% Steel slag as Coarse Aggregates.

Graph 2. Split Tensile Strength of Ambient and Oven Cured Low Carbon Emission Alternative Concrete with 30% Steel slag as Coarse Aggregates.

The following graph 3 and graph 4, mention the results for 40% steel slag which is constant for all specimens. Moreover, proportions of copper along with ferrous slag were added as fine aggregate shown in graph 3 and graph 4.
Graph 3. Compression Strength of Ambient and Oven Cured Low Carbon Emission Alternative Concrete with 40% Steel slag as Coarse Aggregates.

Graph 4. Split Tensile Strength of Ambient and Oven Cured Low Carbon Emission Alternative Concrete with 40% Steel slag as Coarse Aggregates.

The following graph 5 and graph 6, mention the results for 50% steel slag which is constant for all specimens. Moreover, proportions of copper along with ferrous slag were added as fine aggregate shown in graph 5 and graph 6.
Graph 5. Compression Strength of Ambient and Oven Cured Low Carbon Emission Alternative Concrete with 50% Steel slag as Coarse Aggregates.

Graph 6. Split Tensile Strength of Ambient and Oven Cured Low Carbon Emission Alternative Concrete with 50% Steel slag as Coarse Aggregates.

4. Conclusions

1. The temperature and method of curing influence the strength of low carbon emission concrete. The concrete with 50% copper slag and 50% ferrous slag achieves a maximum compression strength of 45.333 MPa and split tensile strength of 4.181 MPa for a period of 48hr in a hot air oven. Moreover, the compressive and split tensile strength achieved with ambient curing for a period of 28 days are 49.33 MPa and 4.45 MPa respectively. It is observed that, the strength achieved with ambient curing for a period of 28 days is similar to that of strength achieved with oven curing for a period of 48hr. Therefore, 28 days strength can be achieved within 48 hours with the help of oven curing.
2. The copper and ferrous slag percentages greatly influence the strength of low carbon emission alternative concrete. The strength of concrete with 25% copper slag & 75% ferrous slag achieves a maximum compression and split strength are 54.666 N/mm² and 4.969 N/mm² respectively for a curing period of 48 hours in oven. Moreover, the compression and split tensile strength of concrete reduced to 40.666 N/mm² and 3.727 N/mm² with 75% copper slag and 25% ferrous slag. The strength increases with increases in the percentage of ferrous slag in the concrete but in limited quantity which depends on copper slag.

3. The strength of concrete with 25% copper slag and & 75% ferrous slag achieves a maximum compression and split tensile strength are 52.888 N/mm² and 4.727 N/mm² respectively for a curing period of 28 days. Concrete with 75% copper slag and 25% ferrous slag reduces compression strength to 41.333 N/mm² and split tensile strength to 3.818 N/mm².

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