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# OPTIMUM DOSAGE OF GGBFS, BROKEN CERAMIC TILES AND COPPER SLAG IN THE PRODUCTION OF SUSTAINABLE CONCRETE

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**Abstract -** *One of the most widely used methods for analyzing the environmental impacts of the production and use of concrete, as well as the components derived from it, is the carbon footprint, which describes the value of carbon dioxide and other greenhouse gases affiliated with this product, demonstrated as $CO_2$ equivalents. Using a life cycle analysis methodological approach, the carbon footprint was used in this work. Concrete made with GGBFS, broken ceramic tiles, and copper slag. Carbon dioxide equivalent emissions decreased, as expected, as the use of GGBFS, broken ceramic tiles, and copper slag increased. This study presents an effort to evaluate the economic and environmental performance of concrete with GGBFS, broken ceramic tiles, copper slag replacement with and without. First, the essential mechanical properties (compressive strength and split tensile strength) of concrete mixes incorporating different amounts of GGBFS (30% replacement of binder), broken ceramic tiles (10%, 15%, and 20% replacement of coarse aggregate), and copper slag were evaluated (40%, 50%, 60% replacement of fine aggregate). The mechanical properties of the concrete were then tested to determine its strength. Finally, the carbon emissions of each mix were calculated using the LCA. Compressive and split tensile testing results revealed that concretes with varying percentages of replacement can outperform conventional plain concrete. The analysis revealed that the proposed concrete has significant environmental benefits. In comparison to other ratios and conventional concrete, the 50% copper slag and 10% ceramic ratio provides maximum strength while emitting the least amount of carbon.*

***Key Words***: GGBFS, Broken Ceramic Tiles, Copper Slag.

***Abbreviations***: *GGBFS = Ground Granulated Blast Furnace Slag, ECF = Embodied Carbon Factor.*

## 1.INTRODUCTION

Concrete, a most widely used building substance in the world, necessitates a significant amount of energy, especially when raw materials are used. Furthermore, the widespread use of OPC has resulted in significant $CO_2$ emissions into the atmosphere. One tonne of OPC requires approximately 2.5 tonnes of materials and produces approximately one tonne of $CO_2$. OPC production generates approximately 135 crore tons of $CO_2$ per year, causing around 5-7% of the world's $CO_2$ emissions. As a result, it is suggested that a material substitute for the cement be developed in order to reduce $CO_2$ emissions.

For decreasing the carbon dioxide from environment which is produce from concrete production and Several studies investigated the possibility of substituting OPC with SCM derived from industrial by-products, such as GGBFS and natural coarse aggregates replacing with alternative material used in this project are copper slag, waste ceramic tiles and calculating the carbon footprint after replacing these materials GGBFS is a cement by-product of steel blast furnaces that is frequently used in concrete work.

Copper slag is produced as a by-product during the copper manufacturing process.

Ceramic tiles having a sloping edge rather than squared one and are thin, flat tiles. These tiles are used for a variety of applications, including lining and covering, and they aid in thermal protection. Ceramic tiles come in a variety of shapes, sizes, and colours.

Embodied carbon is the result of all the tasks involved in the construction and deconstruction of a building. It is the total life cycle carbon footprint minus the operational carbon foot print. According to the IGT report, $CO_2$ emissions occur throughout the life cycle of a building, from preliminary concept to repair and maintenance or eventual demolition These emission levels can be quantitated in order to calculate a building's carbon life cycle footprint, that can then be used to design an efficient reduction strategy [11]. According to Innovation and Growth Team (IGT), the stages of a building project's carbon life cycle emissions are as follows:

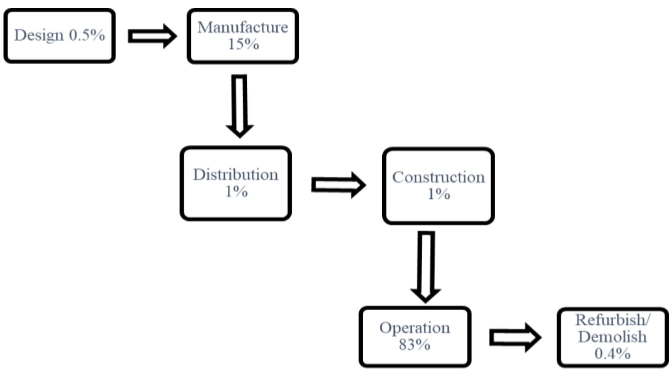



**Fig – 1:** Flow chart of carbon emission

## 2. OBJECTIVES

The present work attention at the study of following objectives: -

1. To determine the optimum dosage of GGBFS, broken ceramic tiles and copper slag to attain maximum strength properties.
2. To determine the carbon footprint of optimum dosage of concrete.
3. To compare the environment impact of modified and conventional concrete.

## 3. METHODOLOGY

In this section, a framework is provided for the experimental investigation. This included a practice system, which had the materials used, testing methods, and other procedures used to carry out the research. With different material ratios, the current work determined the engineering properties of concrete such as split tensile response, compression, and carbon footprint. More information and data about M25 grade mix concrete design, materials, and testing procedures are described

**Table -1:** Mix proportion Ratio

| Cement: Sand: Coarse Aggregates | W/C |
|---|---|
| 1: 1.546: 3.188 | 0.48 |

**Table -2:** Quantity of Material as Per Mix Design

| Group | S No. | Binder | | Fine Aggregates | | Coarse Aggregates | |
|---|---|---|---|---|---|---|---|
| | | Cement | GGBFS | Sand | Copper slag | Natural CA | Broken Ceramic Tiles |
| A | 1. | 70% | 30% | 60% | 40% | 90% | 10% |
| | 2. | 70% | 30% | 60% | 40% | 85% | 15% |
| | 3. | 70% | 30% | 60% | 40% | 80% | 20% |
| B | 4. | 70% | 30% | 50% | 50% | 90% | 10% |
| | 5. | 70% | 30% | 50% | 50% | 85% | 15% |
| | 6. | 70% | 30% | 50% | 50% | 80% | 20% |
| C | 7. | 70% | 30% | 40% | 60% | 90% | 10% |
| | 8. | 70% | 30% | 40% | 60% | 85% | 15% |
| | 9. | 70% | 30% | 40% | 60% | 80% | 20% |

### 3.1 Mixing, Casting and Curing of Specimens

#### 3.1.1 Mixing

An electrically drum operated mixer was used to mix the concrete. Water was sprayed inside the drum to provide moisture. The mixer was first filled with coarse sediments and broken ceramic tiles than it was rotated to ensure that the components were mixed evenly. After that, sand and copper slag were completely mixed into the mixture. To get a uniform dry mix, the dry mix was rotated for 2-3 minutes after adding cement and GGBFS. To obtain a workable concrete, the needed amount of water was added to the dry mix and the mixture was thoroughly rotated to get a workable concrete.

**Fig – 2:** Drum Mixer

#### 3.1.2 Casting

The required number of specimens for various tests were cast. For M25 grade concrete, 6 specimens (three in each sample) of conventional concrete and modified concrete were cast to conduct compressive strength and split tensile tests (consisting of copper slag, GGBFS, and broken ceramic tiles). Similarly, same casted specimens will be evaluated for carbon footprint.

**Fig – 3:** Casting of Specimens

### 3.1.3 Curing

After 24 hours of casting the specimens were taken out from the molds and placed in a curing tank for the next 28 days. Because cement requires water for complete hydration, curing was done using tap water.

**Fig – 4:** Curing of Specimens

### Preparation of Specimens for Compressive Strength Test

After proper curing, the specimens were removed from the water and dried in a laboratory at room temperature. Following proper drying, a compression test was performed on a Compression Testing Machine.

The Compressive strength of the test specimen was calculated from the equation

= P/A

Here, P = Peak load (N)

A = Area of the cube (mm)

### Preparation of Specimens for Split tensile Strength Test

Similarly for split tensile, after proper curing, the specimen was removed from the water and dried in a laboratory at room temperature. Following proper drying, a split tensile test was performed on a Compression Testing Machine (CTM).

The split tensile strength of the test specimen was calculated from the equation

$$T = \frac{2P}{\pi Ld}$$

Here, T = Split tensile strength (N/mm$^2$)

P = Peak load (N)

L = Length of the cylinder (mm)

d = diameter of the cylinder (mm)

### 3.2 Methodology to Calculate Embodied Carbon of materials

Step-1. LCA was used to established the amount of carbon emissions per unit of given material.

Embodied carbon of concrete blocks = Quantity of concrete blocks * Embodied carbon conversions factors of concretes in one block.

Life cycle modules A1 to A5

A1 = Raw material supply

A2 = Transport

A3 = Manufacturing

A4 = Transport

A5 = Construction installation process

A1 to A3 carbon factor ECFA13

**Table -3: Suggested Embodied carbon factor (ECF3) of common construction materials**

| S. No. | Material | Type | Specifications / Details | A1- A3 ECF kg $CO_{2e}$/kg |
|---|---|---|---|---|
| 1. | Concrete | In situ piling, substructure, superstructure | Unreinforced, $C_{30/37}$, UK average ready mixed concrete EPD (35% cement replacement) | 0.013 |
| | | | Unreinforced, $C_{32/40}$, (25% GGBFS cement replacement) | 0.120 |
| | | | Unreinforced, $C_{32/40}$ (50% GGBFS cement replacement) | 0.089 |
| 2. | Steel | Reinforcements Rebars | UK: -UK cares sectors average EPD | 0.76 |
| | | | World Wide: - World steels | 1.99 |
| | | Structural sections | hollow sections: - TATA EPD | 2.50 |
| 3. | Stone | Granite | Granite | 0.70 |
| | | Limestone | Limestone | 0.09 |

| | | | | |
|---|---|---|---|---|
| | s | Sandstone | Sandstone | 0.06 |
| 4. | Timber, carbon sequestration | Manufactured Structural Timber | CLT 100%, FSC/PEFC | 0.437 |
| | | | Glulam, 100% FSC/PEFC | 0.512 |
| | | Stud Work / Framing Flooring | Soft wood 100% FSC/PEFC | 0.263 |
| | | Form work | Ply wood 100% FSC/PEFC | 0.681 |
| 5. | Aluminium | Sheet | European consumption | 6.58 |

Step-2 Selection of Transport Mode and Distance

In this section A4 is concerned with transport of materials or products from the factory gate to the construction site, and the transport of construction equipment (cranes, scaffolding, etc.) and from the site. Remember that some journeys comprise multiple legs over different transport modes. We need to include the whole journey in our calculations. Reuse of components, materials or products that are locally sourced and transported over short distances will help to reduce both Module A4 and overall project emissions.

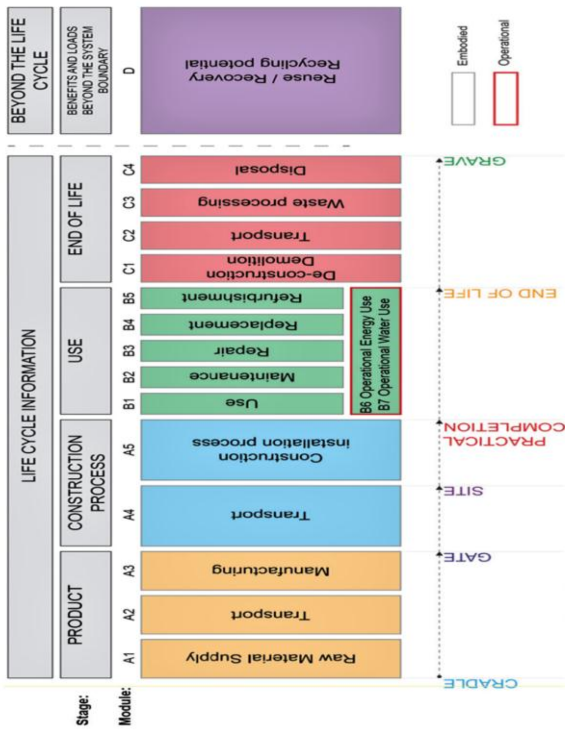



**Fig – 5:** Life Cycle Stages

**Table -4: Selection of transport mode**

| Mode | TEF mode (g $Co_{2e}$ /kg/km) |
|---|---|
| Road emission, average | 0.10650 |
| Road emission, full | 0.07524 |
| Sea emission | 0.01614 |
| Flight emission | 0.59943 |
| Rail emission | 0.02556 |

**Table -5: Selection of transport distance**

| A4 transport | km by road | km by sea |
|---|---|---|
| Locally manufactured | 50 | - |
| Nationally manufactured | 300 | - |
| European manufactured | 1500 | - |
| Globally manufactured | 200 | 10000 |

The carbon factors for transportation of each material are calculated by multiplying the transportation distances by the respective transportation modes emissions factors.

ECF A4,i =∑mode(TD mode*TEF mode)

TD mode = Transport Distance

TEF mode = Transport mode emission factor

Transportation embodied carbon factors (ECFA4,i) for each material will not be known until the project is completed and the material transportation modes and distances have been recorded. In the absence of precise information, the information that follows can be used to estimate ECFA4,i.

Transport emissions factors (TEF) can be estimated using transport emissions.

Step-3 Construction Installation Emission

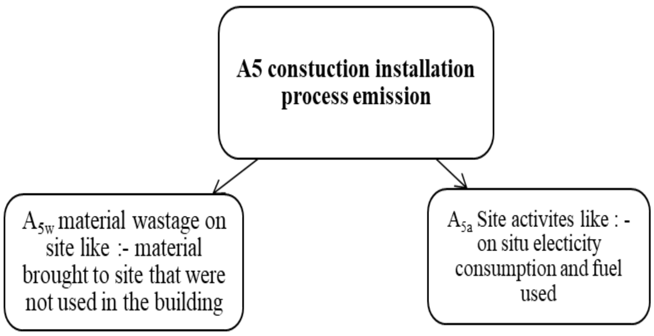



**Fig – 6: Construction Installation Emission**

A5W = Life cycle emissions of material wasted

ECFA5w,i = WFi * ( EFCA13,i +ECFA4,i +ECFc2,i +ECFc34,i)

**Table -6: Selection of material waste on site**

| S. No. | Material/ Products | $W_{Ri}$ (wastage rate) | Wrap net wastage tool | Waste factor |
|---|---|---|---|---|
| 1. | Concrete in situ | 5% | Concrete in situ | 0.053 |
| 2. | Mortar | 5% | Gypsum products | 0.053 |
| 3. | Screed | 5% | Screed | 0.053 |
| 4. | Concrete Precast (Beams and frames) | 1% | Concrete precast (large precast elements) | 0.010 |
| 5. | Steel reinforcement | 5% | Appendix 1 frame in situ concrete frame generic (Ferrous metal) | 0.053 |

**Table -7: Selection of distance transportation of waste material**

| S.No. | EOL scenario | km by road | $ECF_{C2i}$ ($kgCO_{2e}/kg$) |
|---|---|---|---|
| 1. | Reuse/recycle on site | 0 | 0.00 |
| 2. | Reuse/recycle else where | 50 | 0.005 |
| 3. | Land fill/inclination | mean b/w closet land fill rate | 0.005 |

$ECF_{C34,i} = 0.013\ kgCO_{2e}/kg$ Waste

$ECF_{D,I} = ECF_{A13,\ secondary\ product} - ECF_{A13,substituted\ product}$

Step-4 Calculations

$A_1$-$A_5$

Embodied carbon for recycle modules

$$EC_{A15} = \sum_{i=1}^{n} [Qi_{(ECF_{A13,i}+ECF_{A4,i}+ECF_{A5w,i})}]+EC_{A5a}$$

i = 1 sum for material 1 to n

Qi = quantity of I material (kg) obtain from calculation

$ECF_{A13,I}$ = embodied carbon factor modules $A_1 - A_3$ for the material ($kg\ CO_{2e}/kg$)

$ECF_{A4,i}$ = embodied carbon factor for transport (module $A_4$)of the material ($kg\ CO_{2e}/kg$)

$$= \sum_{mode} (TDmode * TEFmode)$$

TD transport distance (in km)

TEF transport emission factor in ($g\ CO_{2e}/km$)

$ECF_{A5w,i} = WF*(ECF_{A13,i}+ECF_{A4,i}+ECF_{C2,i})$

WF = waste factor

V = volume of material and WR = waste ratio as estimate the wrap UK net waste tool

$ECF_{2,I}$ = Transport from site (calculate $ECF_{Mi}$)

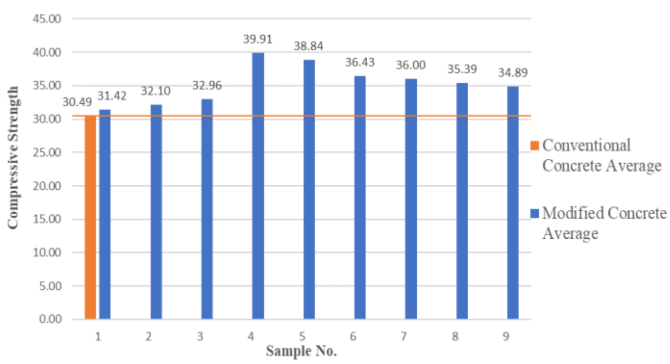
**Table -8: ECF of Material Used in Modified Concrete**

| Materials | ECF $kgCO_{2e}/kg$. |
|---|---|
| OPC Cement | 0.820 |
| GGBFS | 0.143 |
| Copper Slag | 0.007 |
| Broken ceramic tiles | 0.237 |
| Coarse aggregates | 0.046 |
| Fine aggregates | 0.014 |
| Water | 0.540 |

## 4. RESULTS

The results obtained from different tests of distinct specimens are reported and discussed. All test results are displayed followed by a discussion.

### 1. Results for Compressive Strength




**Graph – 1:** Comparison of Compressive Strength between Conventional Concrete and Modified Concrete

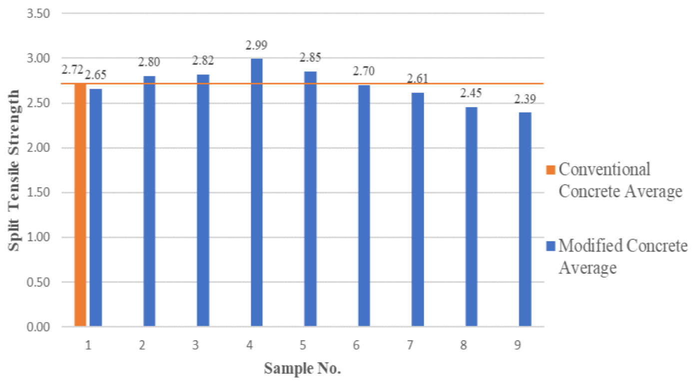
When fine aggregate was replaced with copper slag up to 50% and coarse aggregate were replaced with broken ceramic tiles up to 10%, compressive strength of the modified concrete is maximum when compared to all other specimens. After 50% copper and 10% ceramic, at this point when further increased in replacement of percentage the reduction of compressive strength was seen. As per test result, the maximum strength obtained due to better interaction transition zone with combination of copper slag, broken ceramic tiles, GGBFS and cement, which was performing higher as compare to natural aggregates.

## 2. Results for Split Tensile Strength

1. With the inclusion of copper slag and broken ceramic tiles, increment of split tensile strength of concrete was seen.

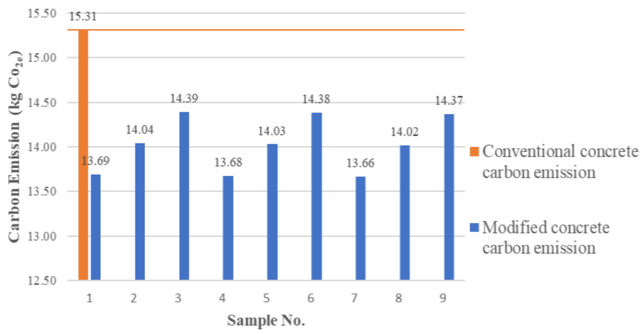
2. The maximum split tensile strength was obtained when 50% of fine aggregates was substituted with copper slag and 10% of coarse aggregates was substituted with broken ceramic tiles.

3. The highest split tensile strength was approximately 9.92% greater, when compared to the conventional concrete. This increase in tensile strength is attributed to the better interlocking between ceramic particles with cement and GGBFS mixture.




**Graph – 2:** Comparison of Split Tensile Strength between Conventional Concrete and Modified Concrete

## 3. Results for Embodied Carbon Footprint




**Graph – 3:** Comparison of Embodied Carbon (kgCo$_{2e}$) between Conventional Concrete and Modified Concrete

The huge difference was seen between the performance of conventional and modified concrete. The modified concrete produced low carbon emission as compare to conventional concrete. This happens due to the reuse of waste and by-product material (GGBFS, broken ceramic tiles and copper slag). As the percentage of the broken ceramic tiles were increased, the amount of carbon emission was increased and usage of copper slag in concrete decreases the carbon emission. This happened because of the various activities involved in the usage process of broken ceramic tiles as coarse aggregates. Activities like transportation of broken ceramic tiles to the site, where these are to be used, disintegration process of tiles to the required size of aggregates, increases the carbon emission.

## 5. CONCLUSIONS

Based on the experimental results, the following specific conclusions are drawn for the current work:

1. It is determined that 50% copper slag and 10% ceramic tiles ratio of modified concrete gives the optimum strength in compression and split tensile both.

2. It is concluded that increasing the ratio of copper slag in the modified concrete mixtures reduces $CO_2$ emissions, stating that the use of this material has an impact on the reduction of the carbon footprint in the concrete production process.

3. After comparing the modified concrete with conventional concrete, it is concluded that the modified concrete is more environment friendly because carbon emission is less as compare to conventional.

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