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# Experimental Investigation on the Properties of Concrete Containing Waste HDPE Plastic and Copper Slag as Coarse and Fine Aggregates Replacement

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**Abstract**

*Resource concerns have become apparent globally, particularly in the construction sector due to the exploitation of resources for developing globalized infrastructures. This has led to challenges, especially in sourcing construction materials. Consequently, numerous studies have focused on waste management strategies with eco-efficient parameters, particularly in the realm of construction aggregates. While previous research has explored alternatives for these aggregates, there remains ample opportunity for further investigation on the effectiveness and potential of alternative materials in construction projects to promote sustainable resource management. The research aims to fill this gap by examining the impact of using alternatives for both fine and coarse aggregates, specifically copper slag and waste HDPE. This study investigates the effects of partially incorporating waste HDPE plastic and Copper slag on the strength and sustainability of concrete, with the goal of evaluating their viability as sustainable alternatives in construction materials in the construction sector. Three percentages of High-Density Polyethylene (HDPE) Plastic (10%, 20%, and 30%) and Two Percentages (30% and 40 %) of copper slag were incorporated with the weight of Coarse aggregate and Fine aggregate respectively. Comparisons of conventional concrete with concrete incorporating HDPE waste & copper slag as coarse aggregate and fine aggregates were conducted. From investigation it was found that concrete incorporating 10% of HDPE and 40% of copper slag cured for 7 and 28 days had 10% increase in compressive strength compared to the nominal mix and flexural strength 25% and 40% more than nominal mix. The concrete incorporating 10% of HDPE and 30% of copper slag had 18% reduction in split tensile strength for cylinders cured for 7 days and 55% increase in split tensile strength for cylinders cured for 28 days.*

## 1. Introduction

As landfill sites are increasingly becoming overcrowded and costly for waste disposal, it's crucial to reduce the amount of waste sent to these sites. When waste production cannot be avoided, finding alternative uses for it in different processes is beneficial. Recycling provides economic advantages by lowering waste removal costs and decreasing pollution and contamination. (A. M.

Mustafa Al Bakri et al., 2011) Globally, 2.01 billion tons of MSW are produced yearly, with much dumped unsustainably. Only 19% is recycled, and plastics account for 12% of MSW. With urbanization, MSW generation will rise to 3.40 billion tons by 2050. (Sonali Abeysinghe et al., 2021) Plastic is lightweight and versatile, making it popular. Global consumption of plastic rose from 335 million tons in 2016 to 348 million tons in 2017 and is expected to reach 485 million tons by 2030. (Tamarin and Juli Nurdiana., 2021) Plastic waste is a major environmental problem due to its long decomposition time. It can take over 50 years to decompose and can last up to 1000 years in landfills. (Milad M. Radhi et al., 2022) India's official plastic waste generation estimate for 2020/2021 was 4 million metric tons, but other estimates suggest it could be up to four times higher. In 2019, the OECD projected India's annual plastic waste production at over 18 million metric tons. (Statista.com) To address plastic waste and reduce landfill use, it's crucial to identify opportunities within value chains. Investing in a circular system for managing plastic pollution can provide social and environmental benefits. To manage large volumes of plastic waste and rising aggregate demand, using plastic in concrete is practical. Plastic aggregates, with their durable crystalline structure, resist crushing and chemical degradation, providing a valuable alternative to constant recycling in construction. (Anju Ramesan et al., 2015) On the other hand, Copper slag is a smooth, glassy by-product of copper production. It contains iron, copper, and oxides like $SiO_2$, $Al_2O_3$, CaO, and MgO. (Caijun Shi et al., 2008) For every ton of copper produced, approximately 2.2 tons of slag are created, resulting in an estimated global annual production of about 24.6 million tons of copper slag. (Abhishek Maharishi et al., 2020) Mining sand can severely harm the environment. Excavation and removal of sand deposits disrupt landscapes, create dust, and destroy natural habitats. Extracting sand from rivers requires environmental studies and restoration efforts, which often prove ineffective. (M.A.G. dos Anjos et al., 2016) The construction industry is a major consumer of waste materials and offers a promising market for recycling. Using industrial waste like Copper Slag in concrete can improve its compressive strength, corrosion resistance, and reduce the need for natural resources. This aligns with sustainable development goals by promoting waste reuse and resource conservation. (Ruijun Wang et al., 2021). Numerous studies have explored using waste materials, particularly as aggregates, in construction. For example, (J. Vijayaraghavan et al., 2017) studied the mechanical properties of concrete with partial replacement of fine and coarse aggregates by copper slag, iron slag and recycled concrete aggregate. The study revealed that the partial replacement of Fine and coarse aggregates by 40% of copper slag 40% of iron slag and 25% of RCA provides the better mechanical properties compared to the nominal concrete. (Abhishek Maharishi et al., 2020) Explored the mechanical properties of concrete incorporating the copper slag as partial replacement of fine aggregate. Here the fine aggregate was replaced by 20%, 40%, 60%, 80% and 100% of copper slag. The study revealed that mechanical properties of concrete decreased beyond 40% incorporation of copper slag. (Syed Nasir Abbas et al., 2024) Investigated the Mechanical properties of concrete when incorporated with HDPE, silica fume, macro synthetic fibers and steel fibers. HDPE was incorporated at volumetric ratios of 10%, 20% and 50% and cement with 20% silica fume. The study revealed that mechanical properties of concrete with 30% HDPE, 0.75 % macro synthetic fibers and 1 % silica fume, had better results when compared with other mixes. And the workability of concrete increases with the addition of HDPE aggregates alone and decreased when fibers were added. (Safeer Ullah et al., 2021) Investigated the use of waste plastic aggregates (LDPE and HDPE) as a partial replacement for natural aggregates in asphalt mixtures. Results showed that incorporating plastic waste reduced the density of the asphalt mixture due to increased air voids. While stability and flow values improved up to 15% plastic replacement, rutting resistance was highest with 25% LDPE. HDPE replacement led to a significant increase in resilient modulus and dynamic modulus. However, dynamic modulus decreased with increasing frequency for all samples. From the literature study it was found that many studies have revealed the mechanical properties & workability of concrete incorporating copper slag and HDPE separately. But there is no study on the combination of both copper slag and HDPE as partial replacement of fine and coarse aggregates. So, a feasibility study can be conducted to evaluate the performance of concrete incorporating both copper slag and waste HDPE as partial replacement of Fine and Coarse aggregate.

## 2. Experimental Properties

### 2.1 Materials

#### 2.1.1 Copper Slag

Copper slag is a by-product during copper smelting and refining process (Figure 1). The copper slag has a black and glassy appearance with a specific gravity of 3.63 and the fineness modulus of 3.2. It was collected from Astra labs, Tuticorin, Tamil Nadu. The chemical and physical properties of copper slag are shown in Table 1 & 2. The particle size distribution of copper slag is shown in Fig 6. The Fig 2 and Fig 3 shows the SEM images and EDAX analysis of copper slag. From the SEM images it can be seen that copper slag has the appearance of the hard matrix with irregular particle shapes with varying sizes.

**Figure 1** Copper Slag

Some of the particles appear spherical, while others have more angular shapes. And from EDAX analysis it can be seen that copper slag has highest amount of iron content with reasonable quantity of Silica.

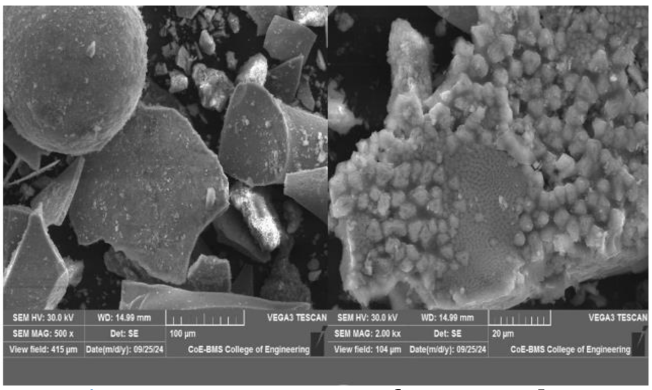

**Figure 2** SEM Images of Copper Slag

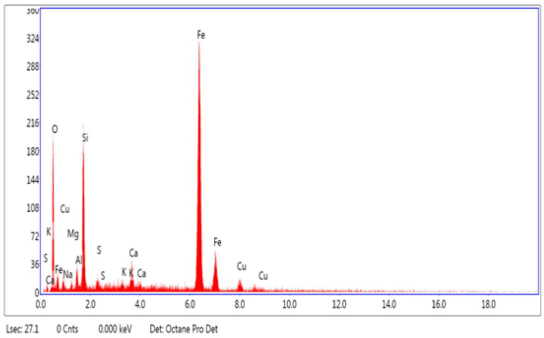


**Figure 3** EDAX Analysis of Copper Slag

#### 2.1.2 HDPE Aggregates

**Figure 4** HDPE Aggregates

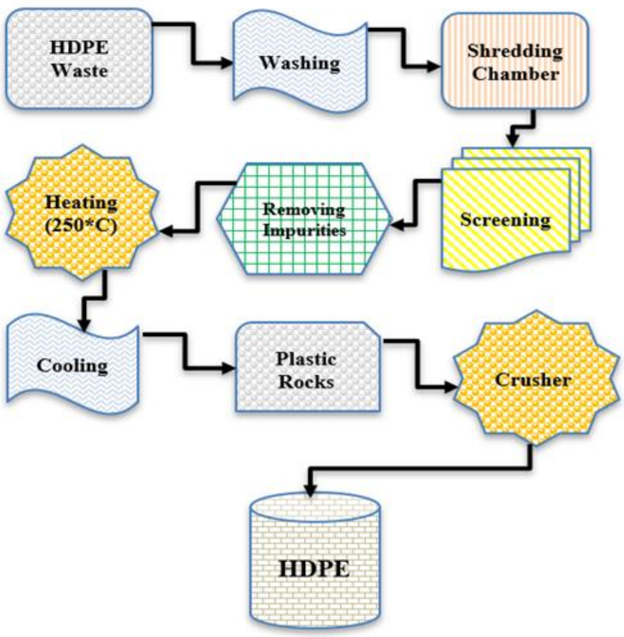


**Figure 5** Process of Manufacturing HDPE Aggregate

Plastic waste was collected from local waste dumpsites located in Bangalore, Karnataka. The collected plastic waste was then sorted into HDPE accordingly. After sorting, it was washed thoroughly. After washing, the plastic was passed on to shredding machine to reduce the size of HDPE. Then the HDPE was sent to screening chambers to remove the impurities and heated to 200°-250° Celsius. Then the hot molten HDPE will be cooled down to room temperature during which the plastic takes irregular rock shapes. Refer Figures 4 to 6. The cooled down HDPE will be crushed to required size in jaw crusher. The physical properties of HDPE aggregates are shown in Table 2

### 2.1.3 Cement

The cement used in this study was Ordinary Portland cement (OPC) purchased from Ultra Tech Cement Company. This cement is the most widely used one in the construction industry in India.

### 2.1.4 Fine Aggregate

In addition, with the copper slag, M sand was used as a fine aggregate, having the fineness modulus and specific gravity as 3.15% and 2.54 respectively.

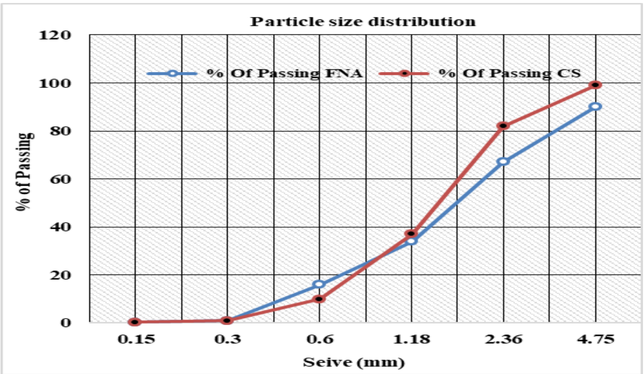


**Figure 6** Particle Size Distribution

### 2.1.5 Coarse Aggregate

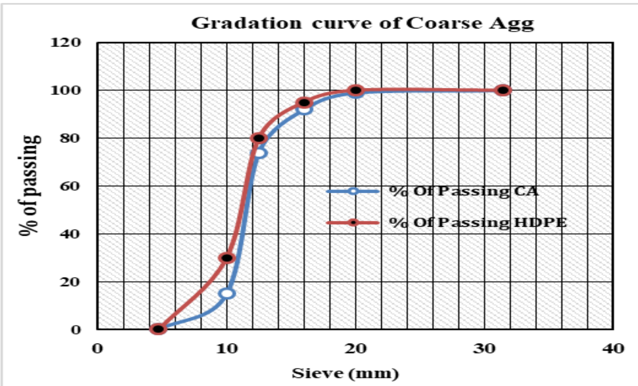


**Figure 7** Gradation Curve of Coarse Aggregate & HDPE

Coarse aggregate is used for making concrete. They may be in the form of irregular broken stone or naturally occurring gravel. Material which are large to be retained on 4.75mm sieve size are called coarse aggregates. Its maximum size can be up to 63mm. Here the coarse aggregate with 20mm down size are used. The Gradation curve of CA is shown in Fig 7.

**Table 1** Chemical Properties of Cement and Copper Slag Data Provided by Seller

| Chemical Property | Cement | Copper Slag |
|---|---|---|
| $SiO_2$ | 25.84 % | 35 % |
| $Al2O_3$ | 0.22 % | 3.10 % |
| $Fe_2O_3$ | 68.29 % | 55 % |
| CaO | 0.15 % | 0.20 % |
| MgO | - | 0.90 % |
| $TiO_2$ | 0.41 % | 0.60 % |
| $K_2O_3$ | 0.23 % | 1.02 % |
| $Na_2O_3$ | 0.58 % | 0.92 % |
| CuO | 1.20 % | 0.42 % |
| $MnO_3$ | 0.22 % | - |
| $SO_3$ | 0.11 % | - |

**Table 2** Physical Properties of Materials

| Physical Properties | Cement | Fine Agg | Coarse Agg | Copper Slag | HDPE |
|---|---|---|---|---|---|
| Specific Gravity | 3.10 | 2.54 | 2.61 | 3.63 | 0.91 |
| Bulk Density | - | - | - | 2.08 | 0.96 |
| Consistency | 30 % | - | - | - | - |
| Fineness Module | 7 % | 3.15 % | 6.2 | 3.2 | 5.2 |
| Water Absorption | - | - | 0.70 % | 0.15 | - |
| Crushing Value | - | - | 23.6 % | - | - |
| Particle size | - | - | 7.31 | - | - |

### 2.2 Mix Design

The grade of concrete was M25. The water cement ratio was 0.45 and mix ratio was 1:1.45:2.5. Different proportions of copper slag and HDPE aggregate were utilized as partial replacements for fine and coarse aggregates in concrete mixtures (Table 3). The copper slag was added at levels of 30% and 40% by weight, while the HDPE aggregate was incorporated at 10%, 20%, and 30% by weight. Concrete specimens were then prepared and compacted according to the guidelines. Each component coarse aggregate, fine aggregate, cement, and water were weighed separately according to the specified requirements, and the materials were mixed.

**Table 3** Mix Deign of M25 Concrete

| Sl. no | Mix Design | Properties |
|---|---|---|
| 1 | Grade of Concrete | M25 |
| 2 | Water Cement Ratio | 0.45 |
| 3 | Cement Content | 425.73 Kg/$M^3$ |
| 4 | Water content | 191.6Kg/$m^3$ |
| 5 | Fine aggregates | 621.12Kg |
| 6 | Coarse aggregate | 1106.145Kg |
| 7 | Mix Ratio | 1:1.45:2.5 |

### 2.3 Sample Preparation

Prioritizing the objectives, 18 cubes for 7 days and another 18 cubes for 28 days of size 150 mm X 150 mm X 150 mm were cast according to the above mix proportions. (Table 4)

**Table 4** Different Samples Partially Incorporated with Copper Slag and HDPE Aggregates

| Sample | % of Copper Slag | % of HDPE |
|---|---|---|
| C0 | - | - |
| C1 | 30 | 10 |
| C2 | 30 | 20 |
| C3 | 30 | 30 |
| C4 | 40 | 10 |
| C5 | 40 | 20 |
| C6 | 40 | 30 |

Apart from cubes the specimen with cylindrical and prisms shapes were also cast. The split tensile test was performed on cylinders with diameter of 150 mm and length of 300 mm. In total of 36 cylinders were cast and cured for 7 and 28 days. Additionally, the prism shaped specimens with dimensions of 100 mm X 100 mm X 500 mm were also cast to determine the flexural strength. In total of 36 prisms were cast in which 18 were cured for 7 days and other 18 for 28 days.

### 2.4 Test Procedure

The research evaluated the strength effectiveness of different mix designs, including compressive, tensile, and flexural strength. Each type of strength test provides a unique perspective on the proposed mix due to the different testing procedures involved Compression testing is a fundamental mechanical test used to determine a material's behavior under crushing loads (Table 5). It's a common test performed on various materials, like metals, plastics, & concrete.Flexural testing is a mechanical test used to determine a material's ability to resist bending or deflection under load. It's particularly valuable for materials like concrete, wood, and composites, which are often used in applications where bending is a primary concern. The split tensile test is a common method used to determine the tensile strength of concrete. It's particularly useful for materials that are difficult to test directly in tension, such as concrete.

**Table 5** Various Samples with Different Mix Proportions

| Specimen | W/C Ratio (kg/$m^3$) | Cement Content (kg/$m^3$) | Water (kg/$m^3$) | Coarse Aggregate (kg/$m^3$) | Fine Aggregate (kg/$m^3$) | HDPE (kg/$m^3$) | Copper Slag (kg/$m^3$) |
|---|---|---|---|---|---|---|---|
| C0 | 0.45 | 425.73 | 191.6 | 1106.79 | 621.12 | - | - |
| C1 | 0.45 | 425.73 | 190.2 | 996.1 | 434.78 | 110.69 | 186.34 |
| C2 | 0.45 | 425.73 | 190.2 | 885.43 | 434.78 | 221.36 | 186.34 |
| C3 | 0.45 | 425.73 | 189.3 | 774.75 | 434.78 | 332.04 | 186.34 |
| C4 | 0.45 | 425.73 | 189.3 | 996.1 | 372.67 | 110.69 | 248.45 |
| C5 | 0.45 | 425.73 | 189.3 | 885.43 | 372.67 | 221.36 | 248.45 |
| C6 | 0.45 | 425.73 | 189.3 | 774.75 | 372.67 | 332.04 | 248.45 |

## 3. Results and Discussions

### 3.1 Workability

The Fig 8 shows the slump values of different concrete mixes labelled C0 to C6. Based on the graph, the slump values of the mixes range from 65 mm to 75 mm. Nominal Mix C0 has the slump value of 65 mm. The workability decreased as the concrete was incorporated with HDPE. The workability of concrete mix C5 had the lowest workability compared to all the mixes. Adding HDPE to concrete can make the flow difficult and reduces workability as the plastic can get in the way of the concrete's natural movement. Mixes incorporating the 40% copper slag had better workability than concrete incorporating 30% of copper slag.

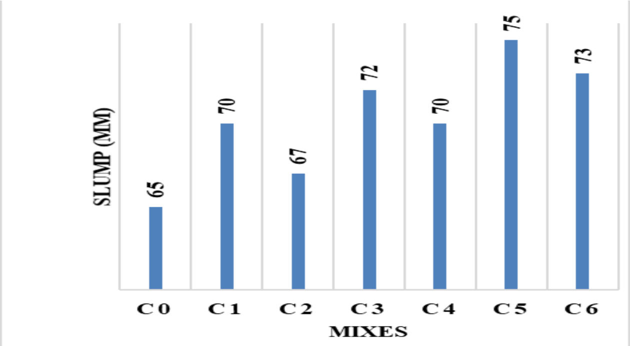


**Figure 8** **Workability of Concrete with Different Mix Proportions**

### 3.2 Compressive Strength

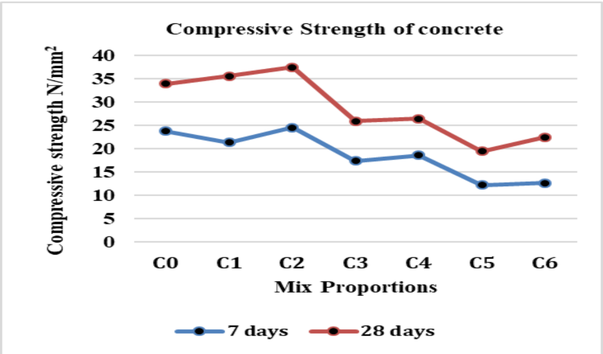


**Figure 9** **Compressive Strength of Cubes**

The effects of HDPE and copper slag as a partial substitute for coarse and fine aggregates on the compressive strength for the cubes with different mix proportions cured for 7 and 28 days are presented in Fig 9. The results indicate that the compressive strength increases significantly from 7 days to 28 days for all mix proportions. Mix proportion C2 consistently exhibits the highest compressive strength at both 7 and 28 days. Mix proportions C0 and C1 also show relatively high strength values. However, mix proportions C5 and C6 demonstrate significantly lower compressive strength compared to others, especially at 7 days.

### 3.3 Flexural Strength

The Fig 10 shows the flexural strength of prisms with different mix proportions. From the investigation it was found that the flexural strength had increased significantly from 7 days to 28 days. Mix proportion C1 consistently exhibits the highest flexural strength at both 7 and 28 days. Mix proportions C2 and C4 also show relatively high strength values. However, mix proportions C5 and C6 demonstrate significantly lower flexural strength compared to others, especially at 7 days.

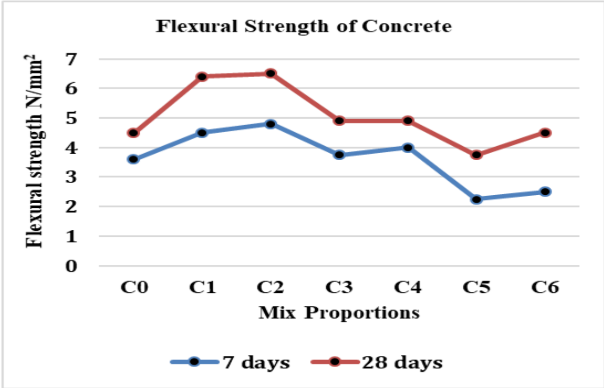


**Figure 10** **Flexural Strength of Prisms**

### 3.4 Split Tensile Strength

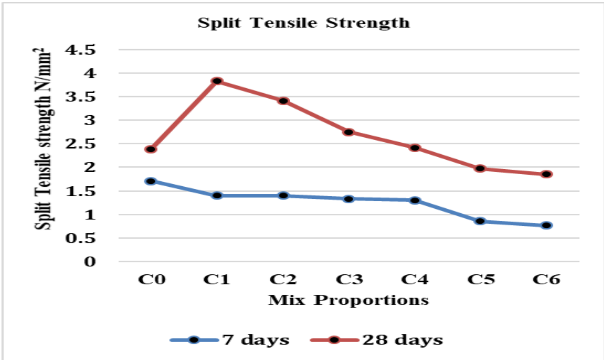


**Figure 11** **Split Tensile Strength of Cylinder**

The Fig 11 shows the split tensile strength of concrete for different mix proportions over time. The results indicate that the split tensile strength increases significantly from 7 days to 28 days for all mix proportions. Mix proportion C1 consistently exhibits the highest split tensile strength at both 7 and 28 days. Mix proportions C2 and C4 also show relatively high strength values. However, mix proportions C5 and C6 demonstrate significantly lower split tensile strength compared to others, especially at 7 days. Refer Figures 12 and 13.

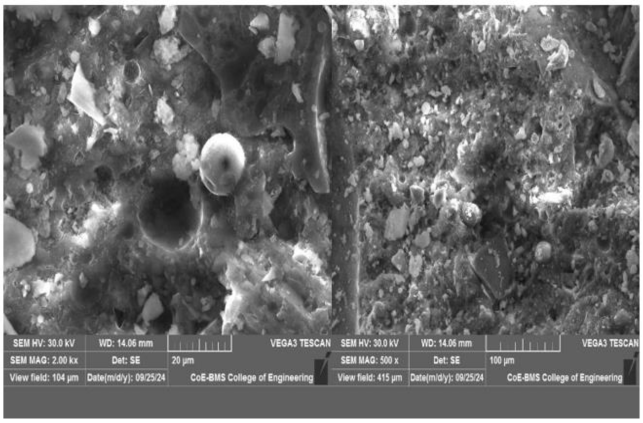

**Figure 12** **SEM Images of C2 Specimen**

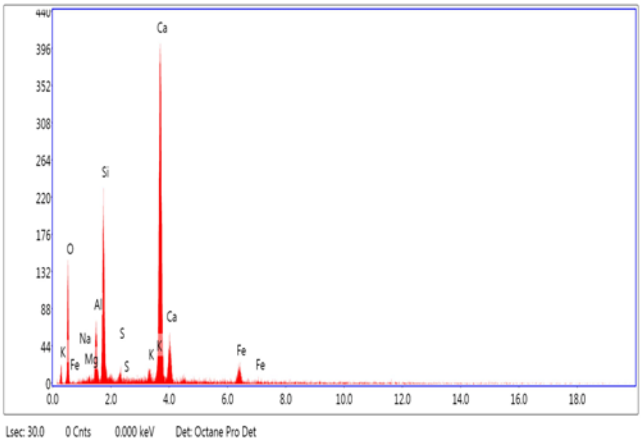


**Figure 13** **EDAX Analysis of C2 Specimen**

The SEM image shows a close-up view of a C2 concrete specimen. The image reveals a porous structure with some spherical particles embedded within the matrix. The addition of CS increases the pores, microcracks, and capillary channels within the concrete, weakening the bond between the components of the specimen. During loading, these weak links lead to early degradation of the specimen's surface. Additionally, the heavy metals present in CS can slow down the hydration process, resulting in an excess of free water. Furthermore, the smooth surface and low water absorption of CS particles negatively impact the concrete's compressive strength. From the EDAX analysis it was found that the concrete specimen had calcium oxide content in large quantity and followed by silicon dioxide.

## 4. Results and Discussion

The inclusion of HDPE and CS in concrete typically reduces compressive strength, particularly at higher concentrations, with their combined impact being more detrimental than individually. Additionally, HDPE and CS usually improve flexural and split tensile strength when added to concrete in lower concentration.

## Conclusion

- The workability of the specimens incorporating 40% of copper slag was highest compared to the specimens incorporating 30% of copper slag. The HDPE aggregates reduce the workability of concrete specimens. The C5 mix had lowest workability whereas C2 showed better workability.
- The Compressive strength of Cube with 10% of HDPE and 40% of copper slag is nearly equal to the Compressive strength of Normal cube cured for 7 days and compressive strength of cube with same mix proportion cured for 28 days had 10% increase in compressive strength. And Cube with 30% of Copper slag and 40% of HDPE had low Compressive strength.
- The flexural strength of Beam cured for 7 days with 10% of HDPE and 40% of copper slag has strength 25% more than conventional Beam. And beam cured for 28 days has strength 40% more than conventional beam.
- The Split tensile strength of Cylinder cured for 7 days with 10% of HDPE and 30% of Copper slag has highest strength among all the combinations and 18% reduction when compared to Conventional Cylinder. While the cylinders with same mix proportion cured for 28 days have strength 55% more than conventional cylinder.

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