Bio-Mineralization process on concrete substituted with different types of waste materials

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Abstract. Million tons of waste materials were produced in the world each year and most of it is not recyclable. To protect the environment from pollution and depletion, it is imperative to find explication for the safe disposal of waste materials. Using waste material in concrete production is a propitious method for eliminating the waste and reducing the cost of concrete. Also, the green concrete technology is expanding, it is necessary to utilize wastes in concrete that is generated from all the sectors. In construction large amounts of concrete from buildings was generated and demolitions made up 30-40% of total wastes. Around 33 tons of Copper slag is produced across the world and 6 to 6.5 tons in India. Electronic waste is emerging as a serious public health and environmental issue in India and approximately 2 million tons of e-waste is generated annually. Concrete produced from wastes will have declination over the strength and it is necessary to improve the properties by some other technique. Self-healing concrete is a brand-new technology that 'heals' its own cracks and indicates a promising future in reducing the inevitable deterioration of concrete structures and the high maintenance costs involved. This research includes the inclusion of waste materials into the concrete and determination of compressive Strength of waste substituted concrete. Three major Wastes such as Demolition Wastes, Copper slag and E-Wastes were chosen to replace for aggregate and Bacteria subtilis a spore forming bacteria was used as an admixture to improve the properties of concrete. From the results obtained it has been observed that self-healing technology proves to be the fruitful and considerable increase in mechanical properties.

1. INTRODUCTION
Concrete is given prime importance in construction of infrastructure and improvement facilities and has the potential for powerful and positive environmental participation [1]. Using waste material in concrete production is a pertinent method for eliminating waste materials and adds positive impact on the properties in concrete [2]. Excessive dumping cost, landfill and disposal problems paid the way for the development of waste substitution in concrete [3,4] Among the wastes generated around the world, Construction and demolition (C&D) waste is considered as major wastes [5]. Demolition Wastes can be effectively used as a replacement for coarse aggregate (up to 50% substitution) for producing concrete under normal curing conditions [6]. Copper slag which is obtained as a by-product in the form of ash during the copper ore smelting process. Normal concrete replaced up to 50% of copper slag as sand replacement can enhance the properties Workability of conventional concrete substituted with increases with the increase in percentage since the surface texture of copper slag is smooth [7,8]. Solid waste filling on the sites creating the serious problem in the developing countries especially with the E-Wastes [9]. Enormous researches have been carried out to check the suitability of E-Wastes to coarse aggregate in concrete [10]. E-Waste concrete enhances the properties, durability and increase in compressive strength can be achieved up to 15% substitution to aggregate [11].
Major problem in conventional concrete is the corrosion of steel due to the cracks formed and concrete has very low tensile strength due to the cracks and pores present in the concrete structure. Microbiologically Induced Calcite Calcium Carbonate (CaCO₃) Precipitation is the latest technique applied over new construction process [12]. Bio concrete method of calcite precipitation is nothing but inducing the bacteria into the concrete. Atmospheric Moisture passes through the crack and activates the precursor compound. The precursor compound in turn makes the bacteria to precipitate calcite crystals [13]. Bacillus Subtilis found in soil grass can be used for repairing the fissures and cracks in concrete. Bacteria incorporated into the concreter should be able to precipitate calcite crystals. Calcium lactate is used as a food to activate bacteria. Researchers also identified that bio mineralization will not affect the initial and final setting time of concrete. Bio mineralization process usually converts organic substances into inorganic crystals which are used for sealing the cracks. The calcium carbonate formation at the early stage is due to the water passage through the cracks and reaction with less CO₂ present. Calcium hydroxide which is in the stage of unreacted get in contact with CO₂ present and precipitates calcite crystals as shown in Equation (1) and Equation (2). The precursor compound added to the concrete gets activated with oxygen present in the atmosphere shown in Equation (3) and activates the bacteria. The limestone thus seals the cracks [14].

\[
\text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2 \quad (1)
\]

\[
\text{CO}_2 + \text{Ca(OH)}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O} \quad (2)
\]

\[
\text{Ca(C}_3\text{H}_5\text{O}_2)_{2}+7\text{O}_2 \rightarrow \text{CaCO}_3+5\text{CO}_2+5\text{H}_2\text{O} \quad (3)
\]

In order to overcome the sand mining problems and land fill deposits of waste materials can be utilized as substitution materials for aggregates in concrete. The percentage of substitution of waste materials and the strength of the waste substituted concrete can be improved by arresting the cracks and fissures using bio mineralization process. Concrete mixtures were prepared with various percentage of substitution of waste materials such as demolition wastes, copper slag and E-Waste. All the mixes were added with minimum percentage of bacteria to improve the properties of concrete. Compressive Strength of waste substituted concrete were determined. The possibility of usage of waste materials to the maximum percentage of substitution to aggregate was found out after the treatment of bacteria. The improvement of mechanical properties with respect to suitable waste material and bacteria was concluded.

2. EXPERIMENTAL

2.1 Materials

2.1.1 Fine Aggregate
The fine aggregate used for this investigation was clean river sand passing through 4.75mm sieve conforming to the Grading zone II and the properties in agreement with IS:383–1970.

2.1.2 Coarse aggregate
Crushed granite aggregate of nominal size 20mm Conforming to Zone III and in accordance to IS:383–1970 was used as Coarse Aggregate.

2.1.3 Water
Ordinary potable water of good quality satisfying the requirements of IS:456-2000 was utilized for research.

2.1.4 Demolition Wastes
Demolition waste aggregates passing through 20mm and retained on 12.5mm sieve has been utilized.

2.1.5 Copper Slag
Copper slag which is the by-product obtained during the manufacturing process of copper has the characteristics similar to that of river sand. The size of copper slag substituted for fine aggregate is
around 4.0 mm. Copper slag was brought from Sterlite Industries India Limited (SIIL), Tuticorin, Tamil Nadu, and India.

2.1.6 E-Wastes
E-Wastes passing through 20mm sieve and retained on 12.5mm sieve was used as a partial substitution to coarse aggregate.

2.1.7 Microorganism
Bacillus subtilis, a laboratory cultured bacterium was utilized to expedite the mechanical properties of concrete substituted with waste materials.

2.2 Mix Design and Sample Preparation
M30 grade of Concrete is used with 0.45 water/cement ratio. The mix design was done as per IS.10262-2009[15]. The final Mix proportion obtained after concrete mix Design was 1: 1.37: 2.27. Five concrete mixes M1, M2, M3, M4 and M5 were prepared with concrete substituted with different percentage of substitution of Demolition wastes, copper slag and E-Wastes for aggregate. All the five mixes were applied with microorganisms.

2.3 Compressive strength test
Compressive strength test was performed as per the recommendations given by IS 516:1959[16]. Cube samples of dimensions 150 x 150 x 150mm were casted for all the mixes. The prepared specimens loaded to compression tester are shown in Figure 1. The Ultimate load (P) at failure of cube specimen was determined. Compressive strength of concrete cube was computed by dividing the ultimate load by area of the specimen.

3 RESULTS AND DISCUSSION

3.1 Basic properties of Concrete materials
The basic properties of coarse aggregates were determined produced in Tables1 and 2 and the values obtained are to the requirements of Mix design. The wastes such as Demolition Wastes and E-waste have been customized to the size of coarse aggregate and the properties were compared as shown in Table 1. It is observed that E-Waste has very less water absorption when compared to natural aggregate and attains better workability. Demolition waste possesses high water absorption capacity and hence the workability will be reduced. With respect to fine aggregate the density of copper slag is little higher than that of river sand and the reduced water absorption enhances the workability.

3.2 Compressive Strength Test results
3.2.1 Demolition Waste concrete treated with Bacteria
Compressive strength of the concrete substituted fully and partially with demolition wastes and accelerated with microorganisms are shown in Figures 2 to 4. It is observed that the compressive...
strength has attained a remarkable change. From the past researches it is found that Compressive strength of demolition waste concrete showed a positive result up to 50% substitution and starts decreasing with 75% and 100% substitution of demolition wastes. Bio mineralization improves the compressive strength to 34.2 N/mm² at 75% substitution of demolition wastes and 2% bacteria.

Table 1. Properties of Coarse Aggregate

| Properties            | Natural Aggregate | Demolition Waste | E-Waste |
|-----------------------|-------------------|------------------|---------|
| Impact Value (%)      | 7.6               | 2.71             | 2.1     |
| Specific Gravity      | 2.69              | 2.27             | 1.12    |
| Water Absorption (%)  | 0.6               | 2.02             | 0.04    |

Table 2. Properties of Fine Aggregate

| Properties            | Natural River sand | Copper Slag |
|-----------------------|--------------------|-------------|
| Specific gravity      | 2.65               | 3.86        |
| Fineness modulus      | 2.82               | 4.4         |
| Water absorption (%)  | 1.85               | 0.13        |

Figure 2. Compressive strength of Demolition waste concrete with 0% Bacteria
Figure 3. Compressive strength of Demolition waste concrete with 1% Bacteria

Figure 4. Compressive strength of Demolition waste concrete with 2% Bacteria

3.2.2 Copper Slag concrete treated with Bacteria

The results of compressive strength have shown improvement of density of copper slag concrete and reduction in porosity. Maximum value of compressive strength obtained was 45.6 N/mm$^2$ at 75% substitution of Copper slag remedied by 2% Microorganisms. Nevertheless, replacement of Copper Slag beyond 40% have shown the improvement in Compressive strength with respect to the controlled concrete. Compressive strength of the concrete substituted fully and partially with copper slag treated with microorganisms are shown in Figures 5 to 7.
Figure 5. Compressive strength of Copper Slag concrete with 0% Bacteria

Figure 6. Compressive strength of Copper Slag concrete with 1% Bacteria

Figure 7. Compressive strength of Copper Slag concrete with 2% Bacteria
3.2.3 E-Waste Concrete treated with Bacteria

Compressive strength of E-Waste concrete with 0%, 1% and 2% addition of bacteria were determined. Variation of compressive strength at the age of 7, 14 and 28 days with and without the action of microorganism are represented in Figures 8 to 10. It is observed that E-Waste concrete up to 15% replacement to coarse aggregate showed a better result at 28 days with the maximum compressive strength of 35.9N/mm² at 2% bacterial action whereas the compressive strength at 15% replacement of E-Waste without bacteria is found to be 33.9N/mm².

![Figure 8](image1.png)

**Figure 8.** Compressive strength of E-Waste concrete with 0% Bacteria

![Figure 9](image2.png)

**Figure 9.** Compressive strength of E-Waste concrete with 1% Bacteria
Figure 10. Compressive strength of E-Waste concrete with 2% Bacteria

4. CONCLUSION

Compressive strength of Waste Substituted concrete with and without the action of Microorganisms have been calculated and reported. Bacteria Subtilis gram positive bacteria were used as an admixture to improve the Mechanical properties of waste substituted concrete. The optimum percentage of microorganism used to enhance the properties of concrete is found to be 2%. Comparing the values of Compressive Strength, it is found that the action of microorganisms is found to be effective on copper slag around 45.6N/mm² at 75% of substitution to fine aggregate. The size of copper slag is in agreement with the size of fine aggregate. The properties of copper slag almost match with fine aggregate properties. Past researches have reported the maximum substitution of copper slag around 35% whereas it has been improved to 75% due to the action of bacteria. The bio mineralization process precipitates the calcite crystals which fills in the pores and improves the compressive strength. The copper slag waste material can be the potential substitution to fine aggregate when it is remediated by minimum percentage of bacteria.

ACKNOWLEDGEMENT

The authors would like to express deep sense of gratitude to the management of Sathyabama Institute of Science and Technology for their valuable support in completion of this project work with respect to the utilization of laboratories for conducting the necessary tests. The authors also acknowledge with thanks for the loving inspiration given from their family members. All the friends and relatives are gracefully acknowledged for their timely encouragement.

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