Efficient Eco-Design Integrating Green Materials in Concrete for Sustainability

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Abstract: - "Efficient Eco-Design: Integrating Green Materials in Concrete for Sustainability" looks at the most recent advancements in smart materials and how they are changing the way energy-efficient buildings are designed and built. Integrating green materials into concrete design offers a viable option to generate large energy savings and lessen environmental consequences, especially as the demand for sustainable living solutions develops globally. The science and uses of several green materials, such as waste glass powder, iron waste, and sophisticated insulating solutions, are investigated in this study. It offers a thorough examination of how these materials might raise overall efficiency, control temperature, and achieve the necessary strength in buildings. "Efficient Eco-Design" demonstrates the real advantages of using green materials in building through a combination of theoretical understanding and experimental findings. It presents actual studies where these materials have been effectively applied, demonstrating their effect on lowering pollution levels in the environment and maximizing advantages.

Key-Words: - Efficient; Eco-Design; Sustainability; Lowering Pollution; green materials; waste glass powder;

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1 Introduction

Over time, buildings have become a substantial and quickly expanding sector of energy use. Rising dangers related to energy-passive structures are causing an increase in global temperatures as well as more severe and unpredictable weather patterns. Energy efficiency will be one of the most important topics that the scientific community and society have to deal with in the upcoming years. Improving energy efficiency can help ensure a sustainable world because buildings consume 40% of all energy. Smart grids and smart buildings play a major role in the creation of sustainable smart cities, [1], [2]. The main objective is to ensure that people have comfortable living conditions while minimizing the detrimental effects of energy usage on the environment. Human activities must have the least negative effects on the environments in which they are conducted if environmental sustainability is to be maintained. In the upcoming years, a major increase in energy demand is predicted due to population growth, economic expansion, and the need for greater comfort. Global energy consumption increased by 2.3% in 2018. In addition, environmental degradation elements are creating an alarming situation for people with health concerns, [3], [4]. Energy demand is mostly driven by buildings. Enhancing building energy efficiency is crucial in addressing the global sustainability crisis, [5]. This entails the use of suitable building materials, energy harvesting, energy-efficient storage, renewable energy sources, and intelligent energy management is also required for proper utilization of sources, [6], [7]. Reduced consumption, particularly in public buildings, should be the main goal of energy optimization initiatives. At the same time, efforts should be made to meet urban society's increasing demand for quality. One important factor in lowering energy pollution is efficiency, [8], [9], [10]. One can describe energy-efficient buildings in a number of ways. In addition to providing residents with a comfortable living environment, an energy-efficient building maximizes resource efficiency and minimizes energy use. Throughout a building's lifecycle, from initial construction to use, maintenance, and final demolition, energy-saving measures should be put in place. These kinds of buildings allow their residents to remain fully functioning and enjoy comfort, [11]. The growing cost of energy and the impending energy crisis are driving up demand for energy-efficient building designs. Energy-efficient equipment, renewable energy sources, and passive solar design principles are all balanced in an energy-efficient structure. The primary aim of this research will be the technological developments in this regard, with a special emphasis on the application of smart materials in buildings, [12]. The increased energy efficiency of smart buildings is one of their main benefits. Improving efficiency can result in less water being used, less greenhouse gas emissions, and less other pollutants. In order to support the increasing urban growth, ecologically responsive building materials are required due to the continued exploitation of natural resources. These cutting-edge materials can help save the environment and greatly increase energy efficiency, [13]. Because of advancements made with smart materials, it also encourages better lifestyle choices by limiting exposure to inefficient materials. Because they are more efficient than traditional building materials, these materials can save money and time when used in construction. The improved insight that smart materials offer as a result of data consolidation onto a single platform is another important advantage and further flow diagram for application of smart materials is shown in Figure 1, [14], [15]. By substituting smart materials for conventional materials that are able to sense or respond to changes in their environment, buildings can be made lighter, simpler, and less prone to failure, [16], [17]. Numerous industrial and pozzolanic products are available for use in the building industry. These materials include, for instance, iron waste and waste glass powder. Another practical approach to waste management is the use of building site waste products as resources, [18], [19]. Furthermore, by using these waste products, a sizable amount of inexpensive, recyclable construction material is produced, [20], [21].

The utilization of waste materials in the construction sector has been extensively covered in the literature throughout the last ten years. However, more experimental study is required to optimize the system. The best way to use waste glass powder, silica fume, and iron waste in concrete in replacement of its basic components like cement and sand to some extent is the main purpose of this study, [22], [23], [24]. Additional experimental studies are carried out to verify that the substrate's mix proportion is appropriate for use in civil applications by assessing the substrate's particle size, morphology, strength, and durability, [25].

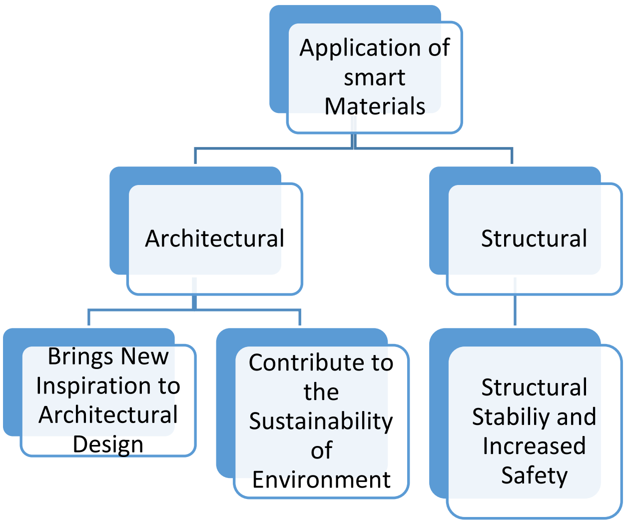

Fig. 1: Application of Smart Materials

2 Materials and Methods

2.1 Sample Collection and Morphology

2.1.1 Waste Glass Powder (WGP)

The WGP sample was obtained by crushing the obtained translucent white glass bottle in a ball mill. The material was completely dried in the oven before being examined. The purpose of the sieving test was to determine the particle size distribution performance of the WGP sample. Following the collection of an adequate amount of sample, WGP was appropriately dried in an electric oven. Following that, the powder was divided into various particle sizes using ordinary sieves. Table 1 shows some of the physical characteristics of WGP.

Table 1. Properties of WGP

Sr No	Physical Properties	WGP	Unit
1	Particle Size Distribution	10–250	µm
2	Specific Gravity	2.94	-
3	Bulk Density	2540	kg/m^3
4	Color	White	-
5	Surface area	3130	m^2/kg

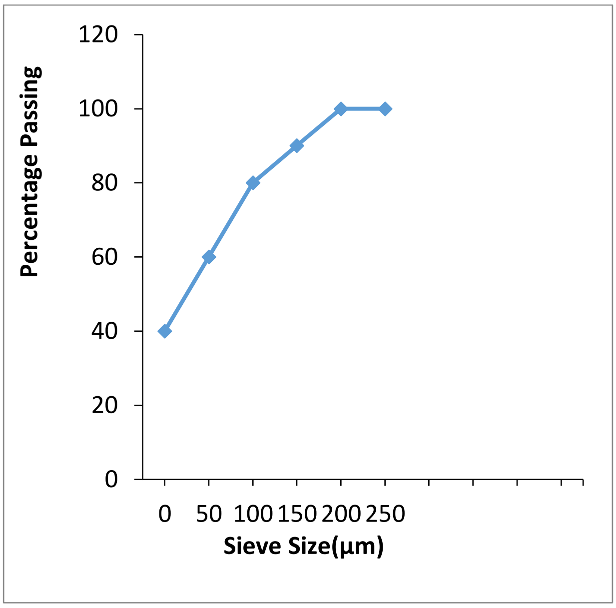

Fig. 2: Particle size distribution of WGP Sample

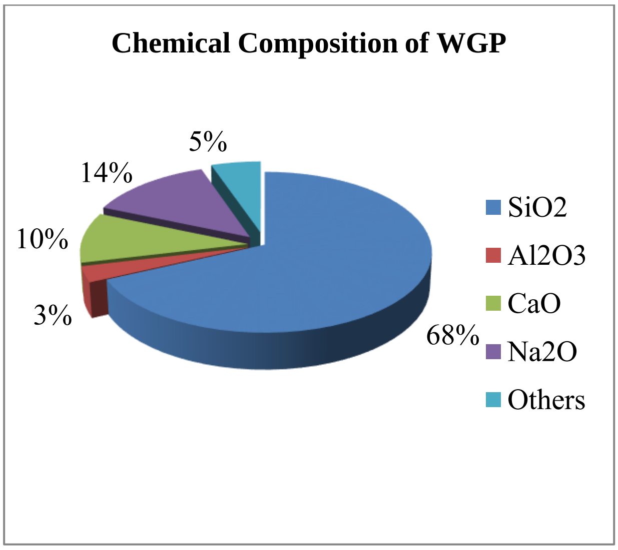

Fig. 3(a): Chemical Composition of WGP

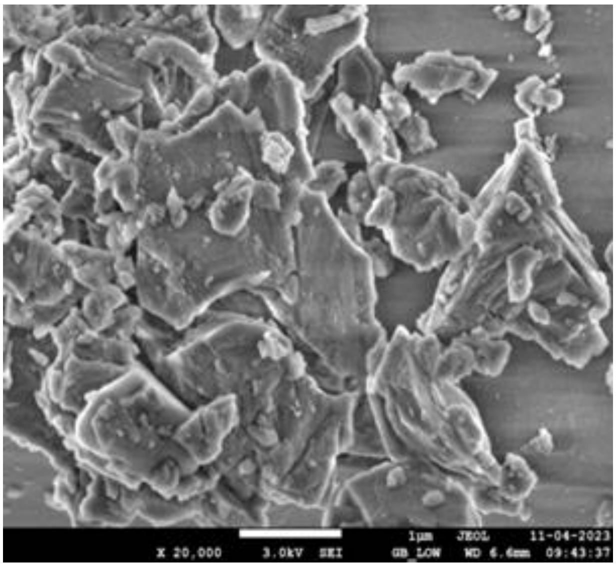

Fig. 3(b): Scanning Electron Microscopy of WGP Sample

In order to quantify the fineness or particle size, the WGP has undergone a sieve examination. To determine the WGP particle size distribution, a mechanical sieve shaker must be used. Standard brass sieves were used, each with a different degree of metallic mesh. The sieves were arranged so that the smaller particles would be caught by the pan. A more detailed example of the WGP particle size distributions is shown in Figure 2. About 40% of the particles in the WGP are finer than 32 microns, and about 48% of the particles are finer than 45 microns.

The shape and elemental composition of the materials were examined using an energy-dispersive X-ray spectrometer (Model: JEOL, 6510 LV) coupled with scanning electron microscopy. Figure 3(a) provides an explanation of each of the distinct chemical elements that make up the WGP sample. The results showed that the proportion of silica oxide was 68.3% and the percentage of aluminum oxide was 5.2. The observations clearly show that a significant amount of the material exhibiting favorable pozzolanic properties, such as low-heat compression during hydration and low-cost material, is present in both materials.

Figure 3(b) displays the specimen's scanning electron microscopy (SEM) at a 20000 magnification. The results of this investigation conclusively demonstrate that WGP particles are not connected in any manner, form, or sense to a group of other particles. The shape of the WGP particles is angular, uneven, and ripped. These small circular particles, also called agglomerates, are widely accessible, making it possible to investigate the feasibility of using them in a wide range of real-world applications. The workability of cement can be increased by substituting WGP for one of the ingredients. This is accomplished by reducing the friction caused by the hard, tiny, flawlessly smooth, and rounded particles.

2.1.2 Iron Waste (IW)

Iron refuse is added to concrete to improve its mechanical properties, including its tensile, flexural, and compressive strengths. This increases the material's durability and resistance to cracking. Concrete can have its flexural strength significantly increased by iron scrap. The strength, toughness, and load-bearing capacity of beams are all increased when their iron content is raised, according to research on the flexural behavior of beams. Along with other major and small companies, iron and steel mills are perhaps the biggest producers of this type of solid waste. For the goal of experiments, iron scraps from KRMU’s Mechanical Workshop were utilized, and sieve analysis and deep morphology were done to check its feasibility in concrete. Table 2 shows some of the physical characteristics of IW.

Table 2. Properties of IW

Sr No	Physical Properties	IW	Unit
1	Particle Size Distribution	75-4750	µm
2	Specific Gravity	3.56	-
3	Bulk Density	2168	kg/m^3
4	Color	Black Grey	-
5	Fineness Modulus	2.53	-

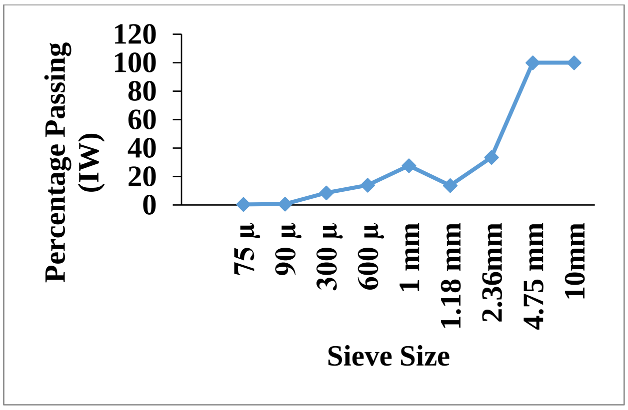

Fig. 4: Particle size distribution of IW Sample

Using sieve testing equipment, the particle size distribution of the sample has been ascertained. Before testing, the samples were oven-dried for a full day to remove any remaining moisture. IW particles ranged in size from 3.12 mm on average, with 8.60% smaller than 300 µm. The biggest particles had a size of 4.75 millimeters. More detailed sieve analysis results are shown in Figure 4. The range of 2.36 mm to 4.75 mm contains the maximum IW content.

Using JEOL and 6510 LV equipment, energy dispersive x-ray spectroscopy and scanning electron microscopy (SEM) were used on an IW sample to determine the sample's chemical composition and element availability. The data was analyzed using ASTM D422 standards. The IW sample has an iron concentration of about 95%, as well as an iron and carbon combination. The remaining 5% of the sample also contains oxides of silicon, calcium, and magnesium. Figure 5(a) displays the elemental composition or particle distribution for the IW sample based on their proportion.

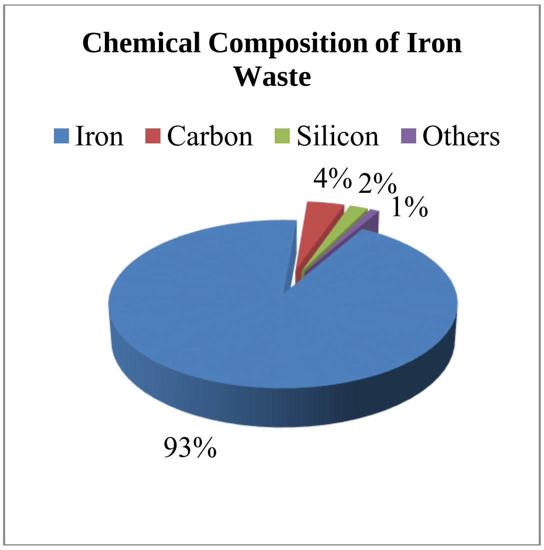

Fig. 5(a): Chemical Composition of IW

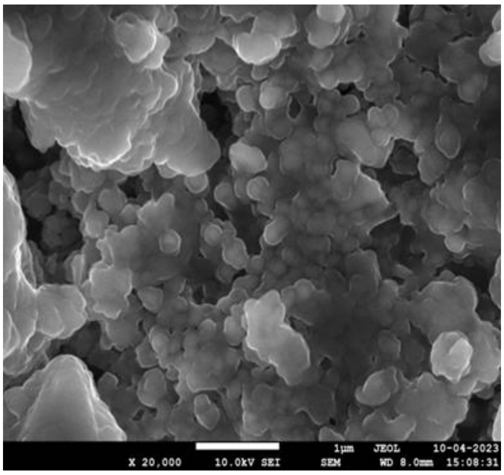

Fig. 5(b): Scanning Electron Microscopy of IW Sample

Figure 5(b) displays the SEM image of iron waste at a magnification of 20,000. The information indicates that the iron waste material particles have an angular shape and a rough surface. The irregular shape of IW particles makes them a good substitute for sand in concrete because they improve workability.

2.2 Methodology

The combinations were made using conventional or common proportions M-25(1:1:2) in order to conduct tests. The initial sample, or mix, contained no additional materials or waste at all and was made up of just the fundamental ingredients of concrete: cement, sand, aggregate, and water. Subsequently, M-25 Grade was used to substitute some of the basic elements, such as some cement content, with Waste Glass Powder and some sand with Iron Waste. The outcomes were then compared to regular concrete. A fresh concrete slump test was conducted following mix preparation. For hardened concrete, tests for split tensile strength, flexural strength, and compressive strength were conducted. The proportioning was done to meet requirements for durability and workability of new concrete, as well as to achieve specified attributes at particular ages.

3 Results and Discussion

The results of an experimental study on green concrete using iron refuse and waste glass powder (WGP) have proven promising. The key findings and comments about the mechanical properties of the produced green concrete mix, including compressive strength, flexural strength, and split tensile strength as well as the durability of the produced concrete are presented in this part. For the M-25 grade of concrete we have replaced 10% of cement with waste glass powder and 5% of sand with Iron Waste as shown in Table 3.

Table 3. Percentage of Green Materials Used

S.No	Material Replaced	Material Used	Replaced Percentage(%)
1	Cement	Waste Glass Powder	10
2	Sand	Iron Waste	5

The M25 concrete mix, which substitutes Waste Materials, underwent all three strengths tests. For replacement percentage, three cubes, three beams, and three cylinders were examined, and the average result was used as the final figure. As shown in Table 4, 10% cement replacement with waste glass powder and 5% sand replacement with iron waste resulted in improved compressive strength, Flexural strength, and split tensile strength values for 7, 14, and 28-day curing periods.

Table 4. Compressive Strengths for Different Curing Periods

Type of Strength	**Compressive Strength(N/mm^2)**		
Curing Period	**7 days**	**21 days**	**28 days**
Normal Concrete	28.7	30.1	34.2
Eco-Concrete	29.5	32.7	36.9

Table 5. Flexural Strengths for Different Curing Periods

Type of Strength	**Flexural Strength(N/mm^2)**		
Curing Period	**7 days**	**21 days**	**28 days**
Normal Concrete	3.1	3.3	3.6
Eco-Concrete	3.4	3.9	4.2

Table 6. Split Tensile Strengths for Different Curing Periods

Type of Strength	**Split Tensile Strength (N/mm^2)**		
Curing Period	**7 days**	**21 days**	**28 days**
Normal Concrete	2.5	2.8	3.2
Eco-Concrete	2.95	3.21	3.8

As depicted in the Figure 6 the compressive, flexural, and split tensile strength has undergone an impressive increase with the increasing curing period as compared to that of normal concrete. The final compressive strength for eco-concrete after the 28-day curing period came out to be 36.9 N/mm^2 which is around 8% more than the conventional concrete. Similarly the flexural and split tensile strength for eco-concrete after 28 days of curing period imparted an increase of 16% and 18% respectively then the old-fashioned concrete.

The rapid chloride permeability test was used to evaluate the concrete's durability. The test's goal was to compare and assess the performance of mixes including calcium nitrate, sodium nitrate, and regular concrete. Calcium nitrite and sodium nitrate prevent corrosion of steel reinforcing bars caused by chloride. Sodium nitrate is used as a chemical additive in commercial and industrial greases, in addition to its role as a corrosion inhibitor. For each concrete mixture, cylinder samples were subjected to chloride ion permeability tests at 7 and 28 days for the design mix M-25 of green concrete. Table 5 displays the average results of chloride permeability in coulombs for various corrosion inhibitors with aging and in Figure 7 we can see the comparison of chloride permeability. The lesser the permeability more corrosion-resistant is concrete and hence is more durable. As we can see clearly in Table 5 Eco-Concrete has lesser permeability of chloride than that of normal concrete so it is more durable. Table 6 shows the strength of normal and eco concrete comparison. In Table 7 it can be seen that chloride permeability of eco-concrete is significantly lower compared to normal concrete due to reduced porosity. This improved resistance enhances durability and sustainability of structures.

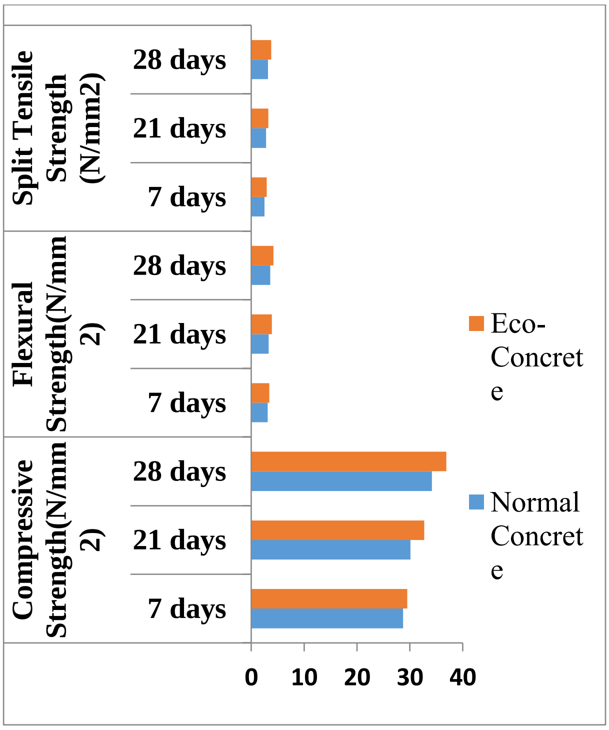

Fig. 6: Comparison of Strengths

Table 7. Chloride Permeability of Normal and Eco-Concrete

Percentage of Corrosion Inhibitor	**Charge Passed in coloumbs(7 Days)**	**Permeability of Chloride as per ASTM C1202**	**Charge Passed in coloumbs(28 Days)**	**Permeability of Chloride as per ASTM C1202**
Normal Concrete (0%)	393.75	Very Low	457.7	Very Low
Eco Concrete (CN 4%)	311.78	Very Low	433.79	Very Low
Eco Concrete (SN 3%)	246.45	Very Low	365.53	Very Low

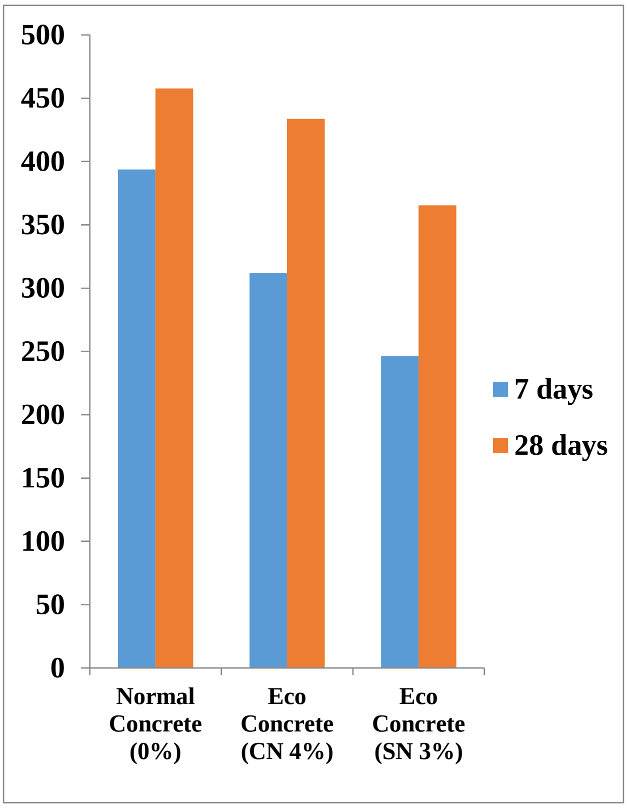

Fig. 7: Comparison of Chloride Permeability

4 Conclusion

On the basis of test results, it was concluded that:

- Waste Materials like Waste Glass Powder and Iron Waste if substituted with cement and sand to the proper extent can impart a higher Compressive strength as compared to that of normal concrete by 8%, higher Flexural Strength to that of Normal Concrete by 16%, and an increase in percentage of split tensile strength by 18% than that for traditional concrete.
- This mix design not only provides higher strength but also a higher durability and it has high corrosion resistance.
- Using such Materials will not only result in lesser cost but will also help in creating a sustainable environment thereby increasing overall efficiency.

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Conflict of Interest

The authors have no conflicts of interest to declare.