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# SUSTAINABLE CONCRETE DEVELOPMENT: UTILIZING WASTE MATERIALS FOR RIGID PAVEMENT APPLICATIONS

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**Abstract:** On The present study seeks to explore the optimal utilization of industrial waste materials as substitutes for cement in highway construction. This initiative stems from the growing awareness of the detrimental environmental and health impacts associated with industrial waste and cement production. Numerous studies conducted globally have underscored the severe repercussions of improper waste disposal, including its adverse effects on ecosystems, human health, and water resources. Furthermore, large-scale cement production is a significant contributor to pollution, linked to various diseases and environmental degradation. Recognizing these challenges, it has become imperative to identify and adopt alternative materials that can effectively replace cement. The objective is not only to mitigate the negative impacts of waste and cement production but also to align with sustainable construction practices. Previous research has demonstrated the potential of integrating various waste materials in highway construction, with replacement proportions ranging from 5% to 50%. However, these efforts, while promising, have yet to achieve a complete substitution of cement. Achieving this requires the identification of materials with chemical compositions and binding properties comparable to those of cement.
This study emphasizes the critical need for innovation in material science to develop sustainable construction materials. It aims to inspire researchers and engineers to advance the development of "green concrete," focusing on balancing environmental, economic, and technical considerations. By highlighting diverse methodologies for repurposing discarded industrial by-products, the study advocates for a transformative approach to highway construction. This includes detailed analyses of the chemical and physical properties of waste materials, their compatibility with construction standards, and their long-term performance under varied environmental conditions. Ultimately, the research underscores the importance of transitioning towards environmentally responsible construction practices. It calls for a collaborative effort among stakeholders to integrate waste management strategies with infrastructure development, paving the way for a more sustainable future.
**Keywords:** Cement, Waste material, Highway pavement, Environment, Sustainable construction.

## 1. Introduction

The economy of any country depend upon a good infrastructure which covers roads, bridges, buildings, warehouses, airports, harbors, instrumentality terminals etc. In today's life, a good infrastructure is a major requirement for the growth of a country which seems impossible to attain without using cement. Cement is a powdery substance which is made up of calcining lime and clay. Mainly cement is used as a binding material which is mixed with water, sand and aggregates for the construction purposes (i.e. highways or building). Though, it is an environmental concern because of the emission of several hazardous gases at various stages of cement manufacturing process. In a previous study (Mehraj et al 2014), it was mentioned that consumption of cement in India is increasing with the rate of 10% per year. It is to note that the cement is the second most consumable material after water across the world. The global cement industry produces over four billion tonnes of cement annually. Therefore, production of cement in so much quantity has become the point of interest for the researchers across the world as the waste produced (i.e. cement dust) from these cement plants is very harmful to the environment and human health also. Fly ash, steel slag, E-plastic and recycled concrete aggregate are the few examples waste materials which can be recycled and used as a polymer concrete mix which will decrease the consumption of Ordinary Portland cement (OPC) and also help in utilization of energy without causing any environmental pollution. To preserve the natural resources some waste material should be used to maintain the sustainability of the environment. However, some guidelines have been provided regarding the use of fly ash in road construction. Therefore, it is the need to propose an alternative of the cement for the construction work when the people are getting affected by several serious diseases while working in these plants or residing nears these plants. Ministry of Environment and Forests (2016) has notified the emission standards for cement plants. Here, one point is to note that the permissible stack dust emissions limit in India is set to 50 mg/Nm which shows the seriousness of the situation in the country.

## 2. Literature Review

**Huda et al. (2014)** investigated the property of recycled course aggregate up to 3 generation of usage by replacing 100% of them. Small sample of 100 X 200mm of cylinder and 150 X 150 X 500 mm were casted and randomly tests were examined to know the physical and mechanical properties of aggregates. Compressive and splitting tensile strength was getting reduced a little when RA was used as the substitution of aggregate. Usage of recycled aggregate was showing the similar maximum stress and axial strain value (i.e. 50 MPa and 0.0027 respectively) as shown by the normal mix (i.e. using natural aggregate). Test for Modulus of elasticity and Poisson's ratio showed that recycled aggregate can be reused thrice.

**Kuo et al. (2012)** used the recycled concrete ready with limestone pieces in the subbase layer of flexible pavement. RCA composed up to size of 45mm for subbase layer by crushers etc. Mechanical property like compressive, tensile, shear strengths and modulus of elasticity of RCA was found 40% lesser than fresh aggregate. For conducting various tests like lime rock bearing ratio (LBR), LA abrasion, soundness of concrete, modified Proctor compaction and hydraulic conductivity, two tracks of RCA and one of lime rock were constructed.

**Ebrahim et al. (2013)** provide different factors like gradation, angularity, soundness, and solubility of aggregate were kept in mind to use the recycled concrete as subbase layer of the pavement. On the basis of the findings it was observed that only 70% of required strength can be achieved by mixing of 5% cement with recycle concrete aggregate. However, this value can be increased up to 77%. Courard et al. (2010) examined the suitability of recycled aggregates for the construction of roller compacted concrete (RCC). It is special types of polymer concrete that do not contain reinforcement while the construction of structure. It has high compressive strength and durability and very less sensitive to shrinkage also. Different test like Los Angeles test, specific gravity test and durability test were conducted in the study. Findings of the study revealed that the recycled aggregates can be used as RCC as overall performance was good.

**Silva et al. (2014)** measures the properties of recycled aggregates obtained from C & D waste. After demolition four forms of concrete were identified namely first is recycled concrete aggregates (RCA), second is recycled masonry aggregate (RMA), third is mixed recycled aggregates (MRA) and last one is construction and demolition recycled aggregates (CDRA). The density of RMA was found lower than the RCA due to high porosity value. It was also concluded that these materials can be utilized in the construction of subbase layer of roads.

**Jaroslav et al. (2017)** studied the effect on mechanical properties of cement paste by adding concrete powder in it. Different 5 samples were made by varying the percentage of RCP from 0% to 50%. Beside this, one sample of Portland cement was also made to make the comparison. All the results obtained from different tests were based on 28 days curing time period. Impact resonance test was conducted to calculate Young's modulus for each sample. Use of RCP up to 30% showed higher porosity and lower modulus of elasticity. The uniaxial compressive test concluded that compressive strength decreases with increase amount of RCP more than 20%.

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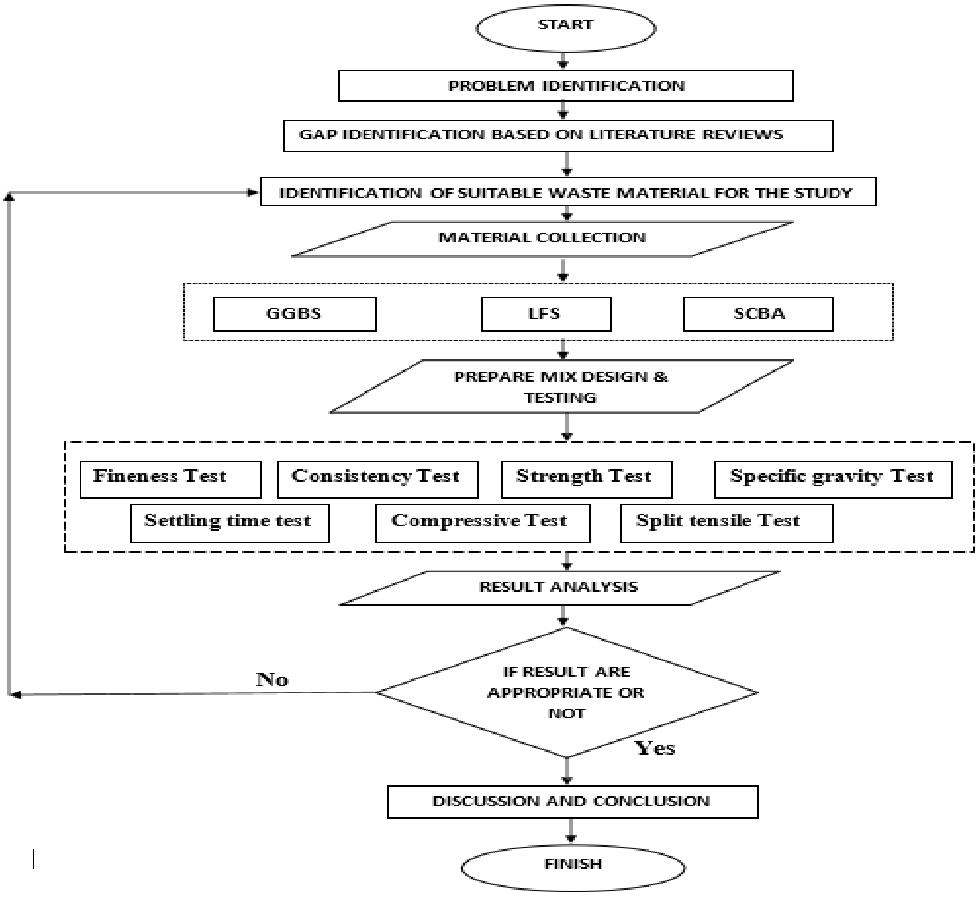
## 3. Research Methodology




## 4. RESULTS & DISCUSSIONS

Different test of materials are conducted to check the suitability of available material. Test of sand, aggregate and cement was performed. According to mix design every material should posses the same property and same values. Test like Normal Consistency test, Initial & Final setting time, specific gravity of sand cement and aggregate, water absorption. And compressive strength was performed. Quantity required for making sample was also estimated. Different tests were performed for testing OPC and the results obtained from these tests were compared.

**Table 1:** Values of different test results

| **S. No.** | **Experiments** | **Results** |
|---|---|---|
| 1 | Normal consistency of cement | 27% |
| 2 | Initial setting time of cement | 27 min |
| 3 | Final setting time of cement | 7 hours |
| 4 | Compressive strength of cement 3 days<br>7 days<br>28 days | 21 $N/mm^2$<br>30 $N/mm^2$<br>42 $N/mm^2$ |
| 5 | Tensile strength of cement 3 days<br>7 days | 22$kg/cm^2$ 27$kg/cm^2$ |
| 6 | Specific gravity of cement | 3.12 |
| 7 | Specific gravity of fine aggregate | 2.74 |
| 8 | Specific gravity of coarse aggregate | 2.67 |

The cube with standard size of 150 X 150 X 150 mm was used to find the compressive strength of concrete by using waste material in them. Place cubes inside the plates of CTM and apply a constant rate of loading until failure of cube will occur. The ultimate load was measured as shown below in Table 2.

**Table 2:** Compressive strength by using GGBS for 7 days

| **% Replacement of GGBS** | **Casting –I (MPa)** | **Casting – II (MPa)** | **Casting – III (MPa)** | **Average (MPa)** |
|---|---|---|---|---|
| 0% | 26.42 | 27.41 | 27.21 | 27.01 |
| 5% | 30.08 | 28.22 | 29.64 | 29.31 |
| 10% | 30.22 | 30.66 | 31.02 | 30.63 |
| 15% | 27.77 | 28.00 | 28.17 | 27.98 |
| 20% | 26.53 | 26.35 | 25.91 | 26.26 |
| 25% | 23.77 | 24.71 | 24.22 | 24.23 |
| 30% | 21.33 | 20.57 | 20.84 | 20.91 |
| 35% | 18.66 | 19.22 | 19.73 | 19.20 |

**Table 3** Average Compressive strength by using GGBS for 28 days

| **% Replacement by GGBS** | **Casting –I (MPa)** | **Casting – II (MPa)** | **Casting – II (MPa)** | **Average (MPa)** |
|---|---|---|---|---|
| 0% | 40.65 | 42.17 | 41.87 | 41.56 |
| 5% | 42.77 | 44.09 | 46.52 | 44.46 |
| 10% | 43.12 | 45.90 | 46.86 | 45.29 |
| 15% | 42.57 | 40.66 | 40.73 | 41.32 |
| 20% | 39.17 | 40.34 | 40.18 | 39.89 |
| 25% | 38.97 | 38.15 | 38.74 | 38.62 |
| 30% | 37.41 | 35.80 | 36.85 | 36.68 |
| 35% | 34.00 | 35.80 | 30.50 | 33.43 |
| 40% | 31.67 | 33.39 | 32.80 | 32.62 |
| 45% | 32.45 | 30.22 | 30.54 | 31.07 |
| 50% | 29.41 | 28.32 | 26.19 | 27.97 |

**Table 4: Compressive strength by using LFS for 7 days**

| **% Replacement by LFS** | **Casting –I (MPa)** | **Casting – II (MPa)** | **Casting – III (MPa)** | **Average (MPa)** |
|---|---|---|---|---|
| 0% | 26.42 | 27.41 | 27.21 | 27.01 |
| 5% | 28.66 | 26.22 | 27.73 | 27.53 |
| 10% | 29. 57 | 31. 84 | 30. 33 | 30.58 |
| 15% | 29.85 | 28.73 | 29.12 | 29.23 |
| 20% | 26.56 | 27.80 | 26.95 | 27.01 |
| 25% | 25.17 | 24.15 | 23.80 | 24.37 |
| 30% | 21.28 | 22.37 | 21.65 | 21.76 |
| 35% | 20.22 | 19.02 | 19.66 | 19.63 |

**Table 5:** Average Compressive strength by using LFS for 28 days

| % Replacement by LFS | Casting –I (MPa) | Casting –II (MPa) | Casting –III (MPa) | Average (MPa) |
|---|---|---|---|---|
| 0% | 40.65 | 42.17 | 41.87 | 41.56 |
| 5% | 43.15 | 40.97 | 42.65 | 42.25 |
| 10% | 42.55 | 44.73 | 45.34 | 44.20 |
| 15% | 46.87 | 44.17 | 43.65 | 44.89 |
| 20% | 42.96 | 40.19 | 40.74 | 41.29 |
| 25% | 39.18 | 39.52 | 38.15 | 38.95 |
| 30% | 37.50 | 37.70 | 36.24 | 37.14 |
| 35% | 35.14 | 33.46 | 32.71 | 33.77 |
| 40% | 31.74 | 34.83 | 30.27 | 32.28 |
| 45% | 29.85 | 28.21 | 26.91 | 28.32 |
| 50% | 27.77 | 25.34 | 26.69 | 26.60 |

**Table 6:** Compressive strength by using SCBA for 7 days

| % Replacement by SCBA | Casting – I (MPa) | Casting – II (MPa) | Casting – III (MPa) | Average (MPa) |
|---|---|---|---|---|
| 0% | 26.42 | 27.41 | 27.21 | 27.01 |
| 5% | 26.43 | 27.77 | 28.83 | 27.67 |
| 10% | 29.23 | 29.48 | 30.59 | 29.76 |
| 15% | 30.18 | 29.11 | 28.57 | 29.28 |
| 20% | 28.59 | 27.85 | 26.74 | 27.72 |
| 25% | 25.48 | 25.49 | 24.79 | 25.25 |
| 30% | 23.83 | 24.83 | 24.28 | 24.31 |
| 35% | 22.85 | 22.28 | 21.92 | 22.35 |

**Table 7:** Average Compressive strength by using Bagasse ash (SCBA) for 28 days

| **% Replacement by SCBA** | **Casting –I (MPa)** | **Casting – II (MPa)** | **Casting – III (MPa)** | **Average (MPa)** |
|---|---|---|---|---|
| 0% | 40.65 | 42.17 | 41.87 | 41.56 |
| 5% | 45.91 | 43.56 | 45.44 | 44.97 |
| 10% | 47.61 | 46.43 | 46.59 | 46.87 |
| 15% | 48.43 | 49.77 | 47.83 | 48.67 |
| 20% | 43.23 | 42.48 | 40.59 | 42.10 |
| 25% | 38.18 | 39.11 | 38.57 | 38.62 |
| 30% | 36.59 | 37.85 | 36.74 | 37.06 |
| 35% | 35.48 | 35.49 | 34.79 | 35.08 |
| 40% | 33.83 | 34.83 | 34.28 | 34.31 |
| 45% | 30.85 | 32.28 | 31.92 | 31.68 |
| 50% | 30.65 | 30.11 | 30.44 | 30.40 |

Split tensile test was performed with the help of UTM on cylindrical sample. Load was applied on the horizontal surface at height of cylinder. Two wood strips will apply at top and bottom surface where load was applied so that crushing of concrete does not take place where plane surface of UTM and surface of specimen meets. Size of cylinder sample will be 150 mm dia and 300mm height.

**Table 8** Split tensile strength of GGBS after 28 days

| **% Replacement by GGBS** | **Casting –I (MPa)** | **Casting – II (MPa)** | **Casting – III (MPa)** | **(Average) (MPa)** |
|---|---|---|---|---|
| 0% | 3.05 | 2.99 | 3.02 | 3.02 |
| 5% | 3.18 | 3.24 | 3.22 | 3.21 |
| 10% | 3.25 | 3.30 | 3.34 | 3.29 |
| 15% | 3.35 | 3.40 | 3.38 | 3.37 |
| 20% | 3.31 | 3.28 | 3.30 | 3.29 |
| 25% | 3.25 | 3.18 | 3.24 | 3.22 |
| 30% | 3.18 | 3.11 | 3.15 | 3.14 |
| 35% | 3.13 | 3.07 | 3.05 | 3.08 |

**Table 9:** Split tensile strength of LFS after 28 days.

| % Replacement by LFS | Casting –I (MPa) | Casting – II (MPa) | Casting – III (MPa) | Average (MPa) |
|---|---|---|---|---|
| 0% | 3.05 | 2.99 | 3.02 | 3.02 |
| 5% | 3.35 | 3.46 | 3.50 | 3.43 |
| 10% | 3.70 | 3.84 | 3.89 | 3.81 |
| 15% | 3.96 | 4.03 | 4.19 | 4.06 |
| 20% | 4.10 | 3.95 | 3.91 | 3.98 |
| 25% | 3.86 | 3.82 | 3.81 | 3.83 |
| 30% | 3.63 | 3.81 | 3.73 | 3.72 |
| 35% | 3.52 | 3.71 | 3.64 | 3.62 |

The Combination of different waste material was used to replace the cement upto maximum percentage so that in table 4.11 compressive strength of combination was represented in a form of 5G5L5S, which mean 5% of GGBS, 5% of LFS and 5% of SCBA were used to make cubes. From fig 4.10 it can be clearly seen that upto 30% replacement does not make such difference.

**Table 10:** Variation in compressive strength of combinations of waste materials

| Combination % | Casting – I | Casting – II | Casting – III | Average MPa |
|---|---|---|---|---|
| 5G5L5S | 42.65 | 46.87 | 44.62 | 44.71 |
| 5G5L10S | 45.58 | 43.80 | 47.90 | 45.76 |
| 5G5L15S | 41.77 | 42.63 | 40.25 | 41.55 |
| 5G5L20S | 39.72 | 41.62 | 40.01 | 40.45 |
| 5G10L5S | 40.90 | 45.15 | 43.42 | 43.15 |
| 5G10L10S | 42.56 | 45.37 | 46.32 | 44.75 |
| 5G10L15S | 46.31 | 45.23 | 47.98 | 46.50 |
| 5G15L5S | 43.91 | 44.52 | 45.31 | 44.58 |
| 5G15L10S | 40.20 | 41.12 | 39.90 | 40.40 |
| 5G20L5S | 46.20 | 42.18 | 43.34 | 43.96 |
| 10G5L5S | 43.80 | 42.34 | 45.80 | 43.98 |
| 10G5L10S | 38.48 | 40.37 | 42.36 | 40.40 |
| 10G5L15S | 39.59 | 41.73 | 40.28 | 40.53 |
| 10G10L5S | 43.59 | 40.79 | 41.37 | 41.96 |
| 10G10L10S | 43.72 | 43.59 | 42.89 | 43.40 |
| 10G15L5S | 44.72 | 42.51 | 41.53 | 42.92 |
| 15G5L5S | 41.64 | 40.96 | 42.65 | 41.75 |
| 15G5L10S | 42.74 | 43.01 | 41.77 | 42.50 |

| | | | | |
|---|---|---|---|---|
| 15G10L5S | 39.90 | 38.62 | 40.15 | 39.55 |
| 20G5L5S | 40.77 | 38.91 | 37.65 | 39.11 |

## 5. CONCLUSION

The study investigated the use of three industrial by-products—Ground Granulated Blast Furnace Slag (GGBS), Lime Sludge (LFS), and Sugarcane Bagasse Ash (SCBA)—as partial replacements for cement in concrete, aiming to enhance strength characteristics and reduce costs. The findings demonstrated that replacing cement with GGBS up to 15% yielded optimal compressive strength after 28 days, with a notable 12% increase in strength at 10% replacement. This highlights the potential of GGBS to significantly improve the performance of concrete when used judiciously. For Lime Sludge (LFS), it was observed that up to 20% replacement could be achieved without compromising the compressive strength of the concrete, showcasing its compatibility and effectiveness as a supplementary material. When it came to Sugarcane Bagasse Ash (SCBA), partial replacement levels were tested up to 50%, with 15% replacement providing the maximum compressive strength after 28 days of curing. This demonstrates SCBA's significant contribution to enhancing concrete properties when used in the right proportions. In addition to individual replacements, various combinations of these materials were tested to evaluate their synergistic effects. Among the combinations, a mix comprising 5% GGBS, 10% LFS, and 15% SCBA exhibited the highest compressive strength, making it the most effective blend for achieving maximum performance. Furthermore, the split tensile strength of concrete containing GGBS, LFS, and SCBA was found to be slightly higher than that of conventional concrete, indicating an overall improvement in mechanical properties. Beyond strength improvements, the incorporation of these by-products also resulted in significant cost savings. The study concluded that the cost of construction could be reduced by up to 18% due to the use of these waste materials, making it not only an environmentally sustainable approach but also an economically viable option for the construction industry.

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