International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 04 April 2025, pp: 1031-1042 www.ijaem.net ISSN: 2395-5252

Eco-Friendly Rigid Pavement Construction Using Alternative Cementitious Waste Materials

Ranjana Sharma[1], Dr. R.R.L.Birali[2], Akhand Pratap Singh[3]
M.Tech Scholar, Professor, Assistant Professor
Department of Civil Engineering
Shri Rawatpura Sarkar University, Raipur

Date of Submission: 15-04-2025 Date of Acceptance: 25-04-2025

ABSTRACT :- The present study focuses on promoting eco-friendly approaches in rigid pavement construction by exploring the use of alternative cementitious waste materials as partial replacements for Ordinary Portland Cement (OPC). With increasing awareness of the environmental and health hazards caused by large-scale cement production including greenhouse gas emissions, air and water pollution, and respiratory diseases there is a pressing need to identify sustainable alternatives. Various industrial and agricultural waste materials such as Ground Granulated Blast Furnace Slag (GGBS), Ladle Furnace Slag (LFS), and Sugarcane Bagasse Ash (SCBA) have shown promising potential as substitutes due to their similar chemical composition and binding properties. This study evaluates the physical, chemical, and mechanical performance of concrete incorporating these waste materials in varying proportions (5% to 50%) for rigid pavement applications. The objective is to achieve a balance between environmental sustainability, economic feasibility, and structural performance. The research aims to raise awareness among engineers and researchers about the benefits of using green concrete for highway infrastructure, thereby contributing to more sustainable construction practices.

Keywords: Eco-friendly concrete, Cement replacement, Industrial waste, Rigid pavement, Sustainable construction.

I. INTRODUCTION

1.1 General

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.

1.2 Introduction

As of 2024, the global cement industry continues to produce over 4 billion tonnes annually, with India contributing approximately 440 million tonnes in 2024, reflecting a 5.4% year-on-year growth This substantial production volume has raised environmental and health concerns due to the emission of cement dust and other pollutants.

Environmental and Health Concerns:-The production of cement releases significant amounts of dust and particulate matter, which can adversely affect air quality and human health. Recognizing these issues, the Ministry of Environment, Forest and Climate Change (MoEFCC) in India has implemented stringent emission standards for cement plants. As per the latest guidelines, the permissible stack dust emissions limit is set to 30 mg/Nm³, a reduction from the previous limit of 50 mg/Nm³, indicating the government's commitment to mitigating environmental pollution from cement manufacturing processes.

Sustainable Alternatives and Waste Utilization:-To address the environmental

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challenges posed by cement production, researchers and industry stakeholders are exploring the use of alternative materials and waste products in construction. Materials such as fly ash, steel slag, e-plastic waste, and recycled concrete aggregates are being investigated for their potential to replace a portion of Ordinary Portland Cement (OPC) in concrete mixes. Utilizing these materials not only reduces the reliance on OPC but also aids in the management of industrial and electronic waste, contributing to a circular economy.

For instance, fly ash, a by-product of coal combustion in thermal power plants, has been effectively used in road construction and other infrastructure projects. The Indian government has issued guidelines promoting the use of fly ash in construction activities, emphasizing its role in sustainable development.

Table 1.1 Production of Cement by Different Companies in India

Company	**Production Capacity (MTPA)**	**Notes**
UltraTech Cement Ltd	156.66	India's largest cement producer
Adani Group (Ambuja, ACC)	93.0	Includes recent acquisition of Penna Cement (14 MTPA)
Shree Cement Ltd	50.9	Commissioned additional capacity
Dalmia Bharat Ltd	46.6	Expanded capacity; targets 110–130 MTPA by 2031.
Nuvoco Vistas Corp.	25.0	Plans to increase capacity to 26 MTPA by 2026.
The Ramco Cements Ltd	22.0	Aims to reach 25 MTPA by 2026.
JK Cement Ltd	20.67	Expanded capacity; targeting 30 MTPA by 2026.
Birla Corp. Ltd	20.0	Plans to expand to 25 MTPA by 2026.
India Cements Ltd	16.6	Acquired by UltraTech Cement in 2024.
Kesoram Industries	10.75	Cement business being acquired by UltraTech Cement
Heidelberg Cement India	12.6	UltraTech Cement is in talks to acquire this unit.
Cement Corporation of India	3.85	Government-owned; operates three profit-making units.

Table 1.2 Main Constituents of Cement

Constituents	**Percentage**
Lime (CaO)	60-67%
Silica (SiO_2)	17-25%
Alumina (Al_2O_3)	3-8%
Iron oxide (Fe_2O_3)	0.5-6%
Magnesia (MgO)	0.1-4%
Sulphur trioxide (SO_3)	1-3%
Soda and/or Potash (Na_2O+K_2O)	0.5-1.3%

Table 1.4 Waste Productions by India in Construction Site

Constituent	**Average Waste (Million Tones/Year)**
Soil, Sand and gravel	4.67
Bricks and masonry	4.00
Concrete	3.04
Metals	0.665
Bitumen	0.275
Wood	0.275
Others	0.125

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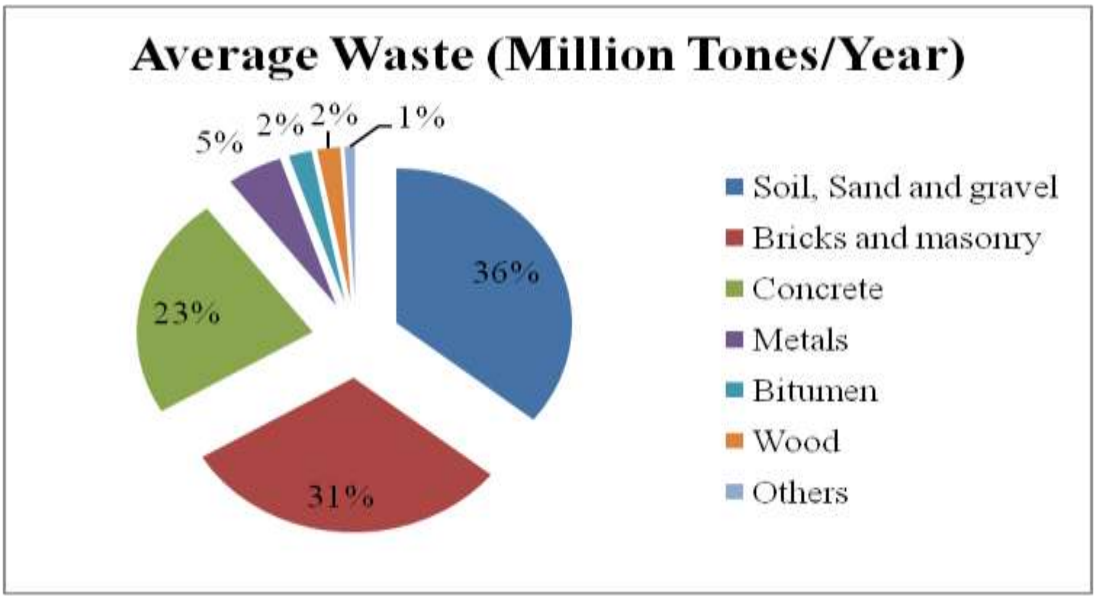

Figure 1.1:- Waste Production rate in India

Table 1.6 Different Type of Waste to be Used in Construction in Past

S. No.	Waste Material	Author (Year)	Remarks
1	Fly Ash	Mohammadinia et al. (2017)	Cementinous property of fly ash was examined in order to use with the reclaimed asphalt pavement and crushed bricks. Stability and strength of the pavement was found increased with an addition of 15% of fly ash.
2	Steel Slag	Shen et al. (2008)	Steel slag mix with solid waste and used into base layer of pavement. Binding property of steel slag is also compared with cement and found to me more superior all other base material
3	Silica Fume	Maddalena et al. (2018)	Low carbon material can be replaced instead of using OPC. 80% of strength can attain by using Silica fumes in concrete.
4	E-Waste	Krishna and Rao (2014)	15% of E-waste can be replaced instead of course aggregate. Optimum compressive and tensile strength are provided by using E-waste.
5	Wood Waste	Wang et al. (2017)	Magnesium phosphate cement (MPC) mixed with wood waste to check reinforcing efficiency. PVA (polyvinyl alcohol) fiber reinforced also increases flexural strength of MPC.
6	Ground Granulated Blast Furnace Slag (GGBS)	Manjunatha et al.(2014)	Addition of GGBS up to 50 % as the replacement of cement in M20 grade of concrete resulted in

			increment of the compressive strength due to extra fine which reduces the void in the mixture.
7	Recycled Course Aggregate (RCA)	Wagih et al. (2012)	Replacement of RCA with natural aggregate up to 50% exhibiting the same strength as shown by fresh aggregate. However, a reduction in strength up to 18% was observed if natural aggregate get replace completely (i.e. 100%).
8	Plastic Waste	Jassim (2017)	Cement was replaced successfully with 35% of plastic waste.
9	Marble Waste	Ashish (2017)	Cement and sand both of 10%replaced by 20% of marble waste.
10	Rice Husk	Sathiparan et al. (2018)	Grinded husk can be replaced instead of using sand only in ratio of 1:5:1 (cement, sand, waste)
11	Bagasse Ash	Amin (2011)	20% of cement can be replaced by bagasse ash optimally.
12	Paper Waste	Rajput et al. (2012)	Waste concrete brick made up of 85% of paper waste gives highest strength.
13	Ladle Furnace Slag (LFS)	Marinho et al. (2017)	Huge amount of CaO approx 88% was found so best suitable for replacement of cement.

1.3 Objective

- To study the physical and chemical properties of waste materials and sustainable utilization of waste.
- To purpose an alternative of cement without compromising with its properties.
- To optimize the Cost effectiveness of concrete by using different waste materials.
- To purpose guidelines regarding the use of waste material in pavement construction and make new concrete mix design.

II. LITERATURE REVIEW

2.2 Literature Review of Different Waste Material

2.2.1 Recycled Concrete Aggregate (RCA)

Wagih et al. (2012) studied the aspect regarding the use of reused concrete and demolished concrete waste as the replacement of natural aggregate (NA). Approx 50 sample were made by replacing of NA with RCA of 0%, 25%, 50%, 75%, 100% and by adding super plasticizer from 0% to 1.3%. Silica fume in very small size were added to 10% of cement. By performing various test different properties of concrete like compressive strength etc, were measured. From the study it was concluded that use of RCA will result in the reduction in the workability of concrete mix and in the compressive strength also.

Singh et al. (2005) examined the suitability of recycled aggregate as a road pavement material. For the same purpose a comparison was made between natural aggregate and recycled aggregate (RA). Virgin aggregate (VA) and RA was mixed with several blend mixture in a ratio of 20% to 80%. Later, CBR and resilient modulus test were conducted. It was observed that 100% of RCA was depicting lesser resilient modulus value then the 100% VA but RAP was having higher value of resilient modulus then VA. So, it was concluded that RAP is better than RAC for the subbase layer of pavement.

2.2.2 Red Clay Brick Waste (RCBW)

Few yew year before **Robayoet al. (2016)** investigated the behavior of RCBW as alkaline and admixture of Na_2SiO_3 and OPC. Five samples were made during the study. Out of which one sample consisting 100% RCBW and remaining samples were contained OPC in different proportion i.e. 5%, 10%, 15%, 20%. It was observed that 10 % of OPC sample mixture shows utmost compressive strength of 41.39 MPa. It was also found that addition of corroborates increase the compressive strength of the mix. The whole combination of NaOH + Na_2SiO_3 and 20% of OPC gives strength of 102.6

MPa at 25°C.

III. METHODOLOGY

3.2 Material and Methods

After comparing the composition of various waste materials with OPC cement it was concluded that waste material like GGBS, LFS and Bagasse ash will be suitable for the partial replacement of cement as shown in table 3.1. In place of sand, stone dust will be used and for aggregate recycled aggregate will be used to some percentage. Different test that will be conducted is shown in table 3.3 to know the best suitable percentage of replacement of cement. In the end, the cost of conventional concrete will be compared with new green concrete.

Table 3.1 Sample to be Made of Different Proportion

Cement %	GGBS %	Ladle Furnace Slag %	Bagasse Ash %
100	0	0	0
95	5	5	5
90	10	10	10
85	15	15	15
80	20	20	20
75	25	25	25
70	30	30	30
65	35	35	35

Table 3.2 Difference in Chemical Composition of Cement and Different Waste Materials

Waste Type	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	MnO
OPC	20.27	5.32	3.56	60.41	2.46	-	-	-	-
GGBS	35.00	13.00	-	40.00	8.00	-	-	-	-
Bagasse Ash	78.34	8.55	3.61	2.15	1.65	3.46	0.12	0.50	0.13
Ladle Furnace Slag	15.00	14.30	1.54	48.37	15.25	0.36	0.43	0.20	-

Table 3.3 Different Tests That Has to be Performed

Cement	Concrete
Fineness Test	Compressive Strength Test
Consistency Test	Split Tensile Test
Strength Test	
Specific Gravity Test	
Settling Time Test	

3.3 Design Mix Procedure

This study aims to make use of the waste material for replacing the cement and using in construction of roads. Therefore, mix design of M40 grade concrete was done by following the guidelines of the Indian standards which is namely; IS: 465-2000 and IS 10262 -1982**.** With help of these codes the quantity of concrete required for 1 cubic meter can be estimated and at which water cement ratio concrete going to be mixed is also selected from these codes as shown in Fig 3.4.

Table 3.4 Mix Proportioning of Concrete for 1m^3

S. No.	Materials as Per (IS 456-2000)	Calculated Value (IS 10262:2009)
1	Cement	350 kg/m^3
2	Water	1140 kg/m^3
3	Fine Aggregate	896 kg/m^3
4	Coarse Aggregate	1140 kg/m^3
5	Chemical Admixture	7 kg/m^3

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3.4 Estimation of the Quantity of Concrete Mix

The calculations of concrete as per unit volume shall be measured as follows:

The volume of cubes = 0.15 × 0.15 × 0.15 × 3 = .01012m^3

Cement = 350×.01012=3.54kg

Sand = 896×.01012=9.97kg

Aggregate=1140×.01012=11.53kg

Water= 140 × .01012 = 1.41kg

Admixture=7×.01012=0.0708kg

After calculating the quantity some sample were made of some specific size and shapes. Cubes are made for to test the compressive strength of concrete and cylinders are made to measure the tensile strength of concrete. Step by step all the procedure is shown below with the help of different diagrams.fig 3.2 shows the casting of cubes and fig 3.3 shows cylinder moulds filled with concrete. After remolding then sample has to be kept in curing tank for 28 days. Before testing sample should be in dry condition, then with the help of CTM strength was measured.

Figure 3.2:-Casting Cube Sample

Figure 3.3:- (a) Cylinder Mould **(b) Casting Cylinder Sample**

Figure 3.4:-Curing Tank **Figure 3.5:-Sample After Curing**

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Figure 3.6:-Compressive Testing Machine

Figure 3.7:- Universal Testing Machine

IV. RESULT ANALYSIS

4.1 General

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.

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Table 4.1 Values of Different Test Results

S. No.	Experiments	Results
1	Normal Consistency of Cement	27%
2	Initial Setting Time of Cement	27 Minute
3	Final Setting Time of Cement	7 Hours
4	Compressive Strength of Cement 3 Days 7 Days 28 Days	21 N/mm^2 30 N/mm^2 42 N/mm^2
5	Tensile Strength of Cement 3 Days 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 Combination of different waste material was used to replace the cement up to maximum percentage so that in table 4.11compressive 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 fig4.10 it can be clearly seen that up to 30% replacement does not make such difference.

Table 4.11Variation 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

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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

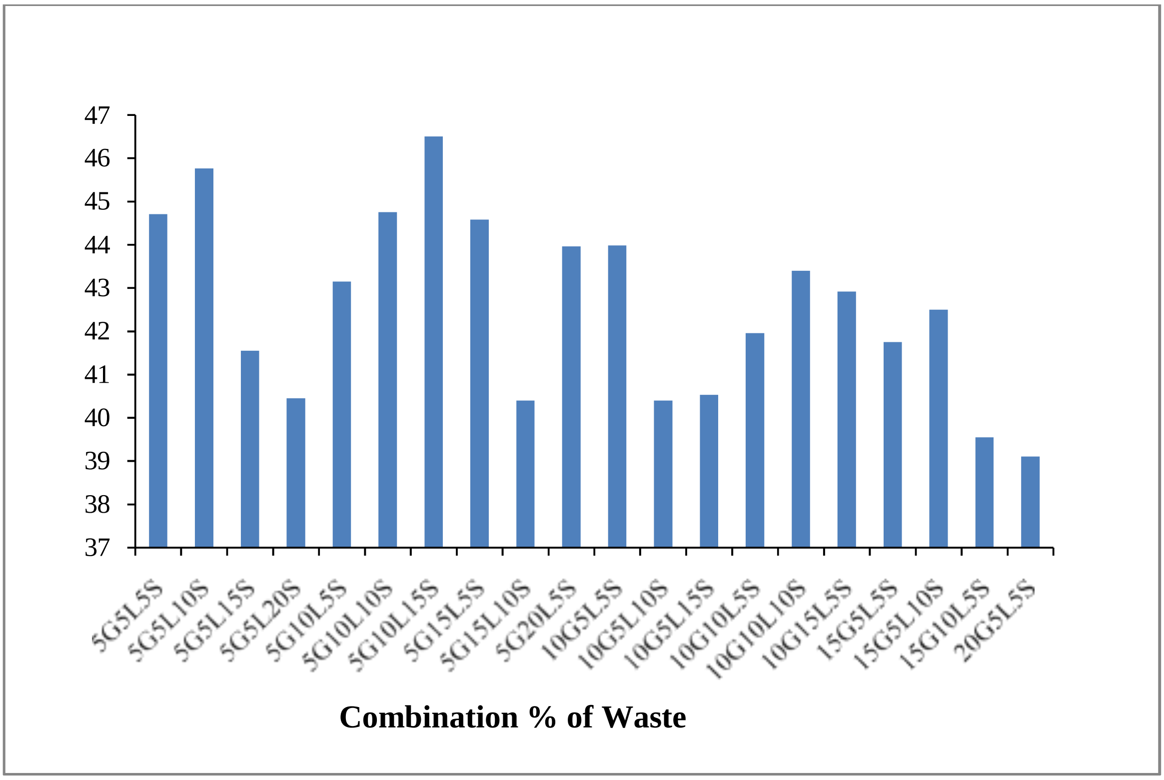

Figure 4.10:- Graph between Compressive Strength and Combination % of Waste Material

Number of cement bags in 1000m^3 concrete = 350 X 1000\50 =7000 bags
Cost of stone dust per tonnes = 778 Rs Cost of aggregate per tonnes=1223Rs

Table 4.12 Comparison of Costs for Conventional and Green Concrete

Materials	**Cost of Conventional Concrete**	**Cost of Green Concrete**
Cement	2870000	2009000
Stone Dust	696889	696889
Aggregate	1393334	1393334
Waste Materials GGBS LFS Bagasse Ash	 0 0 0	 0 0 0
Total Cost	**4960223**	**4099223**

Amount saved=861000Rs

V. DISCUSSION AND CONCLUSIONS

5.1 General

This report emphasis upon the information and knowledge about the utilization of waste materials for the construction of main road. Dubai is the only one country which produces approximately 27.7MT of concrete waste. For make a sustainable environment it is necessary to recycle and reuse the demolished concrete and other waste material also. The material that comes during demolishing building like concrete, asphalt, wood, metals, gypsum, plastics and salvaged building components should be recycled. It also reduces the cost of landfill. If some serious steps will be not taken right now then the production of C&D waste will increase up to 300 million tones per year. The knowledge was obtained after reviewing various literatures supplemented by recent published reports, analysis updated by professors at completely dissimilar forums, and private conferences which was conducted by different consultants. Different types of waste material were used in highway construction but the definite ratio can't be explained until nowadays. However, lots of researches have been take place across the world but none was succeeded in introducing an alternative of cement (i.e. 100% replacement) for the construction purposes. Reviewing of literature revealed that maximum utilization of the waste material was up to 50% (i.e. for GBBS) now till date. Consequently, present study is recommended to utilize the waste materials completely in rigid pavement instead of cement (i.e. 100% replacement of cement) which will be an aid to the environment, human health and construction field also.

5.2 Discussions

In fig 4.1 and 4.2 graph shows the variation in compressive strength with the percentage of GGBS for 7 and 28 days, which results 15% replacement of cement by GGBS optimally. At 10 % replacement there was an increment of 12% compressive strength.

In fig 4.3 and 4.4 graph represented the variation in compressive strength with the percentage of LFS for 7 and 28 days in which 20% replacement was observed without compromising with its strength.

In fig 4.5 and 4.6 graph gives the variation in compressive strength with the percentage of SCBA for 7 and 28 days. While replacing cement up to 50%, it was concluded that 15 % gives the maximum strength after 28 days of curing.

In fig 4.7, 4.8 and 4.9 graph represented the calculated deviation in Split tensile strength with the percentage of GGBS, LFS and SCBA for 28 days which was higher than the normal concrete. There will be not lots of improvement but also not decrement in split tensile strength. After that we can say that replacement of waste material partially has no adverse effect in tensile strength.

In fig 4.10 graph shows the combination results of compressive strength and by analyzing then it come to know that 30% of cement can be replaced. Cost of construction will be reduced to 18% of the total cost.

5.3 Conclusion

a) Compressive strength for 28 days by using GGBS gives optimum results, when cement was replaced up to 15%. At 10 % replacement there was an increment of 12% compressive strength.
b) In case of LFS 20% replacement was observed without compromising with its strength.
c) After that SCBA was partially replaced up to 50% and it was concluded that 15% gives the maximum strength after 28 days of curing.
d) Different combinations of these three waste materials were prepared during the study. On the basis of the results it was observed that 5% of GGBS, 10% of LFS and 15% of SCBA in the mix exhibit maximum compressive strength.
e) Split tensile strength of GGBS, LFS and SCBA are slightly higher than the conventional concrete.
f) Cost of construction will be reduced up to18% of the total cost of the project.

5.4 Future Scope

These waste materials improve the chemical, mechanical and physical properties of concrete. The proposed guidelines of the present study can be implementing in the field in the construction of rigid pavement with the application of reinforcement. Study can be extended by examining the behavior of the green concrete (i.e. made with the waste material) under different loadings and different climatic condition (i.e. to examine different stresses which will take place on green concrete). Beside this, the percent utilization of the waste material proposed in the present study can be increased (i.e. up to 80 or 100 %) by proposing different mix design (i.e. in varying proportion). Furthermore, some other waste materials can also be introduced by analyzing their chemical and physical properties in order to make the green concrete and sustainable environment.

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