EXPERIMENTAL AND NUMERICAL STUDIES ON UTILIZATION OF STABILIZED COPPER SLAG AND FLY ASH IN FLEXIBLE ROAD PAVEMENTS

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ABSTRACT: ***The scope of the present research consists of two main parts, namely, experimental investigations on engineering properties of different waste material and three-dimensional finite element analysis of five layer flexible pavement system. The experimental program is carried out in two parts. First, compaction characteristics, unconfined compressive strength, CBR, resilient modulus and cumulative plastic strain of different trial mixes of the waste materials are investigated and the optimum mixes are determined. These mixes werechosen based on their strength characteristics and availability of those particular waste materials in the vicinity of the corresponding metal industry. The behaviour of the these waste mixes for base course are compared with that of the conventional Wet Mix Macadam (WMM) and the waste mixes for subbase course are compared with that of the conventional Granular Subbase (GSB). As the fly ash percentage in the CFL and CFC mixes increases, the compressive strength increases up to the optimum fly ash content and decreases thereafter. The optimum fly ash content for CFL and CFC mixes was found to be 30% and 20%, respectively. UCS values increase continuously with increase in binder (lime and cement) content. The gel formation increases with an increase in binder content leading to a more efficient binding of the slag particles. A linear correlation between IDT and UCS was observed with a good R2 value for both the mixes. The IDT value was found to be 17.3% and 18.1% of UCS value for CFL and CFC mixes, respectively. Mr value increases with the increase in deviator stress. Most of the CFL and CFC mixes exhibited higher resilient modulus than WMM indicating that a lower thickness of base layer can be adopted if WMM is replaced with the CFL and CFC mixes***

Fly ash with minimum 6% lime and fly ash with minimum 6% cement satisfy the minimum strength criteria recommended by IRC: 20-2002 for their use in the subbase course of flexible pavements. The CBR value of only fly ash is 12. As per IRC: 37-2012, the sub base materials should have minimum CBR value of 30 percent for traffic exceeding 2 msa. The CBR value was found upto 89% and 73% for FAL and FAC mixes, respectively.The resilient modulus test Mr value increases when cell pressure and deviator stress increases. A three parameter model provides the best fit for the effects of both confining pressure and deviator stress on resilient modulus of FAL and FAC mixes.

Among the three stress-dependent models of resilient modulus, the three- parameter model provided the best fit. A power model provided a very good fit regression equation for the estimation of permanent strain. The service life of a flexible pavement having the optimum mixes such as copper slag-fly ash-lime (CFL) and copper slag-fly ash- cement (CFC) in the base course vis-a-vis the conventional Wet Mix Macadam (WMM) base layer and fly ash- lime (FAL) and fly ash-cement (FAC) optimum mixes in the subbase course vis-a-vis the conventional Granular Subbase (GSB) layer is also evaluated. Finite-element analyses of a five layer flexible pavement system resting on subgrade soils of CBR values of 3% and 4% are carried out. The boundary conditions employed and the finite element mesh adopted based on a small parametric study. The pavement section model as an axisymmetric solid and 15- noded triangular elements were used for all the layers. Roller supports are provided along the left and right boundaries. At the bottom boundary, fixed supports are provided to restrain any movement in the vertical and lateral direction. Linear elastic-perfectly plastic model was used for the subbase, base (WMM), bituminous layer (DBM) and wearing course (BC). The equivalent thicknesses of optimum mixes base and subbase as obtained by fatigue failure criterion obtained by AASHTO method.

Key Words: Stabilized Copper Slag, Fly Ash, Flexible Road Pavements

I. INTRODUCTION

Roads are the key to the development of an economy. A good road network constitutes the basic infrastructure that accelerates the development process through connectivity and opening up of the backward regions to trade and investment. Roads also play a key role in inter-modal transport development establishing links with airports, railway stations and ports. In addition, they have an important role in promoting national integration, which is particularly important in a large country like India.

India is passing through a great construction boom in the road industry. Several thousand kilometers of roads are being or to be constructed in the next five to ten years across the country in the form of either National Highways Development Programme (NHDP) or in the form of rural roads Pradhan Mantri Gramin Sadak Yojna (PMGSY). This requires huge quantities of road construction materials. The most difficult challenge for development of road network is to execute projects in harmony with the concept of sustainable development. The road industry is therefore looking forward for alternative materials and construction technology, which areenvironment friendly, energy efficient and cost effective for the construction and maintenance of roads.

In order to mitigate the problems associated with the use of rock aggregates, locally available materials and soils are to be harnessed for use of road construction. These materials or soils may not exactly match with the specifications as we are currently adopting for construction of roads. This may be turned as non-standard or non-traditional materials. The World Roads Association has defined non-standard and non-material a “any material not wholly in accordance with the specification in use in a country or region for normal road materials but which can be used successfully either in special conditions, made possible because of climatic characteristics or recent progress in road techniques or after having been subject to a particular treatment” which are easily accessible and available in sufficient quantity and can be used forroad construction either directly or with treatments. In this connection locally occurring materials like soil, gravel, moorum, laterite, sand, and emerging materials like mine waste, industrial slag, Municipal waste, Waste Plastic, jute geo-textile, soil- enzymes, etc. can be effectively used singly or in combination with other materials alternative to conventional materials, with significant economy after studying their physical and engineering properties for their suitability in road construction.

Objectives

The detailed objectives of the present work are listed below: To study the engineering properties of copper slag-fly ash-lime (CFL) and copper slag- fly ash-cement (CFC) mixes for use in base material and also studied the fly ash- lime (FAL) and fly ash-cement (FAC) mixes to be used in road subbase materials.

I. To study the mechanical characteristics of the waste materials in different combinations under static and cyclic loading conditions.

II. To study the long term behavior of these mixes under the durability tests.

III. To study the micro structural behaviour and generation of hydration products of all mixes through SEM and XRD tests.

IV. To find out the service life ratio by using Plaxis software.

V. To find out the economical benefit, when the optimum mixes materials replaced by conventional granular materials.

II. MATERIALS USED

In this experimental program, the primary stage includes the preliminary research on selecting the raw materials.

Materials

Copper Slag

This feasibility study of super fine copper slag waste material in land filling and road construction is sponsored by M/S Hindalco Industries Limited, Dahej, Gujrat. Super fine copper slag is a waste material produced during extraction of copper concentrate from high copper ore by floatation and filtration processes.

Fly Ash

Fly ash was collected from Hindalco Industries Ltd. (Unit: Birla Copper) Dahej, Bharuch, Gujarat. It was air dried and mixed thoroughly in dry condition. Then the fly ash sample was stored in air tight container for subsequent use. Also, this fly ash satisfies all the physical requirements for use as a pozzolana in lime-fly ash concrete as per IRC: 20 (2002). In accordance with ASTM C618 (1999), this fly ash belongs to Class F type.

Lime

Lime used for the present study is hydrated lime. It was procured from local marketand was kept in air tight polythene bags. CaO content in the lime is more than 70%.

Cement

Cement used in the research work is 53 Grade Ordinary Portland cement produced by J K Laxmi Cement and procured from the local market. Cement was stored in an air tight container kept at dry place.

III. EXPERIMENTAL PROGRAM

The experimental program is carried out in two parts. First, compaction characteristics, unconfined compressive strength, CBR, resilient modulus and plastic strain of different trial mixes of the waste materials are investigated and the optimum mixes are determined. Next, durability tests, X-ray diffraction (XRD) tests, scanning electron microscopy (SEM) tests and pavement model tests are performed on the optimum mixes.

Mix proportions and compaction characteristics

Modified proctor compaction test was carried out on different trial mixes of base and sub base materials to determine the optimum moisture content (OMC) and maximum dry density (MDD). The different trial mixes for each materials are as follows:

Base course materials

Copper slag-fly ash-lime (CFL) and Copper slag-fly ash-cement (CFC) mixes used in base course layer inflexible pavement system. Copper slag was replaced bydifferent percentages (10, 20, 30, 40 and 50%) of fly ash by weight. Different percentages of (0, 3, 6, 9, 12) of lime and (0, 4, 6, 8, 10) of cement by weight were then mixed with each combination of copper slag - fly ash mixes. For CFL and CFC mixes, the weight of binder content such as (lime and cement) percentage of the totalweight of copper slag and fly ash.

Subbase course materials

Fly ash mixed with different percentages (3, 6, 9, and 12%) of lime (FAL) and (4, 6, 8, and 10%) cement (FAC) by weight as used in subbase course layer in flexible pavement system.For all mixes, the weight of lime/cement is stated as the percentage of the total combined weight of slag and fly ash. For example, if the total weight of a CFL mix is 110 grams, then a 70C-30F-10L mix indicates that the weights of copper slag, fly ash and lime in the mix are 70, 30 and 10 gms, respectively

Unconfined compressive strength

Unconfined compressive strength (UCS) test was carried out on all the trial mixes of the base and subbase materials. For the determination of unconfined compressive strength, the raw materials were blended together in a required proportion in drycondition. A right amount of water (close to OMC) was added to give proper consistency to the mixture for easy molding. Cylindrical samples of 50 mm diameter and 100 mm height were then prepared by compacting the mix at their corresponding OMC and MDD. The samples were sealed in an airtight polythene bag and kept at room temperature of 27±2º C for different curing period. The unconfined compressive strength of these cured samples was then determined using a conventional compression testing machine at a constant strain rate of 0.6 mm/min as per IS: 2720 (Part X)-1991 as shown in Fig 3.1. A typical scatter in UCS data, three identical specimens were tested for each trial mix and the average value was observed. Fig 3.2 shown the failure of UCS test sample and a view of UCS sample specimen.

Figure 1. UCS sample test in progress

California bearing ratio (CBR)

For the determination of California bearing Ratio test, is essential to study its feasibility for the utilization in the subbase course of flexible pavement system as per IRC: 37-2012. All the materials i.e. fly ash, binder with lime and cement content mixed together in dry condition. Then the required amount of water (close to OMC) was added in the sample Samples were moulded in standard mould of 150 mmdiameter and 127.7 mm height specified in IS: 2720 (Part-16)1987. To find out the effect of curing period on the strength, samples were cured for 7 days. Then samples were soaked in water for a period of 4 days. Then the CBR of these soaked samples were then determined using a compression testing machine at strain rate of 1.25 mm/ min. CBR test specimen is shown in Fig.

Durability Test

Durability tests adopted in the present study are applicable for the stabilized pavement materials. The tests were carried out in accordance with ASTM D 559 (2003). The specimens were first cured for 28 days and then subjected to several wetting and drying cycles. One wetting and drying cycle consists of 5 hours soaking in water and 42 hours of heating at a temperature of 72º C in a thermostatically controlled oven. The strength loss of the specimens was determined after 12 such cycles of alternate wetting and drying.The loss in weight was calculated using the formula written below:

Loss in weight (%) = (WI – W F) / (WI)

Where, WI = Initial dry weight of samples, WF = Final dry weight of sample after 12 cycles of wetting and drying

IV. RESULTS AND DISCUSSION

The results obtained in this research work were presented here.

Physical and Chemical Properties of Raw Materials

Table. 4.1 Physical properties of the raw materials.

Physical properties	Copper slag	Fly Ash
Color	Black	Grey
Specific Gravity	3.24	2.38
Particle Size Distribution as per IS: 2720 (Part IV)-2006		
Coarse Sand size (%) (2 mm to 4.75 mm)	21%	0
Medium Sand size (%)(0.425 mm to 2.0 mm)	72%	0
Fine Sand size (%)(0.075 mm to 0.425 mm)	7%	9%
Silt + Clay size (%) (less than 0.075 mm)	0	91%
Coefficient of uniformity (Cu)	2.5	6
Coefficient of curvature (Cc)	1.74	2.67
IS Classification	SP	ML

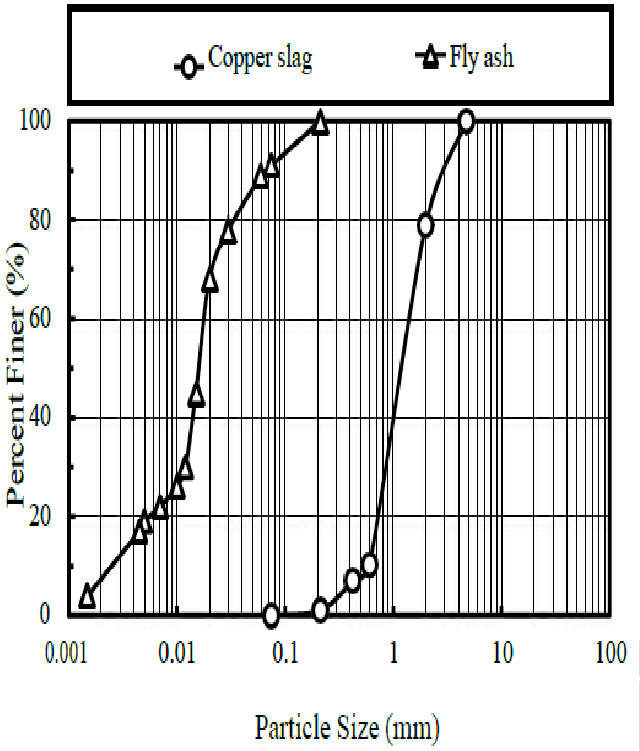
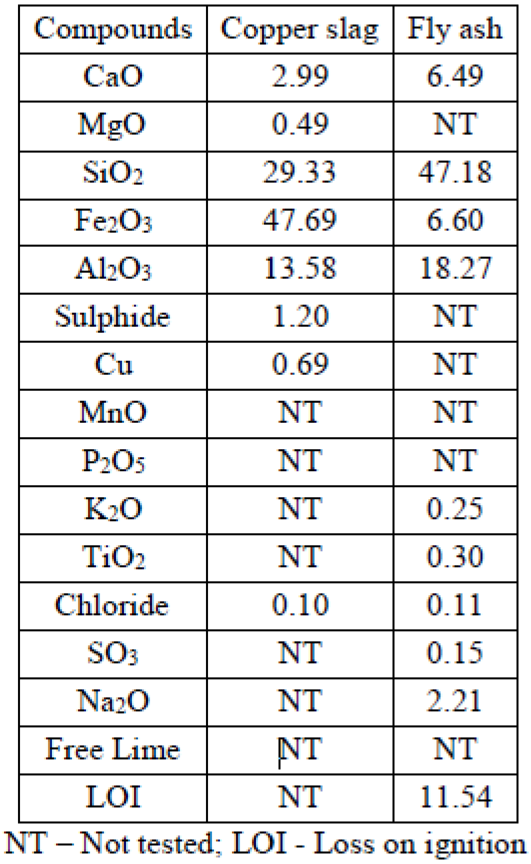


Fig 2. Grain size distribution.

Table 4.2 Chemical composition of the raw materials in percentage by weight



Compounds	Copper slag	Fly ash
CaO	2.99	6.49
MgO	0.49	NT
SiO_2	29.33	47.18
Fe_2O_3	47.69	6.60
Al_2O_3	13.58	18.27
Sulphide	1.20	NT
Cu	0.69	NT
MnO	NT	NT
P_2O_5	NT	NT
K_2O	NT	0.25
TiO_2	NT	0.30
Chloride	0.10	0.11
SO_3	NT	0.15
Na_2O	NT	2.21
Free Lime	NT	NT
LOI	NT	11.54

NT – Not tested; LOI - Loss on ignition

Unconfined compressive strength

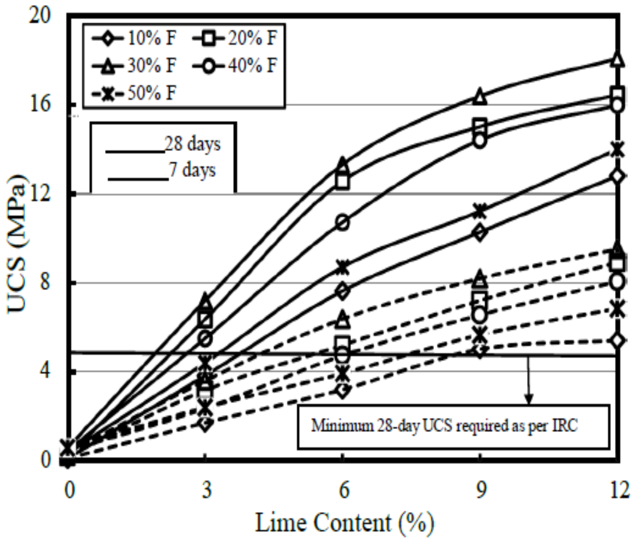
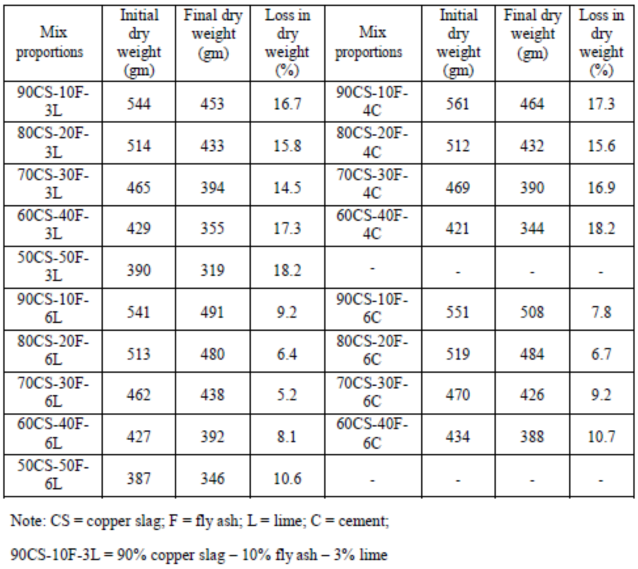


Fig. 3. Variation of UCS with lime content for different copper slag-fly ash-lime mixes

Durability

Table 4.3 Durability test results



Mix proportions	Initial dry weight (gm)	Final dry weight (gm)	Loss in dry weight (%)	Mix proportions	Initial dry weight (gm)	Final dry weight (gm)	Loss in dry weight (%)
90CS-10F-3L	544	453	16.7	90CS-10F-4C	561	464	17.3
80CS-20F-3L	514	433	15.8	80CS-20F-4C	512	432	15.6
70CS-30F-3L	465	394	14.5	70CS-30F-4C	469	390	16.9
60CS-40F-3L	429	355	17.3	60CS-40F-4C	421	344	18.2
50CS-50F-3L	390	319	18.2	-	-	-	-
90CS-10F-6L	541	491	9.2	90CS-10F-6C	551	508	7.8
80CS-20F-6L	513	480	6.4	80CS-20F-6C	519	484	6.7
70CS-30F-6L	462	438	5.2	70CS-30F-6C	470	426	9.2
60CS-40F-6L	427	392	8.1	60CS-40F-6C	434	388	10.7
50CS-50F-6L	387	346	10.6	-	-	-	-

Note: CS = copper slag; F = fly ash; L = lime; C = cement;

90CS-10F-3L = 90% copper slag – 10% fly ash – 3% lime

Indirect tensile strength

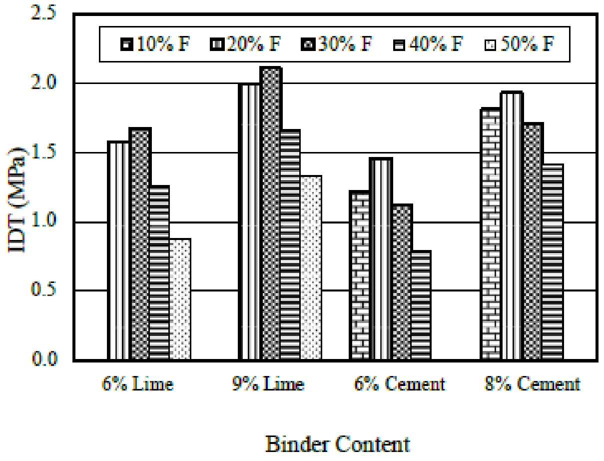


Fig. 4. Influence of fly ash content and binder content on IDT values of CFL and CFC mixes for 28 days of curing

Relationship between UCS and IDT test

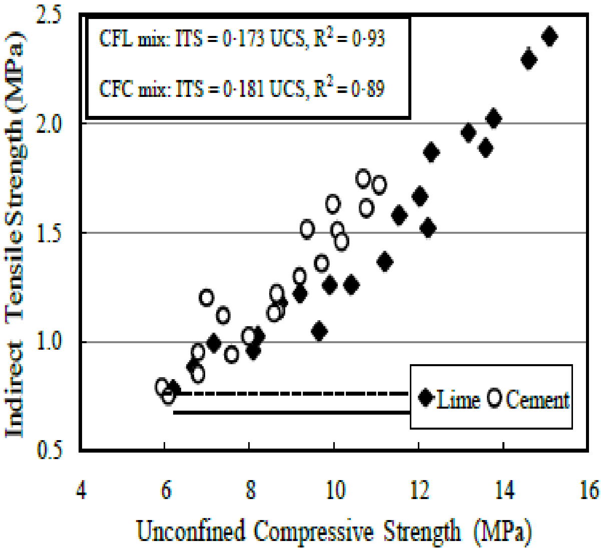


Fig. 5. Relationship between UCS and IDT for different curing period for copper slag-fly ash-lime and copper slag-fly ash-cement stabilized materials

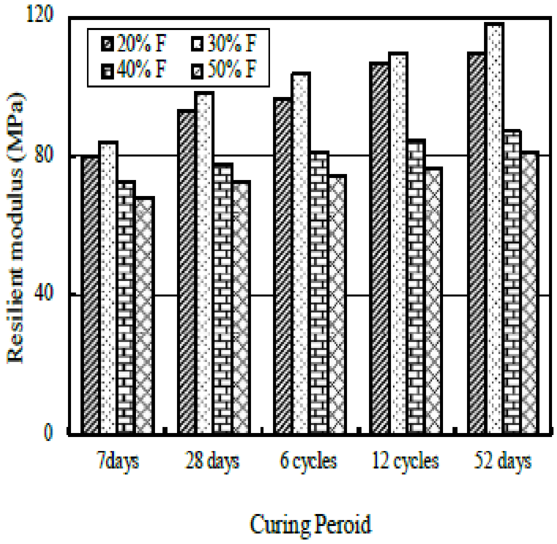


Fig. 6. Effect of curing period and wetting-drying cycles on resilient modulus of CFL mixes with 6% lime content ($\sigma 3$ = 34.5 kPa and σd = 93.1 kPa)

Permanent deformation characteristics

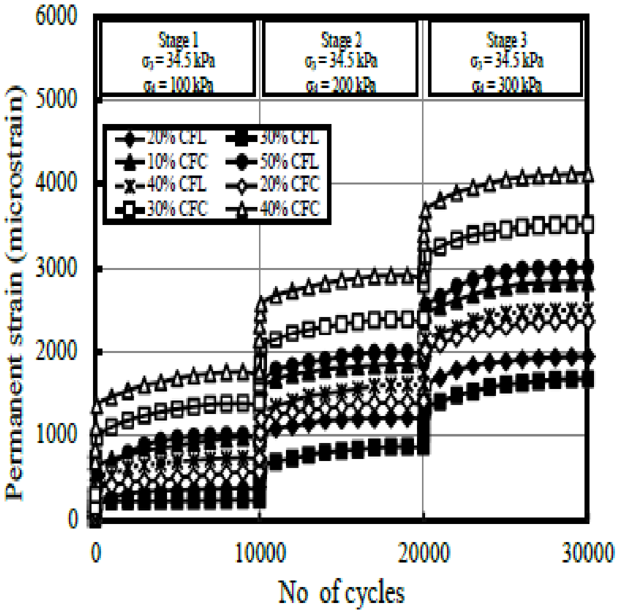


Fig. 7. Variation of permanent strain with loading cycles for different mixes at 28 days of curing

V. CONCLUSIONS

These following conclusions are given based on the above experimental results.

Engineering properties of copper slag-fly ash-lime (CFL) and copper slag-fly ash-cement (CFC) mixes were investigated for their utilization as base course material in flexible pavements. The following conclusions are drawn:

- As the fly ash percentage in the CFL and CFC mixes increases, the compressive strength increases up to the optimum fly ash content and decreases thereafter. The optimum fly ash content for CFL and CFC mixes was found to be 30% and 20%, respectively.
- Beyond the optimum percentage fly ash simply serves as weak filler in the mix resulting in a decrease of strength and stiffness. The variation of indirect tensile strength as well as resilient modulus follows the same trend as that of UCS for the variation in fly ash content.
- UCS values increase continuously with increase in binder (lime and cement) content.

The gel formation increases with an increase in binder content leading to a more efficient binding of the slag particles.

For a given fly ash and binder content, UCS values as well as IDT and Mr values of CFC mix were found to be lower than that of CFL mix. This may be due to the lower specific surface area of cement as compared to that of lime.

- A linear correlation between IDT and UCS was observed with a good R2 value for both the mixes. The IDT value was found to be 17.3% and 18.1% of UCS value for CFL and CFC mixes, respectively.

CFL mixes with 6% lime content and CFC mixes with 6% cement content satisfy both the UCS and durability criteria suggested by Indian Road Congress and hence, recommended for use as base course material in flexible pavement.

- Resilient modulus of all the CFL and CFC mixes was found to be increased with an increase in W-D cycles.
- As a result of strain hardening phenomenon Mr value increases with the increase in deviator stress. Most of the CFL and CFC mixes exhibited higher resilient modulus than WMM indicating that a lower thickness of base layer can be adopted if WMM is replaced with the CFL and CFC mixes.
- The main draw back of the two parameter model is its in capablity of separating the effect of confining pressure and deviator stresses on resilient modulus for the prediction of Mr. Higher values of coefficient of determination were obtained using the three parameter model, which separates the effect of confining pressure and deviator stress on Mr values.
- The three-parameter model (Model 3) among the five stress-dependent models provided the best fit model for the prediction of resilient modulus. The influence of deviator stress was found to be higher than that of confining stress on Mr values was observed for all CFL and CFC mixes.
- Model 1 and Model 2 do not account for the effect of stress level on permanent strain and hence, the model constants of these two models are dependent on the applied deviator stress. Model 1 was found to be the best performing model for the estimation of permanent strain for CFL and CFC mixes.
- A greater influence of stress level compared to that of load repetitions on permanent strain was observed in Model 3 and Model 4.XRD and SEM analysis show that the amount of unutilized binder (lime and flyash) particles was minimum and the amount of gel formation was maximum for the optimum CFL and CFC mixes for 28 days curing period, which compared 1 days curing to other combinations of CFL and CFC mixes, resulting in higher strength and stiffness values for the optimum mix.
- Based on the results obtained from finite-element analysis, the pavement with CFL or CFC mixes in the base layer has higher service life compared to the pavement with WMM as the base course material.
- The performance of the cemented material used in the base layer of pavement based on fatigue criteria was found to be higher than its performance based on rutting criteria. The use of CFL and CFC mixes in the base layer of flexible pavement has dual benefit of better performance as well as use of industrial waste contributing towards sustainability.
- For a given service life of the pavement the thickness of the two optimum mixes, i.e, 70% copper slag-30% fly ash-6% lime mix and 80% copper slag-20% fly ash-6% cement equivalent to 250mm WMM were found to be 150 mm 160 mm, respectively as per AASHTO method.
- A cost saving of Rs 9,43,966.00 and Rs 83,560.00 per km length of 7 m wide road was obtained by using 70% copper slag-30% fly ash-6% lime mix and 80% copper slag- 20% fly ash-6% cement mix in the base layer of the pavement, respectively.

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