Journal of The Gujarat Research Society
ISSN: 0374-8588
Volume 21 Issue 16, December 2019

Engineering Cementitious Material (ECC) Overlay Development for Durable Rigid Pavements

Nandini[1], K. Pavan Kumar[2], J K Manjunath[3], S Maneesh Nandu[4]

[1]Associate Professor,[2,3]Assistant Professor,[4]Student
Department Of Civil Engineering
Bheema Institute of Technology and Science, Adoni

ABSTRACT: The structural defects of concrete pavements include low tensile strength, rigidity, brittle failure mechanism under stress, and more. This project replaces more costly fly ash with locally produced silica fume. Measurements of the flexure's compressive strength, stress-strain curves, and dynamic loading tests are all part of the experimental methodology. These experiments' results showed that the fly ash and silica fume-infused ECC mixes had better tensile properties than ordinary concrete. The feasibility of the test was examined to support the results. But the ideal ratio turned out to be 25% cement mixed with silica fume. Consequently, using locally produced silica fume in Egypt's ECC with M30 grade concrete mix is more sensible. Because of its versatility, ECC is a material that shows promise for use in construction. In this case, it is used as an overlay on firm pavements to minimise damage and make repairs easier.

I. INTRODUCTION

Worldwide, roadway transportation systems are some of the most widely used, maintained, and visible public facilities. In 2006 alone, American drivers drove 3.0 trillion vehicle-miles along nearly 4 million miles of public roadways [1]. While there is little argument over the need to expand and maintain roadway infrastructure systems around the world to spur both economic development (in developing countries) and conti 4flexural strength and toughness, and show ductile properties under loading. The material must maintain construction feasibility and be able to reach high strengths at early ages to facilitate short traffic diversion times. Finally, the material must provide these properties at reasonably low costs to be an economical solution to deteriorated pavements. One identifying component of ECC is short, discontinuous fibers. Polyvinyl alcohol (PVA) fiber, a newly developed high performance fiber, is used in ECC to help achieve high tensile strain capacity, toughness and structural integrity that is vital to pavement overlays. The design of the modified ECC to be studied in this research included PVA fibers; however, other mix components and proportions were altered to more closely follow standard concrete pavement design. This was done in hope of gaining the benefits of PVA-ECC, including tensile ductility and high flexural strength, while still maintaining important performance characteristics of conventional concrete pavement.

Sustainability of ECC overlays:

Numerous researchers have studied the life cycle costs and impacts of pavement systems (i.e. asphalt versus concrete pavement systems) Results from these studies have shown that Portland cement concrete pavements exhibit lower energy consumption and related impacts during the first three life cycle stages (extraction of raw material, manufacture, and placement) as compared to asphalt pavements. But energy consumption and emissions throughout service life is heavily dependent upon local parameters, such as traffic volume, truck loads, and climate.) has looked at the overall sustainability of unbonded concrete overlays, HMA overlays, and ECC overlays using economic, environmental, and social metrics. Zhang et al found that ECC overlays were able to improve the sustainability of rigid pavement overlays by using ECC materials to extend overlay service life and reduce surface roughness thereby improving vehicle fuel economy. Most important among these findings was the large impact that service life and the suppression of reflective cracking failure mechanisms have on overlay system sustainability. The motivation behind this research is the development of new ECC composites that incorporate large proportions of industrial waste streams for use in rigid pavement overlay applications. These new versions of ECC are controlled to incorporate waste while maintaining high ductility, high fatigue resistance, and the ‘‘kinking-and-trapping’’ mechanism for suppression of reflective overlay cracking.

Engineered Cementitious Composites:

A new class of cementitious materials, called Engineered Cementitious Composites (ECC) is presented in this article as an alternative to conventional rigid pavement repairs and overlays to improve the overall sustainability of these systems. Considered a type of high performance fiber reinforced cementitious composite (HPFRCC), ECC exhibits ductility similar to metals, along with inherently tight crack widths that result in highly durable ECC applications Due to this combination of large ductility and associated durability, ECC represents a new approach to the design of more sustainable pavement systems. The most distinctive characteristic separating ECC from other concrete or cement-based materials is an ultimate strain capacity between 3 and 5%, depending on the specific ECC mixture. This strain capacity is realized through the formation of many closely spaced microcracks, allowing for a strain capacity over 300 times that of normal plain concrete. These cracks, which carry increasing load after formation, allow the material to exhibit strain hardening, similar to many ductile metals, as seen in a typical uniaxial tensile stress-strain curve While the mechanism underlying this inelastic strain is not dislocation slip on crystallographic planes, as in metals, when viewed over a representative gauge length, the deformation resulting from distributed microcracks under increasing tensile load may be interpreted as strain. This is uniquely different from typical concretes or fiber reinforced concretes (FRC) that form a single localized fracture when loaded. In the case of plain normal concrete, the crack opens wide with a rapid drop in load capacity. In the case of FRCs, the crack opens with a gradual drop in load, exhibiting a tension softening behavior. While the mechanism behind concrete and FRC deformation is similar to ECC in that it cracks, all deformation is localized at a single section (i.e. the crack face) and the concept of gauge length, and consequently strain,

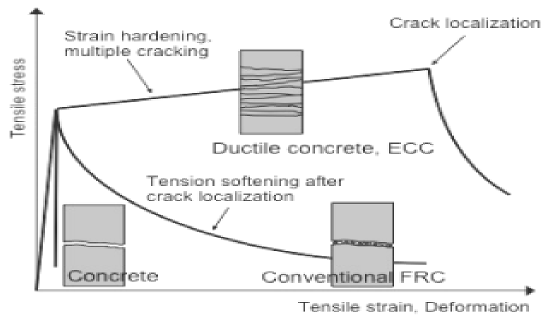


Figure: Comparison between Quasi-brittle, Tension-softening, and Strain-hardening Cement-based Material Performance in Uniaxial Tension

Rigid Pavement:

Overlay thickness criteria are presented for three conditions of bond between the rigid Pavementsand existing rigid pavement: fully bonded, partially bonded, and non-bonded. The fully bonded condition is obtained when the concrete is cast directly on concrete and special efforts are made to obtain bond. The partially bonded condition is obtained when the concrete is cast directly on concrete with no special efforts to achieve or destroy bond. The non-bonded condition is obtained when the bond is prevented by an intervening layer of material. When a fully bonded or partially bonded rigid overlay is to be used, the existing rigid pavement will be cleaned of all foreign matter (such as oil and paint), spalled concrete, extruded joint seal, bituminous patches, or anything else that would act as a bond-breaker between the overlay and existing rigid pavement. In addition, for the fully bonded overlay, the surface of the existing pavement must be prepared according to the recommendations in the professional literature. A sand-cement grout or an epoxy grout is applied to the cleaned surface just prior to placement of the concrete overlay. When a non-bonded rigid overlay is being used, the existing rigid pavement will be cleaned of all loose particles and covered with a leveling or bond-breaking course of bituminous concrete, sand asphalt, heavy building paper, polyethylene, or other similar stable material. The bond-breaking medium generally should not exceed a thickness of about 1 inch except in the case of leveling courses where greater thicknesses may be necessary. When a rigid overlay is being applied to an existing rigid pavement, the surface of the existing pavement will be cleaned of loose materials, and any potholing or unevenness exceeding about 1 inch will be repaired by cold planing or localized patching or the application of a leveling course using bituminous concrete, sand-asphalt, or a similar material.

ISSN: 0374-8588
Volume 21 Issue 16, December 2019

A rigid overlay of an existing rigid pavement should be designed in the same manner as a rigid pavement on grade. A modulus of subgrade reaction k should be determined by a plate-bearing test made on the surface of the existing rigid pavement. If not practicable to determine k from a plate-bearing test, an approximate value may be determined using methods described in the professional literature. These will yield an effective k value at the surface of the rigid pavement as a function of the subgrade k and thickness of base and sub-base above the subgrade. When using these methods, the bituminous concrete is considered to be unbound base course material. Using this k value and the concrete flexural strength, the required thickness of plain concrete overlay must be determined. However, the following limitations should apply:

• In no case should a k value greater than 500 pci be used.

• The plate-bearing test to determine the k value should be performed on the rigid pavement at a time when the temperature of the bituminous concrete is of the same order as the ambient temperature of the hottest period of the year in the locality of the proposed construction.

II. LITERATURE REVIEW

To evaluate the performance of the MECC mixes in this study, a multitude of tests were conducted on the material to evaluate its hardened mechanical and durability properties. From the literature review, multiple mix proportions for MECC mixtures were identified. From these, three mix proportions were selected and evaluated in this laboratory study. Previous studies on ECC showed that the mixing sequence would affect the quality of the material. Several mixing sequences were evaluated prior to the laboratory evaluation to determine which sequence would yield the most homogenous MECC material.

A. Behnooda, M. Amerib,(2012)carried out an experimental investigation of stone matrix asphalt mixtures and investigated the feasibility of utilizing steel slag aggregates in Stone Matrix Asphalt (SMA) mixtures. The results showed that the use of steel slag as the coarse portion of aggregates can enhance Marshall Stability, the Marshall properties of mixtures, resilient modulus, and tensile strength, resistance to moisture damage and resistance to the permanent deformation of SMA mixtures. The maximum average stability value of the mixture prepared with limestone was 8.84 kN. The use of steel slag in preparation of Marshall Specimens resulted in increased values of Marshall Stability. Also, Marshall Quotient values increased in mixtures that contained steel slag. The use of steel slag as coarse portion of SMA mixtures resulted in an increase in MQ values compared to samples that contained limestone in their coarse portion. Therefore, the use of steel slag in SMA mixtures provides a positive contribution to the overall performance of asphalt pavements.

III. MATRIALS AND METHODS

Concrete is an artificial material obtained by cementing together fine and coarse aggregate (sand and broken stone) using a binding material (cement). Compressive strength and durability are two factors for good concrete pavements, often called rigid pavements, are made up of Portland cement concrete and may or may not have a base course between the pavement and sub grade. As a general rule, the concrete, exclusive of the base, is referred to as the pavement.

Preparation Procedure for ECC:

mixing procedure for ECC was as follows: (1) Cement, fly ash, and silica sand were added into a blender and mixed at 100 rpm for 3 min.

Water and water reducer which was previously dissolved in the water were added and mixed at 100 rpm for 1 min and then 400 rpm for 4 min.

Fibers were added slowly and manually along the stirring direction and mixed at 400 rpm for 10 min.

Materials:

The concretes with recycled aggregates need a higher cement content when designed for a given strength. For 30 MPa concrete, the cement content increased by 7.2%. To obtain higher strengths in recycled aggregate concrete, the cement content was increased progressively up to 17.3% for a 57.5 MPa concrete.

Fly ash:

Fly ash is produced by coal-fired electric and steam generating plants. Typically, coal is pulverized and blown with air into the boiler's combustion chamber where it immediately ignites, generating heat and producing a molten mineral residue. Boiler tubes extract heat from the boiler, cooling the flue gas and causing the molten mineral residue to harden and form ash. Coarse ash particles, referred to as bottom ash or slag, fall to the bottom of the combustion chamber, while the lighter fine ash particles, termed fly ash, remain suspended in the flue gas. Prior to exhausting the flue gas, fly ash is removed by particulate emission control devices, such as electrostatic precipitators or filter fabric baghouses

Figure: fly ash

ISSN: 0374-8588
Volume 21 Issue 16, December 2019

Production

Fly ash is produced from the combustion of coal in electric utility or industrial boilers. There are four basic types of coal-fired boilers: pulverized coal (PC), stoker-fired or traveling grate, cyclone, and fluidized-bed combustion (FBC) boilers. The PC boiler is the most widely used, especially for large electric generating units. The other boilers are more common at industrial or cogeneration facilities. Fly ashes produced by FBC boilers are not considered in this document. Fly ash is captured from the flue gases using electrostatic precipitators (ESP) or in filter fabric collectors, commonly referred to as baghouses. The physical and chemical characteristics of fly ash vary among combustion methods, coal source, and particle shape.

Table: Fly ash production and use

	Million Metric Tons	Million Short Tons	Percent
Produced	61.84	68.12	100.0
Used	19.98	22.00	32.3

Table: Fly ash uses

	Million Metric Tons	Million Short Tons	Percent
Cement/Concrete	12.16	13.40	60.9
Flowable Fill	0.73	0.80	3.7
Structural Fills	2.91	3.21	14.6
Road Base/Sub-base	0.93	1.02	4.7
Soil Modification	0.67	0.74	3.4
Mineral Filler	0.10	0.11	0.5
Mining Applications	0.74	0.82	3.7
Waste Stabilization /Solidification	1.31	1.44	6.3
Agriculture	0.02	0.02	0.1
Miscellaneous/Other	0.41	0.45	2.1
Totals	19.98	22.00	100

Handling:

The collected fly ash is typically conveyed pneumatically from the ESP or filter fabric hoppers to storage silos where it is kept dry pending utilization or further processing, or to a system where the dry ash is mixed with water and conveyed (sluiced) to an on-site storage pond.

The dry collected ash is normally stored and handled using equipment and procedures similar to those used for handling portland cement:

- Fly ash is stored in silos, domes and other bulk storage facilities
- Fly ash can be transferred using air slides, bucket conveyors and screw conveyors, or it can be pneumatically conveyed through pipelines under positive or negative pressure conditions
- Fly ash is transported to markets in bulk tanker trucks, rail cars and barges/ships
- Fly ash can be packaged in super sacks or smaller bags for specialty applications

Dry collected fly ash can also be moistened with water and wetting agents, when applicable, using specialized equipment (conditioned) and hauled in covered dump trucks for special

ISSN: 0374-8588

Volume 21 Issue 16, December 2019

applications such as structural fills. Water conditioned fly ash can be stockpiled at jobsites. Exposed stockpiled material must be kept moist or covered with tarpaulins, plastic, or equivalent materials to prevent dust emission.

This increase contributes to an improvement of aggregate interface properties and system durability. It has also been proved that data scatter of compressive strength data is similar to that of conventional concretes development result from laboratory refers to the Table

Table: Chemical compositions of cement

Components	SiO2	Al2O3	Fe2O3	CaO	MgO	LoI
Composition (%)	23.27	5.17	3.93	62.37	1.70	1.33

Steel Fibers:

Steel fibers are short discontinues strips of specially manufactured steel. Their inclusion in the concrete improves the mechanical properties of concrete significantly. As the most common matrix, which is now in use in construction industry is Reinforced Cement.

Plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. Internal micro cracks are inherently present in the concrete and its poor tensile strength is due to the propagation of such micro cracks, eventually leading to brittle fracture of the concrete. It has been recognized that the addition of small, closely spaced and uniformly dispersed fibers to the concrete would act as crack arrester and would substantially improve its Compressive and flexural strength properties.

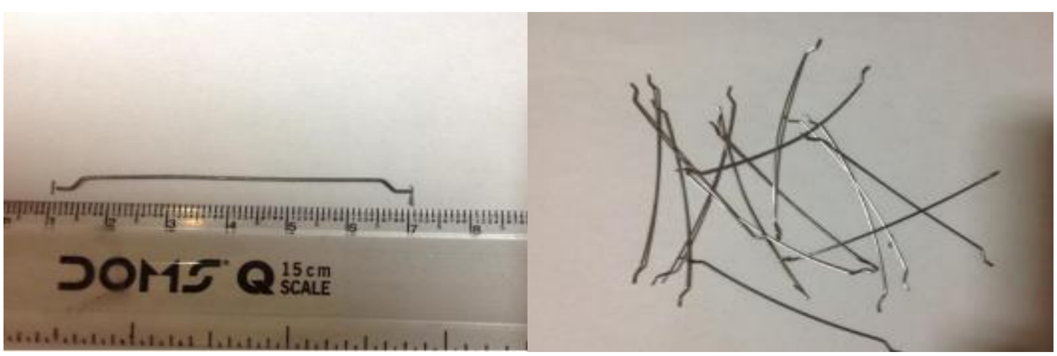


Figure: Steel fibers

Table: Manufacturing of steel fibers

Journal of The Gujarat Research Society
ISSN: 0374-8588
Volume 21 Issue 16, December 2019

Carbon	0.06/0.12%
Manganese	0.38/0.60%
Phosphorus	0.055/0.065%
Sulphur	0.035%
Nitrogen	0.008/0.12%

Silica fume:

Silica fume, a by-product of the ferrosilicon industry, is a highly pozzolanic material that is used to enhance mechanical and durability properties of concrete. It may be added directly to concrete as an individual ingredient or in a blend of portland cement and silica fume.

Figure: Silica fume

Table: Mix Proportions for (M30) Grade for Silica fume ((Kg/M3)

	W/C Ratio	Cement	SF	Sand	water
FA	0.42	380	0	711	160
SF25	0.42	378.10	1.9	711	160
SF29	0.42	376.20	3.8	711	160
SF35	0.42	374.30	5.7	711	160

Journal of The Gujarat Research Society

ISSN: 0374-8588

Volume 21 Issue 16, December 2019

Table: Mix Proportions for (M30) Grade for optimum strength (Aggregates & Silica fume)

	Aggregates +SF (%)	**W/C Ratio**	**SF**	**Sand**	**water**
FA	0	0.42	1.5	711	160
SF25	20+1.5	0.42	1.9	711	160

Table 1: Comparison between Recycled Aggregate and Original Material

		Recycled Aggregate		Original Material
		Recycled Once	Recycled Twice	Granular
Coarse Aggregate	Absorption	3.43 – 5.0	8.36	1.02
	Specific Gravity	2.31 – 2.4	2.11	2.67
Fine Aggregate	Absorption Specific	7.17 – 8.3		1.38
	Gravity	2.15 – 2.3		2.6

Properties of Fresh Silica Fume Concrete

- Silica fume concrete requires higher water content, for the same workability as of conventional concrete.
- Low workability.
- Low slump value.
- Possibility of bleeding and segregation is low.
- The mixture is cohesive.
- High plastic shrinkage.

Journal of The Gujarat Research Society
ISSN: 0374-8588
Volume 21 Issue 16, December 2019

IV. RESULTS AND DISCUSSIONS

Compressive Strength Test

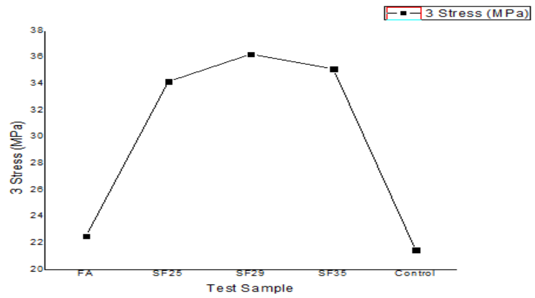
The compressive strength test was done on the cubes for each of the 4 ECC mixes as well as a control mix. Nine cubes were produced for each mix, every 3 cubes were tested at 3, 7, 28 and 56 days after pouring the M30 grade mix. The mold used was 50x50 mm sized, used for mortar cubes.

Figure: Compressive strength test

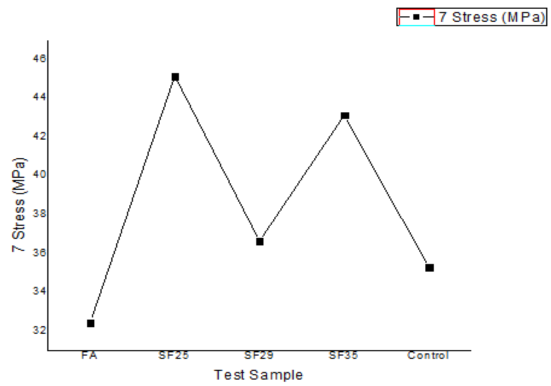
The test was performed using the Compressive Strength machine in order to determine the load applied. The test was conducted for various reasons; first, the compressive strength of each sample was to analyze the performance of ECC when subjected to load; the second objective was to visualize the mode of failure of the cubes after the test is performed that would convey the brittleness or rather ductility of the samples.

Table: Compressive Strength Results at 3, 7, 28 and 56 days

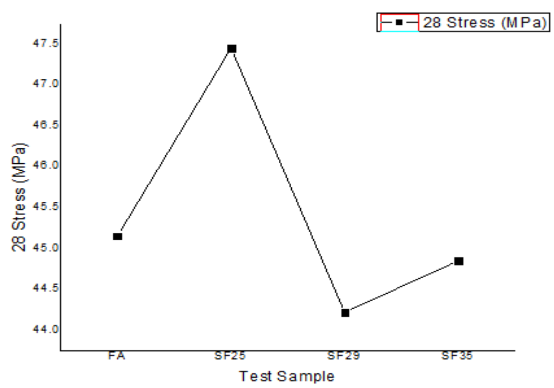
Test Sample	3 Stress (MPa)	7 Stress (MPa)	28 Stress (MPa)	56 Stress (MPa)
FA	22.53	32.44	45.15	55.25
SF25	34.17	45.13	47.45	57.83
SF29	36.24	36.64	44.22	64.75
SF35	35.12	43.11	44.85	54.91
Control	21.48	35.28	44.25	54.28



Graph: Test sample vs 3 days stress variation



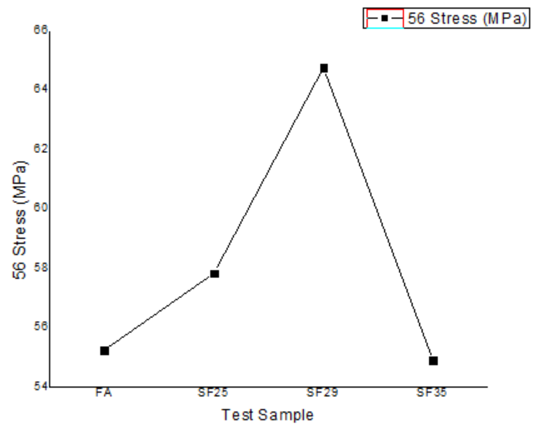
Graph: Test sample vs 7 days stress variation



Graph: Test sample vs 28 days stress variation

ISSN: 0374-8588

Volume 21 Issue 16, December 2019



Graph: Test sample vs 56 days stress variation

Test Results

After the test was performed, the effect of fiber was seen using a crack microscope. The device was used to magnify the crack. Apparently, the PVA fibers action was clear as they were bridging the crack and giving the prism a more deformable shape; thus, increasing the prism's bendability. The microscopic image below shows a crack width of 0.4mm

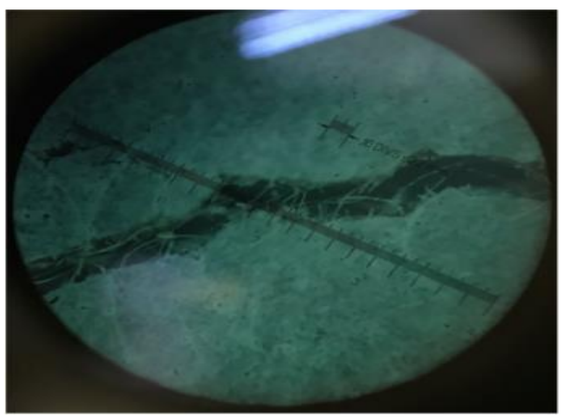


Figure: PVA Fiber Bridging the Crack with a scale of 10 Divisions= 0.2 mm

The loading curve showed that the Silica Fume 25% (Yellow Curve) was the best mix in the flexural test. It had the highest load and the highest deformation from the curve which is for the results at 28 days.

Discussions

Due to the high potential that ECC has as an overlay for rigid pavements, it is recommended that it should be used; especially when the ECC overlay is un-bonded over the crack as it was determined. However, in order for ECC to be ready to be used in the market as an overlay, further tests need to be conducted in order to determine the durability of ECC, its behavior under various temperatures, porosity, resistance against chemical attack, freezing and thawing tests, and skid resistance properties of ECC. All of these tests are important to ensure that ECC is a suitable material to be used in pavements. Additionally, comparative analysis should be done between ECC and asphalt as an overlay for rigid pavements in terms of durability and cost. Finally, other uses of ECC in the construction industry should be investigated, such as its use in water tanks, its use for slab on grades for factories, and its use against impact forces.

V.CONCLUSION

The objective of this project is to investigate the mechanical characteristics of several mix designs of engineered cementitious composites and find the best mix design to be tested as an overlay for the rehabilitation of inflexible pavements. The ECC-FA, ECC-SF25, ECCSF29, ECC-SF35, and a control mix devoid of PVA fibres were the mixes that were put to the test.

- The mechanical qualities that were ascertained were the cubes' compressive strength at 7, 14, 28, and 56 days; the cylinders' compressive stress-strain curves at 7, 14, 28, and 56 days; and the prisms' flexure capacity at 7, 14, 28, and 56 days. The ECC-SF25 mix was found to have the maximum flexural capacity of all the mixes, making it the ideal mix design.
- The overlay for the dynamic test that was run was made using the ECC-SF25 mix. Two samples were used for the dynamic test: a fully bonded ECC-SF25 overlay and an unbonded ECC-SF25 overlay over the crack. It was found that the unbonded ECC overlay performed significantly better than the fully bonded overlay because it could withstand more cycles without exhibiting any cracks or delamination.
- Lastly, to examine the impact of ECC as an overlay for stiff for large-scale models under dynamic loading, a finite element analysis model using a Von Mises constitutive model was run.
- In general, adding steel and glass fibres to M30 garde concrete has shown to significantly increase a variety of strengths.
- On the other hand, it has been discovered that the quantity of fibre content determines the maximal strength increase of concrete. The ideal fibre content to provide the most benefit in different strengths varies depending on the kind of strength.
- By using a variable w/c ratio, satisfactory workability was maintained while the volume percent of fibres increased.

REFERENCE

[1] Shaopeng Wu, YongjieXue and Wenfeng Yang "Experimental Evaluation of Stone Matrix Asphalt Mixtures Performance Using Blast Oxygen Furnace Steel Slag as Aggregate", Wuhan University of Technology, Wuhan 430070, Hubei, P. R China

[2] Koranne, S.S. Bansode, S.S.(2010) presented paper on "Innovative Ground Improvement Technique for Utilization of Steel Slag for Roads" Indian Geotechnical Conference – 2010, GEOtrendz, December 16–18, 2010 ,IGS Mumbai Chapter & IIT Bombay.

[3] Zore T. D. , S. S. Valunjkar "Utilization of Fly Ash and Steel Slag in Road Construction – A Comparative Study."

[4] Marco Pasetto, Nicola Baldo presented paper on "Experimental evaluation of high-performance base course and road base asphalt concrete with electric arc furnace steel slag", Construction and Transportation Department, University of Padova, Via Marzolo 9, Padova, 35131, Italy.

[5] A.Behnooda, M. Amerib (2012) presented paper on "Experimental investigation of stone matrix asphalt mixtures containing steel slag" ScientiaIranica, Transactions A: Civil Engineering 19 (2012) 1214– 1219

[6] Praveen Mathew, Leni Stephen, Jaleen George(2013) presented paper on "Steel Slag ingredient for concrete pavement" International Journal of Innovative Research in Science, Engineering and Technology Vol. 2, Issue 3, March 2013

[7] N. Sumi&Malathy(2013) presented paper on "Experimental investigation on effect of fly ash and steel slag in Concrete pavements" International Journal of Research in Engineering & Technology (IJRET) Vol. 1, Issue 2, July 2013, 117-124.

[8] Dubruel, P., and De Belie, N. (2012)."Super absorbent polymers to prevent water movement in cementitious materials." Int. J. 3R's, 3(3), 432–440

[9]Weimann, M.B. and Li, V.C., (2003). Drying Shrinkage and Crack Width of ECC, Seventh International Conference on Brittle Matrix Composites, pp. 37-46, Warsaw, Poland.

[10] Fischer, G. and Li, V.C., (2003). Deformation Behavior of Fiber-Reinforced Polymer Reinforced Engineered Cementitious Composite (ECC) Flexural Members under Reversed Cyclic Loading Conditions, ACI Structural Journal, 100(1), pp. 25-35.

[11] Lepech, M.D. and Li, V.C., (2009). Water Permeability of Engineered Cementations Composites, Cement and Concrete Composites, 31(10), pp. 744-753.