A

Major Project Report on

DURABILITY STUDY AND SHEAR BOND BEHAVIOUR BETWEEN CONCRETE AND HYBRID FIBER REINFORCED ENGINEERED CEMENTITIOUS COMPOSITES

Submitted for partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY
in
CIVIL ENGINEERING

by

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CERTIFICATE

This is to certify that the project entitled **“DURABILITY STUDY AND SHEAR BOND BEHAVIOUR BETWEEN CONCRETE AND HYBRID FIBER REINFORCED ENGINEERED CEMENTITIOUS COMPOSITES”** is being submitted by SK.Nourin (21K85A0107), A.Saikiran (21K85A0115), G.Akhil (21K85A0125), G.Saikrishna (21K85A0129) in fulfilment of the requirement for the award of degree of **BACHELOR OF TECHNOLOGY IN CIVIL ENGINEERING** is recorded of bonafide work carried out by them. The result embodied in this report have been verified and found satisfactory.

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DECLARATION

We the students of **Bachelor of Technology** in Department of **Civil Engineering,** session: **2021-2024, St. Martin's Engineering College, Dhulapally, Kompally, Secunderabad** hereby declare that the work presented in this project entitled **'DURABILITY STUDY AND SHEAR BOND BEHAVIOUR BETWEEN CONCRETE AND HYBRID FIBER REINFORCED ENGINEERED CEMENTITIOUS COMPOSITES'** is the outcome of our own bonafide work and it is correct to the best of our knowledge and this work has been undertaken taking care of Engineering Ethics. The result embodied in this project report has not been submitted in any university for award of any degree.

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ABSTRACT

HFECC is exposed to a variety of environmental factors during its service life, including freeze-thaw cycles, wet-dry cycles, and chemical exposure. These factors can cause significant damage to concrete structures, leading to premature deterioration and failure. HFECC's durability is attributed to a number of factors, including its high fiber content, low permeability, and self-healing properties. Hybrid fibers help to bridge cracks, reduce shrinkage, and improve the overall tensile strength of HFECC. The low permeability of HFECC helps to reduce the ingress of harmful chemicals and moisture. Additionally, HFECC's self-healing properties allow it to repair minor cracks and defects, which further enhances its durability. Shear bond strength is a critical property for concrete overlays, as it determines the ability of the overlay to adhere to the underlying substrate. HFECC is often used as an overlay material on conventional concrete substrates, so it is important to understand the shear bond behavior between the two materials. The shear bond behavior between HFECC and conventional concrete can be characterized through rigorous experimental testing, such as pull-off tests or push-off tests. These tests measure the force required to separate the HFECC overlay from the underlying substrate. The number of factors can influence the shear bond strength between HFCC and conventional concrete, including the type and content of hybrid fibers, surface preparation methods and curing conditions. The mix design and fiber content of HFCC are critical factors in determining its durability and shear bond performance.

Key Words: Engineered Cementitious composites, Hybrid Fiber reinforced concrete, Durability

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CHAPTER 1

INTRODUCTION

1.1 General

Engineered Cementitious Composites Concrete (ECC) also called as stain Hardening Cement based Composites (SHCC) or more popularly as Bendable Concrete, is an easily moulded mortar-based composite reinforced with speciallyselected short random Fibers usually polymer Fibers. ECC acts more like a ductile metalthan a brittle glass which then leads to a wide variety of application. The tensile strain capacity of ECC can reach 3-5%, compared to 0.01% for normal concrete. Thecompressive strength of ECC is similar to that of normal to high strength concrete. Theaim of research work is to study ductile behaviour of concrete, crack resistance capacity& concrete should give warning before its failure. Normal concrete is brittle in nature while ECC is ductile in nature, due to this property; it has wide applications and wide future scope in various fields.

1.2ECC concrete

1.2.1 About Engineered Cementitious Composites

Beginning as early as the 1980's, interest in creating a fiber reinforced concrete materialwith tensile ductility has been gaining ground. Within FRC, the toughness of the material is increased, but no change in ductility is attained. Ductility is a measure of tensile deformation (strain) capacity typically associated with ductile steel, for example,but not with concrete material. Attempts in achieving tensile ductility in concrete material are exemplified by the early efforts of Aveston et al. (1971), and later Krencheland Stang (1989) who demonstrated that with continuous aligned fibers, high tensile ductility hundreds of times that of normal concrete can be attained. The modern-day version of continuous fiber reinforcement is represented by textile reinforced concretematerials that may be prestressed.

Infiltrated Fiber Concrete) has resulted in concrete composite materials that attain higher tensile strength than normal concrete and which are not as brittle, but with muchless ductility than their continuous fiber and textile reinforced counterparts.

These materials may be considered classes of materials separate from FRC in those different degrees of tensile ductility are achieved, often accompanied by a strain hardening response distinct from the tension-softening response of FRC. Naaman and Reinhardt (2003) classified such material as High-Performance Fiber Reinforced Cementitious Composites (HPFRCC). It should be noted that most members of this class of material have a matrix that does not contain coarse aggregates, and should therefore be regarded as Fiber reinforced cement pastes or mortars. However, in keeping with the broadened meaning used in the literature, we shall use the term "concrete material" in this chapter to include concrete, mortar, and cement paste.

Illustrates schematically the differences between the tensile response of normal concrete, FRC, and HPFRCC, such as obtained from a uniaxial tension test. This figureemphasizes the transition from brittle concrete to quasi-brittle FRC (tension softening)to ductile HPFRCC (strain-hardening). Specifically, during tension-softening, deformation is localized onto a single fracture plane, most appropriately described in terms of crack opening.

During strain-hardening, deformation is co opening of multiple subparallel fine cracks,and elastic stretching of the material between these cracks. Over a length scale that includes many such cracks, the deformation may be considered tensile "strain" smearedover a representative volume of material. As will be seen in the following sections, these distinctions between FRC and HPFRCC have significant ramifications in terms of load capacity and structural durability.

While the HPFRCC materials mentioned above embody the highly desired tensile properties lacking in normal concrete or in FRC, until recently they have mostly been limited to academic research laboratories or specialized applications. This is due to additional demands in industrial projects, particularly in on-site construction, such as economic feasibility and constructability. These two demands are difficult to meet when either continuous fibers or high Fiber content are used in the composites.

In recent years, two new classes of HPFRCC have emerged. Ductal® has high tensile strength of 12MPa and a ductility of 0.02-0.06% and ECC originally developed at the University of Michigan.

Two types of HPFRCCs are illustrated. The development approach for these two classes of materials is quite different. For Ductal, which can be traced back to the work of Bache (1981), the approach is to employ a tightly packed dense matrix to increase both tensile and compressive strength of the material. Fiber is added to counteract the resulting high brittleness of the densified matrix. The dense matrix allows a strong bond with the fiber that results in a high post cracking strength as longas a fiber with high strength is utilized.

For ECC, the approach is to create synergistic interactions between fiber, matrix and interface, to maximize the tensile ductility by development of closely spaced multiple microcracks while minimizing the fiber content (generally 2% or less by volume). Ductal is designed for use in the elastic stage, sothat the fiber action becomes effective only when the structural ultimate limit state (ULS) is approached. ECC is generally designed for use in the elastic and strain- hardening (inelastic) stages, so that fiber action becomes effective even under normal service loads.

The development of ECC is still evolving, even though a number of full-scale structural applications have already appeared in Japan, Europe and the US. This article summarizes some basic knowledge of ECC. In the following, the fundamental characteristics of ECC are described. This is followed by a section on structural behavior of steel reinforced ECC elements (RECC), and a section on durability behavior of ECC material and R/ECC.

The literature on ECC is rapidly expanding with contributions from academic researchand industrial organizations around the world. Some good sources of references includerecent workshop or conference proceedings on this subject, e.g. HPFRCC in StructuralApplications, FRAMCOS-6 and HPFRCC 5 These documents contain a number of papers on ECC and related subjects. In assisting the transition to broader industrial use,the Japan Society of Civil Engineers has published a design guideline (JSCE 2007; Rokugo et al, 2007), and the RILEM TC HFC technical committee will be publishing two states of the art reports on this subject. To aid the reader in manoeuvring this literature, some clarification on semantics will be helpful. The name EngineeredCementitious Composites (ECC) was adopted by the original developers (Li, 1993) to emphasize the micromechanics basis behind the design of this material. Micromechanics serves as a powerful tool to guide materials design for targeted composite properties, and enables a meaningful linkage between materials engineering.

structure performance design (Li, 2007). In 2006, the RILEM TC HFC technical committee decided to emphasize the unique tensile strain-hardening response of this material as a constitutive law for structural engineering design, and gave the more descriptive name Strain Hardening Cementitious Composites (SHCC) to this class of materials. JSCE, however, prefers to emphasize the multiple fine cracking, thus namingthe material as “Multiple Fine Cracking Fiber Reinforced Cementitious Composites”. In essence, all of these materials are designed using micromechanical tools and represent identical material technology.

Bendable concrete additionally referred to as designed building material Composites abbreviated as ECC is category of ultra-ductile fiber bolstered building materialcomposites, characterized by high plasticity and tight crack dimension management. Conventional concretes area unit nearly steady and have a strain capability of solely 0.1% creating them extremely brittle and rigid. This lack of flexibility may be a majorreason behind failure beneath strain and has been a pushing think about the event of a chic material particularly, ECC. This material is capable to exhibit considerably enhanced flexibility. A bendable concrete is reinforced with micromechanically designed polymer fibers. ECC is formed from identical basicingredients as standard concrete however with the addition of High-Range Water Reducing (HRWR) agent is needed to impart sensible workability.

However, coarse aggregates aren't employed in ECCs, the powder content of ECC is comparatively high. Cementitious materials, such as GGBS, Nano silica, etc., may be used in addition to cement to increase the paste content. Additionally, ECC uses low amounts, typically 2% by volume, of short, di

continuous fibers. ECC incorporates super fine silicon dioxide sand and little Polyvinyl Alcohol fibers coated with a really skinny (manometer thick), silk coating. This surface coating allows the Fiber to begin slipping when they are over loaded so they are not fracturing. It prevents the Fiber from rupturing which would lead to large cracking. Thus, associate degree ECC deforms way more than a standard concrete however while not fracturing.

The behaviour of ECC under flexural loading and it can be seen that the beam can deform sufficiently without direct failure. ECC has proved to be 50 yet one more versatile than ancient concrete, and 40% lighter, which could even influence design choices in skyscrapers. Additionally, the excellent energy absorbing properties of ECCmake it especially suitable for critical elements in seismic, crushed stone, river sand and water.

The challenge in creating a light-weight concrete is decreasing the density whereas maintaining strength and while not adversely touching value. Introducing new aggregates into the combination style may be a common element thatarea unit typically replaced with light weight aggregates. Thanks to lower density of concrete.

Fig. 3 Bond test on conventional concrete cube

Figure:1.1 ECC Concrete

1.2.1 Properties of ECC concrete

ECC has a variety of unique properties, including tensile properties superior to other Fiber-reinforced composites, ease of processing on par with conventional cement, the use of only a small volume fraction of fibers (~ 2%), tight crack width, and a lack of anisotropic ally weak planes. These properties are due largely to the interaction between the fibers and cementing matrix, which can be custom-tailored through micromechanicsdesign. Essentially, the fibers create many microcracks with a very specific width, rather than a few very large cracks (as in conventional concrete.) This allows ECC to deform without catastrophic failure. These products appear as a white scar material filling in the crack. This lack of flexibility may be a majorreason behind failure beneath strain and has been a pushing think about the event of a chic material particularly, ECC. This material is capable to exhibit considerably enhanced flexibility. A bendable concrete is reinforced with micromechanically designed polymer fibers.

This microcracking behaviour leads to superior corrosion resistance (the cracks are so small and numerous that it is difficult for aggressive media to penetrate and attack the reinforcing steel) as well as to self-healing. In the presence of water (during a rainstorm, for instance) unreacted cement particles recently exposed due to cracking hydrate and form a number of products (Calcium Silicate Hydrate, calcite, etc.) that expand and fillin the crack. These products appear as a white 'scar' material filling in the crack. This self-healing behaviour not only seals the crack to prevent transport of fluids, but mechanical properties are regained. This self-healing has been observed in a variety of conventional cement and concretes; however, above a certain crack width self-healingbecomes less effective. It is the tightly controlled crack widths seen in ECC that ensureall cracks thoroughly heal when exposed to the natural environment.

When combined with a more conductive material, all cement materials can increase andbe used for damage-sensing. This is essentially based on the fact that conductivity willchange as damage occurs; the addition of conductive material is meant to raise the conductivity to a level where such changes will be easily identified. Though not a material property of ECC itself, semi-conductive ECC for damage-sensing are being developed.

Interactive System is developing a user-friendly Interaction Engine, using cognitive technology. With system quickly becoming more able to assist us, human system interaction is the next big challenge that needs to be solved for system to successively enter into our society. System not only need to perform tasks for us but need to do so in a way that makes sense to us. This requires systems with social intelligence to understand us, system that have natural interaction capabilities to talk with us, and robots that are able to adapt to us. Our Interaction Engine enables you to quickly develop interactive scenarios for your application. Interactive systems' solutions deliver an optimal interaction with people.

Durability of ECC

As a new construction material, it is not enough to have excellent mechanical performance compared with conventional concrete or FRC. It is important also to verifythe durability of the ECC material itself in various environments typical of where suchmaterials are expected to be used. In addition, the influence of this material on structuraldurability performance of ECC must also be confirmed. In most cases, laboratory studies are performed under accelerated conditions. However, long-term performance.

In the field is most valuable even though this is difficult to obtain, especially for a relatively new material.

Since the greatest value of ECC lies in its superior tensile ductility, this material will that the structure must remain serviceable even if the material undergoes tensile strain hardening accompanied by multiple microcracking. For this reason, the examination ofECC material durability should be carried out in the deformed cracked state. That is, the ECC specimen should undergo preloading to varying strain levels, in order to deliberately create microcrack damage, prior to accelerated exposure tests.

Experimental data thus determined from preloaded specimens may be considered as material durability properties under combined mechanical and environmental load. It should be noted, however, that most of these experiments were undertaken with crackedspecimens in the unloaded state for experimental testing convenience.

On unloading, crack widths in ECC tend to reduce by 10-20% from the loaded state. This reduced crack width is used in all experimental data reported. This difference fromfield conditions where cracks are typically under load is not expected to have a significant impact on the measured durability of ECC material or ECC structures, but should be verified in future studies.

As will become clear in the following subsections, the durability of ECC and especiallyof ECC structures can be sensitive to the width of the microcracks. Fortunately, microcrack widths are designed to be small, typically less than 100 um for ECC, and potentially much lower. These cracks remain small under fatigue loading. However, a recent study by Boshoff and van Zijl indicates that crack width may open wider undersustained loading due to creep mechanisms. Care must be taken for the long-term durability of a structure under combined conditions of sustained loading, deformation to the strain-hardening stage and exposure to an aggressive environment.

Current knowledge of ECC durability under various environments is summarized. The durability of RECC under chloride exposure is presented. This is followed by highlights of limited long-term performance data on ECC materials already in structuresexposed to the natural environment and in one case) also in combination with mechanical loads.

1.2.2 Types of ECC Concrete

- Lightweight (i.e., low density) ECC have been developed through the addition of air voids, glass bubbles, polymer spheres, and/or lightweight aggregate. Compared to other lightweight concretes, lightweight ECC has superior ductility. Applications include floating homes, barges, and canoes.
- ‘Self-compacting concrete’ refers to a concrete that can flow under its own weight. For instance, a self-compacting material would be able to fill a mould containing elaborate pre-positioned steel reinforcement without the need of vibration or shaking to ensure even distribution. Self-compacting ECC was developed through the use of chemical admixtures to decrease viscosity and through controlling particle interactions with mix proportioning.
- Sprayable ECC, which can be pneumatically sprayed from a hose, have been developed by using various super plasticizing agents and viscosity-reducing admixtures. Compared to other sprayable fiber-reinforced composites, sprayable ECC has enhanced pumpability in addition to its unique mechanical properties. Sprayable ECC has been used for retrofitting/repair work and tunnel/sewer linings.
- An extrudable ECC for use in the extrusion of pipes was first developed in 1998. Extruded ECC pipes have both higher load capacity and higher deformability than any other extruded fiber-reinforced composite pipes.

1.2.3 Characteristics of Engineered Cementitious Composites

The Family of ECC Materials ECC can be regarded as a family of materials with a range of tensile strengths and ductility’s that can be adjusted depending on the demandsof a particular structure. ECC also represents a family of materials with different functionalities in addition to the common characteristics of high tensile ductility and fine multiple cracking. Self-consolidating ECC (e.g. ECC M45 and its variants) is designed for large-scale on-site construction applications. High early strength ECC (HES-ECC) is designed for applications which require rapid strength gain such as transportation infrastructure that needs fast reopening to the motorist public.

Light-weight ECC (LW-ECC) is designed for applications where the dead load of structural members must be minimized. Green ECC (G-ECC) is designed to maximize material greenness and infrastructure sustainability.

Emphasizes the functionality of recovering transport and mechanical properties after experiencing damage.

ECC using local material ingredients have been successfully produced in various countries, including Japan, Europe (Mechtcherine and Schulze, 2006), and S. Africa inaddition to the US. To successfully develop local versions of ECC, a good understanding of the underlying design approach is helpful. A synopsis of the ECC design approach.

A summary of major physical properties of ECC is given. It should be emphasized thatECC properties are tailorable through the use of micromechanics tools. Even broader ranges of properties beyond those in this table can be expected in future as the need arises.

The very high strength and modulus version was attained by Kamal et al (2007). The version was described in Wang and Li (2003). The common characteristic of these ECCmaterials is that they have tensile ductility orders of magnitude higher than those in typical concrete or FRC materials.

It should be noted that while a large body of literature has developed around ECC basedon PVA fiber, commonly referred to as PVA-ECC, other fibers have been successfullyutilized. These include high modulus polyethylene (PE) fibers and polypropylene (pp)fibers. The principle behind the design of ECC as discussed does not depend on a particular fiber. Fibers with certain properties, however, may meet the criteria for tensile strain-hardening at a lower volume fraction. Decisions on what fibers to use willdepend on their natural characteristics, including mechanical, diameter ranges, and surface characteristics, on resulting ECC mechanical, durability, and sustainability performances and on economics.

Tensile Characteristics

As indicated earlier, the most important characteristic of ECC is the high tensile ductility represented by a uniaxial tensile stress-strain curve with strain capacity as highas 5%. This metal like behavior shows a characteristic "yield point” at the end of the elastic stage when the first microcrack appears on the specimen. Subsequent increase in load results in a strain-hardening response, i.e., a rise in tensile deformation (volumetric straining in the form of multiple microcracking as opposed to occurs when one of the multiple cracks forms a fracture plane. Beyond this peak load, ECC is no different than normal FRC, showing a tension-softening response. The high tensile ductility is of great value in enhancing the structural ultimate limit state (ULS) in termsof structural load and deformation capacity as well as energy absorption. In this manner,ECC can offer structural safety improvements.

The formation of multiple microcracking is necessary to achieve high composite tensile ductility. Between first cracking strain (about 0.01%) and 1% strain, the microcrack opening increases from zero to about 60 um. Further loading beyond 1% causes more multiple cracks to form, but with no additional crack opening beyond the steady state value of 60 um. Governed by the mechanics of the fiber-matrix interaction within ECC, this unique characteristic is critically important for durability of both material and structure. Unlike concrete or FRC, the steady state crack width is an intrinsic material property, independent of loading (tension, bending or shear), structure size and geometry, and steel reinforcement type and amount.

This observation has important implications in service life, maximum member size, economics, and architectural aesthetics. In short, where steel reinforcement is used to control crack width in concrete, such steel reinforcement can be completely eliminatedin ECC. By suppressing cracks with large crack width even in the presence of large imposed structural deformations, ECC can offer structural durability improvements in addition to water tightness and other serviceability enhancements.

Compressive and Flexural Characteristics

The compressive properties of ECC are not significantly different from normal to high strength concrete. Compressive strength of ECC ranges from 30MPa to 90MPa. With an elastic modulus (around 20-25 GPa) typically lower than concrete due to the absenceof coarse aggregates. The compressive strain capacity of ECC is slightly higher, around0.45-0.65%. Strength development curve of an ECC (M45) compressive cylinder.

The post-peak behaviour of ECC under compression tends to descend more gently thanhigh strength concrete, accompanied by a gradual bulging of the specimen rather than explosive crushing failure. The flexural response of ECC reflects its tensile ductility. Under bending, multiple microcracking forms at the base of the beam allowing it to undergo a large curvature.

Development – a phenomenon that has resulted in the popular name of "bendable concrete." A flexural strength (modulus of rupture or MOR) of 10-15 MPa is easily achievable and accompanied by a large extent of deflection hardening regime. Deflection hardening is an intrinsic property of ECC and does not depend on geometry.This is not the case for tension-softening FRC for which deflection hardening becomesmore difficult to attain as beam height increases. A highly deformed ECC beam and fine multiple cracking on the tensile side of the beam..

ECC has significant improvements in fatigue response over normal concrete and FRC. Suthiwarapirak et al conducted flexural fatigue test on ECC and demonstrated higher ductility and fatigue life compared with polymer cement mortars commonly used in repair applications.

Structural Response of ECC Elements

Flexural Elements Fischer and Li studied the behavior of R/ECC flexural elements under reversed cyclic loading. A regular R/C beam was also tested as control. The substantial difference in hysteretic response for the R/ECC and the R/C control columnspecimens. A significantly fuller hysteretic loop with larger energy dissipation was achieved by the R/ECC beam despite the fact that no shear stirrups were used at the base of the flexural element. The damage experienced by these elements at 10% interstudy drift is compared. Even at this high drift level, no spalling of the ECC was observed. In contrast, the R/C column lost all concrete cover near the fixed end subsequent to bond splitting and spalling. Clearly, the R/ECC element demonstrated significant damage tolerance under severe loading.

High cycle fatigue response of RECC flexural elements was studied by Kim et al (2004)in conjunction with a bridge deck link slab application. The full thickness slab test configuration with the steel girder (anchored to the slab by steel studs) on top for convenience of testing. Over 100,000 cycles, no degradation in stiffness was observedin the R/ECC or in the R/C control beam. However, the cracks in the R/C beam grew continuously to 0.6 mm at the end of the test, while the microcracks in R/ECC beam remained at approximately 50 um.

Motivated by the need to increase the stiffness and to reduce the tendency for fatigue cracking in steel bridge decks, a steel/ECC composite beam was studied by Walter et al under monotonic flexural loading.

composite beam were also tested in the same configuration. FRD is a fiber reinforced Density material, a very high strength and dense concrete reinforced with steel fibers similar to Ductal.

All concrete materials were cast onto the steel plate and bonded only by adhesion to the roughened steel surface. The load-deflection response demonstrates a much higher load capacity in the case of the steel/ECC beam which showed multiple microcracking during testing, suppressing the formation of a brittle fracture that limits the capacity of the steel/concrete beam. The single fracture in the FRC and FRD beams led to their immediate debonding from the steel plate.

Shear Element Fukuyama et al studied the behavior of R/ECC shear elements under reversed cyclic loading. The specimen configuration while the hysteretic loops for ECC. Again, the hysteretic loops for ECC showed much greater stability and ability todissipate energy. The ECC specimen suffered extensive bond splitting and loss of cover, accompanied by large diagonal cracks. In contrast, the damage experienced by the ECC shear element was significantly lower. No bond splitting and cover loss was observed and microcracks continued to carry loads up to 5% rad deflection angle.

The shear capacity of a ECC beam can be estimated from a linear superposition of the contributions of the ECC material and the shear and axial steel reinforcements due to the compatible deformation of the two materials even after steel yields. This approach was suggested to be reasonably accurate and conservative. However, numerical analysis combined with experimental data suggested that only a fraction of the ECC's tensile strength and strain capacity might be utilized in shear element due to possible damage of bridging fibers on sliding crack surfaces.

Column Element The response of RECC and R/C columns under fully reversed cyclic loading was studied by Fukuyama et al. These columns were tested under anti-symmetrical moment condition. The axial force applied to the column is 20% of the axial compressive strength of the column, calculated without the contribution of the steel reinforcements. The hysteretic behavior in terms of stability and energy dissipation was improved in R/ECC column over R/C column in a similar manner as for flexural and shear elements. Large bond splitting cracks were observed in the R/C column which failed by shear without yielding of the longitudinal reinforcements. Subsequently, the resistant shear force in the envelope curve of shear force – deflection.

Angle relationship decreased with increase of deflection angle. On the other hand, the R/ECC column did not fail by shear or bond splitting. Instead, it maintained a ductile response up to the end of the test with fine cracks revealed on the specimen surface.

Beam-Column Connection Element Beam-column connection was studied by Parra-Montesinos and Wight (2000), with the test set up. The hysteretic response for the R/ECC shear panel was substantially improved over the R/C, even when all shear stirrups were removed in the RECC shear panel. Under fully reversed cyclic loading, aset of orthogonal cracks formed in both specimens. While the orthogonal cracks in R/ECC were much more closely spaced, they did not lead to surface spalling as often observed in R/C specimens after large load reversals. In addition, edge spalling was revealed in the R/C specimen, associated with the bearing of the steel beam on the brittleconcrete. This was not found in the R/ECC specimen.

Wall Panel Element Wall panel elements were studied by Kesner and Billington underfully reversed cyclic loading, with the test set up. These tests confirmed that the R/ECCwall panels outperformed the R/C wall panels in hysteretic loop stability, peak load, and energy dissipation.

The structural element experimental testing results briefly summarized above share the common features of enhanced element load and deformation capacity, hysteretic loop stability, and energy dissipation. Further, structural damage is limited to microcrackingwhile large fractures in the form of bond splitting and spalling are suppressed.

1.2.5 Resistance in ECC

From the discussions presented in Section, the transport properties of ECC associated with permeation under hydraulic gradient, diffusion under ion concentration gradient, or sorption and absorption under capillary suction, all show the tendency to improve over concrete and especially cracked concrete. Given that concrete structures are designed to allow some tensile cracking, and that these cracks within reinforced concrete are typically the source of corrosion due to the increased transport of water and corrosives, there is substantial potential for ECC to improve the durability of R/O structures by acting as a quality cover where all transport mechanisms are substantiallyinhibited. The interaction between ECC and steel reinforcement from the viewpoint ofcorrosion resistance has been examined. The nature and rate of steel corrosion in ECC.

And the spall resistance of ECC when specimens are subjected to accelerated testing conditions are presented below.

Nature of Steel Corrosion

A study on chloride penetration rate and corrosion rate of steel reinforcement has beencarried out by Miyazato and Hiraishi. Preloaded R/ECC and R/C beams were exposedto 28-day chloride accelerated environment with wet (saltwater shower 90% RH – 2 days) and dry (60% RH – 5 days) cycles. They found that chloride penetration reaches0-20 mm and 80-100 mm in the R/ECC and the R/C beams respectively. The total (macro and micro cell) steel rebar corrosion rate was measured to be less than 0.0004 mm/year in the RECC but exceeded 0.008 mm/year in the R/C beams.

The observed smaller chloride penetration depth is consistent with the smaller effective diffusion coefficient found by Şahmaran et al discussed in Section. The nature of corrosion in ECC is decidedly different from that in R/C. Microcell currents formed between the closely spaced microcracks in the ECC dominate microcell currents so thatthe length of steel reinforcement that experiences corrosion is longer in the ECC. The much higher rebar corrosion rate concentrated at the location of the concrete crack in the R/C specimen suggests a higher tendency for pitting corrosion of the steel reinforcement to occur.

Corrosion Propagation and Spall Resistance

Given the tensile ductility of ECC, the ability for the cover to remain intact despite steel corrosion serves as a possibility to further prolong the service life of R/ECC structures. Şahmaran et al conducted an experimental investigation on R/ECC beams subjected to accelerated corrosion by electrochemical method, designed to induce different degreesof corrosion into the reinforcement (a single steel rebar) embedded in ECC prismatic specimens. These experiments aimed at examining the spall resistance of R/ECC cover,the influence of an intact cover on the corrosion process in the corrosion propagation phase, the rate of loss of steel by corrosion, and the residual load capacity of R/ECC elements.

Corrosion-induced crack width of mortar specimens increased with time as corrosion activity progressed. Larger crack widths, up to 2 mm wide, were obtained at higher levels of corrosion.

(~ 0.1 mm) with time as corrosion activity progressed, while the number of cracks on the surface of the specimen increased. The results of this study also showed that ECC has significant anti-spalling capability as compared to conventional mortar. If a crack width of 0.3 mm (as specified by AASHTO for maximum crack width limit for outdoorexposures) were used to represent the serviceability limit of reinforced concrete structures, the service life of reinforced ECC would be at least 15 times that of the reinforced mortar.

Reinforcement corrosion in mortar specimens resulted in a marked reduction in stiffness and flexural load capacity. After 25 hours of accelerated corrosion exposure, the flexural strength reduced to about 34% of the original flexural capacity of the control mortar beam. In contrast, the ECC specimens after 50 hours of accelerated corrosion exposure retained almost 100% of the original flexural capacity of the controlspecimens. Beyond 50 hours, the flexural capacity decreased, but retained over 45% that of the control specimens even after 300 hours of accelerated corrosion exposure. Longitudinal cracks due to expansion of the corrosion products also affected the failuremode of the reinforced mortar under four-point bend load. On the other hand, ECC deterioration due to the corrosion of reinforcement did not modify the type of failure inECC beams.

The loss in load carrying capacity is related to the mass loss of the steel reinforcementdue to corrosion. The percentage of steel mass losses within the ECC and mortar beamsthroughout the accelerated corrosion process is presented. The average percentage of mass loss of steel reinforcing bars embedded in the mortar specimens were 2.5%, 5.3%and 11.7% at the end of 25, 50 and 75 hours accelerated corrosion test, respectively. Onthe other hand, there was nearly no mass loss of steel reinforcing bars embedded in ECC specimens after up to 50 hours of accelerated corrosion testing and the average percentage of mass loss of reinforcing bars embedded in ECC was 17.5% at the end of300 hours of accelerated corrosion testing.

The observed superior corrosion performance of ECC compared to mortar in terms of corrosion propagation time, tight crack width, lower weight loss, and higher retention of stiffness and flexural strength, is attributable to the high tensile strain capacity, strain hardening performance, and multiple-cracking behavior of ECC. Overall, the experimental results from this study suggest that the propagation period of corrosion.

1.2.6 Long Term Performance of ECC

The long-term performance of ECC in full-scale structures has not been fully established given the relatively recent development of this material. However, at least two field demonstration studies provide limited data that support the contention that ECC can be durable under actual field conditions.

One study involves the use of ECC for repair of a concrete gravity earth-retaining wall(18m in width and 5m in height) that had been damaged by alkali silica reaction (ASR)cracking. The decision to use ECC for the 50-70 mm thick repair overlay was based onthe need to prevent cracks in the substrate concrete from reflecting onto the repair layer.Such reflection was anticipated had normal concrete been used in this repair given continued ASR expansion. For demonstration, the wall was divided into 9 repair blockswith an additional block (block 10) left unrepaired. For the repaired blocks, two types of ECC, one containing 1.5% hybrid PVA and PE fibers (blocks 1-4), and another containing 2.1% PVA fibers (blocks 5-8), were applied. In each block, either welded wire mesh reinforcement, or expanded metal reinforcement, or no reinforcement was used. For control, a welded wire mesh reinforced repair mortar was applied to block

Since the repair took place in 2003, this wall has been continuously monitored. No cracking in the overlay was observed until seven months after repair by ECC, while cracking was visually observed on the blocks repaired with normal mortar just one month after repair. The crack widths in the ECC repair blocks were less than 50 um and120 um at 10 and 24 months, respectively. In contrast, the crack widths in the normal repair mortar block were 200 um and 300 um at 10 and 24 months, respectively. The crack patterns at 12 months and 24 months.

Another long-term performance verification is afforded by a small ECC patch repair placed on the bridge deck of Curtis Road over M-14 in Southern Michigan in 2002, incollaboration with the Michigan Department of Transportation. A complete summary of this work has been outlined by Li and Lepech (2004). During this work, one sectionof a deteriorated bridge deck was repaired with ECC while the remaining portion was repaired with a commercial concrete patching material commonly used by MDOT. Thisrepair scenario allowed for a unique ECC/concrete comparison subjected to identical.

(This road is used frequently by 11 axle trucks heavilyloaded with aggregates, although it has a relatively low averaged daily traffic of 3000 vehicles/day). The concrete repair material used was a pre-packaged mixture of Portland cement and plaster of Paris. At this writing, the repaired bridge deck has experienced more than six complete Michigan winter cycles of freezing and thawing, in addition to live loads. The monitored crack width development. While the ECC patch repair has survived this combined loading state with minor microcracking limited to less than 50 um, the concrete repair portion experienced cracking in excess of 3.5 mm and had to be re-repaired in 2005.

1.2.7 Making of Engineered Cementations Composites

ECC is through with ingredients typically found in concrete, including cement, sand, GGBS, and super plasticizer. However, no coarse aggregates are employed, and no airentrainment is essential. In-stead, micro-fibers are added. The type, size and amount ofall ingredients and their mixing sequence are carefully controlled, so that the resulting composite maintains self-consolidating characteristics during casting and ductile behaviour after hardening. ECC mix design also includes a normal concrete mix designfor comparison.

The components in an ECC mix design have been tailored using a body of knowledge (broadly known as micromechanics) on how the fiber, mortar matrix and the interface between them interact under mechanical loading. As a result, brittle fracture failure is eliminated. Instead, multiple micro cracks form when the composite material is overloaded beyond the elastic state (pseudo yielding), and the propagating micro cracksmaintain very tight crack width in accordance with the tailored nature of the bridging fibers.

The whole inelastic deformation process of ECC can be likened to the “give” built intothe human skeleton due to the presence of muscles and ligaments. A human skeleton with only bones would be significantly more brittle. The design of ECC is analogous tothe design of a well-engineered structure that employs knowledge of load carrying behaviour of structural elements such as beams, columns and connections, as well as the interactions between these elements. In ECC, the design of the composite with fiber,matrix and interface is at much smaller length scales, but conceptually equivalent.

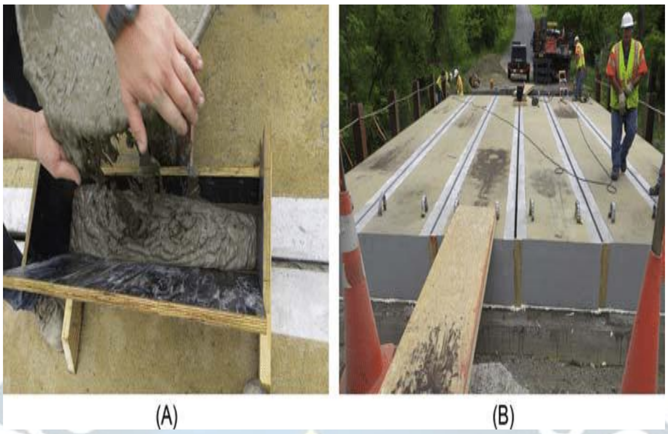

Figure 1.2: Process of ECC

1.2.8 Self-healing of ECC

The chemical make-up and physical properties, self-controlled tight crack width and high tensile ductility in particular, of ECC makes self-healing prevails in a variety of environmental conditions even when the composite is deliberately damaged by tensioning to several percent strain. Self-healing takes place automatically at cracked locations without external intervention.

Self-healing in terms of mechanical and transport properties recovery of pre-damaged (by pre-cracking) composite is revealed in a variety of environmental exposures, include wetting and drying cycles, conditioning temperature, water permeation, and chloride submersion. The establishment of self-healing in ECC looks to improve the long-term ductility and durability of ECC after cracking, and to establish a much moredurable civil engineering material subjected to various environmental conditions.

Cracks can occur during any stage of the life of a concrete structure. They can be due to the concrete material itself as in the case of volume instabilities, or due to external factors such as excessive loading, harsh environmental exposure, poor construction procedures, or design error. These cracks have many negative effects on the mechanicalperformance and durability of concrete structures. The development of concretes whichcan automatically regain this loss of performance is highly desirable. Along these lines, self-healing of cracked concrete, commonly known as autogenous healing, is an often-studied phenomenon.

The phenomenon of self-healing in concrete has been known for many years. It has been observed that some cracks in old concrete structures are lined with white crystalline material suggesting the ability of concrete to seal the cracks with chemical products by itself, perhaps with the aid of rainwater and carbon dioxide in air. Later, anumber of researchers in the study of water flow through cracked concrete under a hydraulic gradient, noted a gradual reduction of permeability over time, again suggesting the ability of the cracked concrete to self-seal itself and slow the rate of water flow. The main cause of self-sealing was attributed to the formation of calcium carbonate, a result of reaction between hydrated cement and carbon dioxide dissolved in water. Thus, under limited conditions, the phenomenon of self-sealing in concrete is well established. Self-sealing is important to watertight structures and to prolonging service life of infrastructure.

In recent years, there is increasing interest in the phenomenon of mechanical property recovery in self-healed concrete materials. For example, the resonance frequency of anultra-high-performance concrete damaged by freeze-thaw actions, and the stiffness of pre-cracked specimens were demonstrated to recover after water immersion. In anotherinvestigation, the recovery of flexural strength was observed in pre-cracked concrete beams subjected to compressive loading at early age. In these studies, self-healing wasassociated with continued hydration of cement within the cracks. As in previous permeability studies, the width of the concrete cracks, found to be critical for self- healing to take place, was artificially limited using feedback-controlled equipment and/or by the application of a compressive load to close the preformed crack. These experiments confirm that self-healing in the mechanical sense can be attained in concrete materials. Deliberate engineering of self-healing in concrete was stimulated by the pioneering research of White and co-workers who investigated self-healing of polymeric material using encapsulated chemicals. A number of experiments were conducted on methods of encapsulation, sensing and actuation to release the encapsulated chemicals into concrete cracks. For example, Li et al demonstrated that air curing polymers released into a crack could lead to a recovery of the composite elastic modulus.

The chemical release was actuated by the very action of crack formation in the concrete,which results in breaking of the embedded brittle hollow glass fibers containing the polymer. Thus, the healing action took place where it was needed.

Taken by Nishiwaki et al , utilized a repair agent encapsulated in a film pipe that melts under heating. A heating device was also embedded to provide heat to the film pipe at the cracked location when an electric current is externally supplied. Yet anotherapproach, suggested by the experiments of Bang et al and Rodriguez-Navarro et al, usedinjected micro-organisms to induce calcite precipitation in a concrete crack. These novel concepts represent creative approaches to artificially induce the highly desirableself-healing in concrete materials.

From a practical implementation view point, autogenous self-healing is most attractive. Compared with other engineering materials, concrete is unique in that it intrinsically contains micro-reservoirs of un hydrated cement particles widely dispersed and available for self-healing. In most concrete and particularly in those with a lowwater/cement ratio, the amount of un hydrated cement is expected to be as much as 25%or higher. These unhydrated cement particles are known to be long lasting in time. Autogenous self-healing is also economical, when compared with chemical encapsulation or other approaches that have been suggested. As indicated above, the phenomenon of autogenous self-healing has been demonstrated to be effective in transport and mechanical properties recovery.

Unfortunately, the reliability and repeatability of autogenous self-healing is unknown. The quality of self-healing is also rarely studied, and could be a concern especially if weak calcite is dependent upon for mechanical strength recovery. Perhaps the most serious challenge to autogenous healing is its known dependence on tight crack width, likely less than 150 microns, which is very difficult to achieve in a consistent manner for concrete in the field. In practice, concrete crack width is dependent on steel reinforcement. However, the reliability of crack width control using steel reinforcementhas been called into question in recent years. The latest version of the ACI-318 code has all together eliminated the specification of allowable crack width. Thus, a number of serious material engineering challenges await autogenous healing before this phenomenon can be relied upon in concrete structures exposed to the natural environment.

To create practical concrete material with effective autogenous self-healing functionality, the following six attributes are considered particularly important.

For convenience, we label a material with all these six attributes of autogenous self-healing as “robust”.

• Pervasiveness: Ready for activation when and where needed (i.e. at the crack when cracking occurs),

• Stability: Remain active over the service life of a structure that may span decades,

• Economics: Economically feasible for the highly cost-sensitive construction industry in which large volumes of materials are used daily,

• Reliability: Consistent self-healing in a broad range of typical concrete structure environments,

• Quality: Recovered transport and mechanical properties as good as pre-damage level.

• Repeatability: Ability to self-repair for multiple damage events.

Previous researchers have engaged in limited studies in the phenomenon of Concrete self-healing, the formation of self-healing products, and the necessary conditions to experience self-healing in concrete materials. These studies have resulted in identifyingthree general criteria which are critical to exhibit reliable autogenous self-healing – presence of specific chemical species, exposure to various environmental conditions, and small crack width. These are summarized below. In some instances, these findingsare contradictory, as in the case of maximum allowable crack width in which some specify maximum crack widths of 10µm while others specify 300µm to exhibit self- healing in various environmental conditions.

1.2.9 Advantages of ECC concrete

- It is stronger, more durable, and lasts longer than the conventional concrete.
- It has more resistance to cracking.
- It does not emit that number of harmful gases as compared to conventional concrete.
- The use of steel reinforcement is reduced.
- It can be used as precast concrete.
- The crack width can be reduced and flexural strength of the concrete can be increased.

- If used in the pavements, the life span of the pavement is more and durable.
- Used in the coupling beams.
- ECC is green construction material.
- ECC is 37% a smaller amount exclusive, consumes 40% less energy, andproduce 39% less carbon dioxide than regular concrete.
- ECC incorporates elevated volumes of industrial wastes including fly-ash, sands and wastes from metal casting processes, wasted cement kiln dust fromcement production.
- Reduced emission of Greenhouse gases.
- Applicable in earthquake resistant structures.
- Used in the construction of jointless bridges.
- ECC is light in weight compared to conventional concrete by anamount of 20 to 40%.
- It has a self-healing property that is it can heal itself by using carbon dioxideand rainwater.
- Its ultimate tensile strain capacity is 3 to 5 %.

1.2.10 Disadvantages of ECC

- It has a high initial cost as compared to conventional concrete.
- It requires skilled labour for its construction.
- It needs some special type of materials which can be difficult to find in some areas.
- Its quality depends upon the material used and the condition under which it is made.
- Its compressive strength can be lesser than the conventional concrete.

Applications of ECC

The main applications of ECC are:

1. Construction of Roads and Bridges

Construction of roads and bridges using ECC eliminates the use of expansion and contraction joints. This is because the ECC has the abilityto change its shape within it.

Fig.1.3. ECC link slab, bridge Deck

2. Construction of Earthquake Resistant Buildings

Buildings made out of ECC have the ability to take more tensile stresses.Hence, these can resist high vibration caused due to dynamic forces like an earthquake.

3. Construction of Concrete Canvas

The concrete canvas mostly constructed for military purposes is supposed to be highly strong and durable. This can be achieved efficiently by the use of ECC.

1.2.11 Field application

ECC have found use in a number of large-scale applications in Japan, Korea,Switzerland, Australia and the U.S. These include:

- The Mitaka Dam near Hiroshima was repaired using ECC in 2003. The surfaceof the then 60-year-old dam was severely damaged, showing evidence of cracks.
- A 225-mm thick ECC bridge deck on interstate 94 in Michigan was completed in 2005. 30 m3 of material was used, delivered on-site in standard mixing trucks. Due to the unique mechanical properties of ECC, this deck alsoused less material than a proposed deck made of ordinary Portland cement. Boththe University of Michigan and the Michigan Department of Transportation aremonitoring the bridge in an attempt to verify the theoretical superior durabilityof ECC; after four years of monitoring, performance remained undiminished.
- The self-consolidating and high-early-strength ECC patch repair wasplaced on Ellsworth Road Bridge over US-23 in November 2006. The high- early-strength ECC can achieve a compressive strength of 23.59 ± 1.40 MPa (3422.16 ± 203.33 psi) in four hours and 55.59 ± 2.17 MPa (8062.90 ± 315.03 psi) in 28 days.

spalling, and some water leakage. A 20 mm-thick layer of ECC was applied byspraying over the 600 m2 surface.

- lso in 2003, an earth retaining wall in Gifu, Japan, was repaired using ECC. Ordinary Portland cement could not be used due to the severity of the crackingin the original structure, which would have caused reflective cracking. ECC was intended to minimize this danger; after one year only microcracks of tolerable width were observed.
- The 95 m (312 ft.) Glorio Roppongi high-rise apartment building in Tokyo contains a total of 54 ECC coupling beams (two per story) intended to mitigateearthquake damage. The properties of ECC (high damage tolerance, high energyabsorption, and ability to deform under shear) give it superior properties in seismic resistance applications when compared to ordinary portland cement. Similar structures include the 41-story Nabeaure Yokohama Tower (four coupling beams per floor.)
- The 1 km (0.62 mi) long Mihara Bridge in Hokkaido, Japan was opened to traffic in 2005. The steel-reinforced road bed contains nearly 800 m3 of ECC material. The tensile ductility and tight crack control behaviour of ECC led to a40% reduction in material used during construction.
- Similarly, a 225-mm thick ECC bridge deck on interstate 94 in Michigan was completed in 2005. 30 m3 of material was used, delivered on-site in standard mixing trucks. Due to the unique mechanical properties of ECC, this deck alsoused less material than a proposed deck made of ordinary Portland cement. Boththe University of Michigan and the Michigan Department of Transportation aremonitoring the bridge in an attempt to verify the theoretical superior durabilityof ECC; after four years of monitoring, performance remained undiminished.
- The first self-consolidating and high-early-strength ECC patch repair wasplaced on Ellsworth Road Bridge over US-23 in November 2006. The high- early-strength ECC can achieve a compressive strength of 23.59 ± 1.40 MPa (3422.16 ± 203.33 psi) in four hours and 55.59 ± 2.17 MPa (8062.90 ± 315.03 psi) in 28 days.
- Allowing for fast repair and re-opening the session to traffic. The high-early- strength ECC repair has shown superior long-term durability in field conditionscompared to typical concrete repair materials.

1.2.12 Performance of ECC

The Fibers act as the reinforcement material in the ECC. In ECC, after a crack, the composite strain hardens, unlike fiber reinforced concrete. In a fiber reinforced concrete, the cracks start developing with the rupture of fibers. This reducesthe stress-bearing capability of Fiber reinforced concrete. But in the case of ECC, they score good because they have high fracture toughness and high damagetolerance. Special features of bendable concrete include:

- The tensile strength of ECC ranges from 10 to 15 MPa
- The compressive strength of ECC can be achieved up to 70MPa.
- ECC gains self-healing property which helps to fill the microcracksby a complex product that is formed by the reaction of cement with therainwater.
- The ultimate tensile strain of bendable concrete can go up to 3 to 5%.
- The strain capacity of ECC is three hundred times greater than the conventional concrete. This is the factor that provides flexibility to the concrete.

1.2.13 Composition of ECC

In a ECC mix, the coarse aggregate is eliminated and more of fibers are incorporated.

ECC is composed of:

1. Cement
2. Fibers
3. Sand
4. Water
5. Superplasticizer

Some of the important constituents of ECC are briefly explained below:

Fibers in ECC: The most commonly used fibers are silica fibers, asbestos fibers, glass fibers, steel fibers, etc. The flexibility property in a bendable concrete is imparted by the Fibers present in it. The Fibers also act as reinforcement forthe concrete.

The fibers are provided with an anti-friction coating called the slick coating. This coating helps the fibers to slip over the other. This won't create friction between the fibers that hence prevent the formation of cracks in the concrete. This also increases the flexibility of the concrete. Cement used here can be normal ordinary portland cement.

Fine Aggregates in ECC

Normally, the fine sand used for water treatment activities is the best fine aggregate for ECC. If this is unavailable, normal sand can be used. Some of the replacements like Nano silica, blast furnace slag and GGBS can also be used for this concrete making.

Superplasticizers in ECC

ECC requires higher workability which hence demands superplasticizers. Some of the superplasticizers used for ECC are:

a) Lignin
b) Naphthalene
c) Melamine formaldehyde
d) Sulphonate
e) Polycarboxylate ether
f) Lignosulfonates
g) Poly ethylene glycol

1.3 Nano silica

1.3.1 General

Concrete is the material of present as well as future. The wide use of it in structures, from buildings to factories, from bridges to airports, makes it one of the most investigated materials of the 21st century. Due to the rapid population explosion and the technology boom to cater to these needs, there is an urgent need to improve the strength and durability of concrete. Out of the various materials used in the productionof concrete, cement plays a major role due its size and adhesive property. So, to produceconcrete with improved properties, the mechanism of cement hydration has to be studied properly and better substitutes to it have to be suggested. Different materials known as supplementary cementitious materials or SCMs are added to concrete improve its properties. Some of these are GGBS, blast furnace slag, rice husk, Nano silicas and even bacteria. Of the various technologies in use, nano-technology looks to be a promising approach in improving the properties of concrete.

1.3.2 CEMENT- Composition and Hydration

Cement can be described as a crystalline compound of calcium silicates and other calcium compounds having hydraulic properties (Intht). The four major compounds that constitute cement (Bogue's Compounds) are Tricalcium silicate, abbreviated as C3S, Dicalcium silicate (C2S), Tricalcium aluminate (C3A), Tetra calcium aluminoferrite (C4AF) where C stands for CaO, S stands for SiO2, A stands for Al2O3 and F for Fe2O3.

Tricalcium silicate and dicalcium silicate are the major contributors to the strength of cement, together constituting about 70 % of cement. Dry or anhydrous cement does nothave adhesive property and hence cannot bind the raw materials together to form concrete. When mixed with water chemical reaction takes place and is referred toas 'hydration of cement'. The products of this exothermic reaction are C-S-H gel and Ca (OH)2. Calcium hydroxide has lower surface area and hence does not contribute muchto the strength of concrete.

On hydration of cement aluminates, a product is formed known as ettringite, which hasneedle like morphology and contributes to some early strength of concrete. C-S-H gel refers to calcium silicate hydrates, making up about 60 % of the volume of solids in a completely hydrated cement paste. It has a structure of short Fibers which vary from crystalline to amorphous form. Owing to its gelatinous structure it can bound various inert materials by virtue of Van der Waal forces. It is the primary strength giving phasein cement concrete.

The C-S-H phase is the main product of PC hydration. Its structure is similar to that ofthe C-S-H phase formed in the hydration of pure dicalcium and tricalcium silicate. Thematerial exhibits a very low crystallinity. Its mean CaO/SiO_2 molar ratio may vary depending on the cement composition, water/cement ratio and hydration.

Although the formulas above treat C–S–H as a specific stoichiometry, with the formula C3S2H3, it does not at all form an ordered structure of uniform composition. C–S–H is actually an amorphous gel with a highly variable stoichiometry.

Figure:1.4 Nano silica

1.3.3 MATERIALS- Use in Concrete

Nanomaterials are very small sized materials with particle size in nanometres. These materials are very effective in changing the properties of concrete at the ultrafine levelby the virtue of their very small size. The small size of the particles also means a greatersurface area. Since the rate of a pozzolanic reaction is proportional to the surface area available, a faster reaction can be achieved. Only a small percentage of cement can be replaced to achieve the desired results. These nanomaterials improve the strength and permeability of concrete by filling up the minute voids and pores in the microstructure.The use of Nano silica in concrete mix has shown results of increase in the compressive,tensile and flexural strength of concrete. It sets early and hence generally requires admixtures during mix design. Nano-silica mixed cement can generate nano-crystals of C-S-H gel after hydration. These nano-crystals accommodate in the micro pores of thecement concrete, hence improving the permeability and strength of concrete.

1.3.4 Concrete with Nano silica

Nano-silica incorporation into cement concrete is the direct application approach of nanomaterials. Researchers have worked on the mechanical and durability properties and microstructure analysis of concrete with nano-silica as discussed below.

Fresh properties

Reduced setting times were observed by various researchers on incorporation of nano-silica in concrete which is same as observed for pastes and mortar. Also, decrease in initial and final setting time was observed on incorporation of NS in various quantities,with increase in viscosity and yield stress reported

Mechanical properties

Concrete strength is influenced by lots of factors like concrete ingredients, age, ratio ofwater to cement materials, etc. Nano-silica incorporation into concrete resulted in higher compressive strength than that of normal concrete to a considerable level. Li et al. (2004) reported 3-day compressive strength increase by 81% and also at later stages,same trend was observed with 4% nano-silica in high volume GGBS concrete. Naji Givi, Abdul Rashid, Aziz, and Salleh (2010) also reported higher compressive strengthat all ages, for nano-silica blended concretes up to maximum limit of 2% with averageparticle size of 15 and 80 nm. Same results were obtained for split tensile and flexural strength. Pourjavadi et al. (2012) reported that negative effect of super absorbent polymer reduced compressive strength by addition of nano silica, but same results werenot observed for flexural strength.

An increase of about 23–38% and 7–14% at 7 days and 28 days, respectively, in compressive strength of nano-silica concrete was reported, whereas low increase of 9.4% (average) was reported for flexural strength. Zhang and Islam (2012), Zhang et al. (2012) used GGBFS, GGBS and slag and increase in compressive strength was observed as 22% (3 days) and 18% (7 days) and 30% (3 days) and 25% (7 days) of concretes with GGBFS and GGBS and slag, respectively. Heidari and Tavakoli (2013) incorporated nano-silica in ground ceramic concrete and improvement in strength at early stage was observed. Mechanical mixing and sonication techniques were followedto disperse nSiO2 into Ep resin. Furthermore, the same nSiO2/Ep is reinforced with carbon fabric by hand lay-up followed by vacuum-bagging technique

Durability properties

Durability properties of concrete include aspects such as permeability, pore structure and particle size distribution, resistance to chloride penetration, etc. Investigations on nano-silica concrete for its permeability characteristics showed that the addition of nano-silica in concrete resulted in reduction in water absorption, capillary absorption, rate of water absorption, and coefficient of water absorption and water permeability than normal concrete. The pore structure determines the transport properties of cementpaste, such as permeability and ion migration. Reduction in water absorption, capillary absorption, rate of water absorption and water permeability has been observed by various researchers. Pore size distribution in concrete was refined and porosity lowered even at short time, curing on addition of 4% nano-silica.

Also, increasing nano-silica dosage decreased capillary porosity. Water absorption capacity of nano-silica concretes decreased with incorporation of nano-silica Enhancement of resistance to chloride penetration of concretes with addition of nano- silica was reported. Zhang and Islam (2012) studied the behaviour of high-volume GGBS and slag concretes with nano-silica addition and reported that the addition of nano-silica reduced the length of dormant period during hydration and also accelerated the hydration. Chloride ion penetration was also reduced with the addition of nano-silica into GGBS and slag concrete.

The increased use of cement is essential in attaining a higher compressive strength. But cement is a major source of pollution. The use of nanomaterials by replacement of a proportion of cement can lead to a rise in the compressive strength of the concrete as well as a check to pollution. Since the use of a very small proportion of Nano SiO2 canaffect the properties of concrete largely, a proper study of its microstructure is essentialin understanding the reactions and the effect of the nanoparticles.

The existing papers show the use of admixtures in concrete mix. In the present study, no admixture has been used in order to prevent the effect of any foreign material on thestrength of the concrete. This study is an attempt to explain the impact of a nano-silicaon the compressive strength of concrete by explaining its microstructure.

1.3.15 Advantages of Nano silica

- Development of high-performance cement and concrete materials as measured by their mechanical and durability properties;
- Development of sustainable concrete materials and structures through engineering for different adverse environments, reducing energy consumption during cement production, and enhancing safety;
- Then Development of intelligent concrete materials through the integration of nanotechnology-based self-sensing and self-powered materials and cyber infrastructure technologies;
- Development of novel concrete materials through nanotechnology-based innovative processing of cement and cement paste; and
- Development of fundamental multi scale model(s) for concrete through advanced characterization and modelling of concrete at the Nano-, micro- and macro scales.
- Improves the material's bulk properties.
- Ability to control or manipulate materials at the atomic scale.
- To obtain thinner final products and faster setting time.
- Cost effectiveness.
- Lowered levels of environmental contamination.
- Concrete is stronger, lighter and more durable.
- Concrete with good workability.
- Lower cost per building site.
- Cessation of contamination caused by micro silica solid particles.
- Concrete with high initial and final compressive and tensile strengths.
- Cessation of super plasticizing utilization.
- Cessation of silicosis risk.

1.4 Fibers

1.4.1 Natural Fibers

Natural fibers develop or occur in the fiber shape, and include those produced by plants, animals, and geological processes.

They can be classified according to their origin:

Vegetable fibers are generally based on arrangements of cellulose, often with lignin: examples include cotton, hemp, jute, flax, abaca, piña, ramie, sisal, bagasse.

Plant fibers are employed in the manufacture of paper and textile (cloth), and dietary fiber is an important component of human nutrition.

Wood fiber, distinguished from vegetable fiber, is from tree sources. Forms include groundwood, lacebark, thermomechanical pulp (TMP), and bleached or unbleached kraft or sulfite pulps. Kraft and sulfite refer to the type of pulping process used to remove the lignin bonding the original wood structure, thus freeing the fibers for use inpaper and engineered wood products such as fiber board.

Animal fibers consist largely of particular proteins. Instances are silkworm silk, spidersilk, sinew, catgut, wool, sea silk and hair such as cashmere wool, mohair and angora, fur such as sheepskin, rabbit, mink, fox, beaver, etc.

Mineral fibers include the asbestos group. Asbestos is the only naturally occurring long mineral fiber. Six minerals have been classified as "asbestos" including chrysotile of the serpentine class and those belonging to the amphibole class: amosite, crocidolite, tremolite, anthophyllite and actinolite. Short, fiber-like minerals include wollastonite and palygorskite.

Biological fibers, also known as fibrous proteins or protein filaments, consist largely of biologically relevant and biologically very important proteins, in which mutations or other genetic defects can lead to severe diseases.

Instances include the collagen family of proteins, tendons, muscle proteins like actin, cell proteins like microtubules [citation needed] and many others, such as spider silk, sinew, and hair.

1.4.2 Steel fibers

Figure:1.5 Steel Fibers in ECC

Steel fibers have continuously been present in friction material, although they had a decline in the first decade of the twenty-first century. However, the banning of copper in car brake pads in certain states in the United States (virtually causing it to no longerbe used throughout the country) has started a revival of steel fibers. As said, steel fibersare involved in the noise process. Their revival is linked to their substitution for Cu, to contribute to thermal conductivity.

Nevertheless, this process required a rethinking of steel fiber processing: i.e., the content of carbon must be lowered and the annealing processes to release stresses mustbe considered as well. For instance, several companies already offer steel fibers with less than 0.10% carbon to decrease noise problems. Steel fibers as metallic compounds are also involved in the stability of friction and in the thermal conductivity of the brakepad composite.

The main effects of thermal conductivity on friction material performances concern severe conditions such as fading and recovery. In this case, a high temperature is reached through repeated braking applications as in a downhill stress and recovery; thematerial must be able to restore the steady coefficient of friction after cooling. A studyconducted by Bijwe and Kumar in a Krauss machine was not conclusive, at least for steel fiber contents, till 12 wt.% in a model matrix.

However, they showed that fading and recovery is better for the material with the 12 wt.% steel fibers. These studies, where the formula balance is achieved by adjusting barite content, always have the limitation that the effect of the raw materials varied can be exchanged, since the supposed friction inertness of barite is still to be demonstrated, especially for formulas with mild abrasives and low metallic content.

Steel fibers have continuously been present in friction material, although they had a decline in the first decade of the twenty-first century. However, the banning of copper in car brake pads in certain states in the United States (virtually causing it to no longer be used throughout the country) has started a revival of steel fibers. As said, steel fibers are involved in the noise process. Nevertheless, this process required a rethinking of steel fiber processing: i.e., the content of carbon must be lowered and the annealing processes to release stresses must be considered as well.

1.4.3 Polypropylene fiber

Figure:1.6 Polypropylene fibers in ECC

Polypropylene is a form of synthetic Fibers commonly used in concrete as a way to reduce potential cracking and generally improve the durability of this construction material. In order to use these Fibers, you do not need to make any special modifications to the concrete or rely on different tools, making PP Fibers an easy and even cost-effective way to enhance the material.

Polypropylene Fibers are popular concrete reinforcers because they are resistant to drying plastic shrinkage. These Fibers are able to absorb energy and distribute the load of the concrete much more efficiently. This results in less concrete needed, and lower maintenance costs. These Fibers are also lightweight, non-magnetic, and homogenous, and they can withstand corrosion really well, unlike steel Fibers or wire mesh known to have these problems.

The Fibers will essentially hold the concrete blend together, and slow down its settlement to reduce water bleeding. While bleeding will still happen, it will do so at a much slower rate, which slows down drying time.

1.5 Objectives

- To evaluate and compare the long-term durability performance of hybrid fiber reinforced ECC with conventional concrete under various environmental conditions.

- To examine the shear bond behaviour between hybrid fiber reinforced engineered cementitious composites substrate by conducting pill-off test and push-off test. To determine the influence of hybrid fibers on the interfacial bond strength, crack propagation, and debonding mechanism between the hybrid fiber reinforced engineered cementitious composites overlay and the base concrete.

- To identify the optimal combination of hybrid fiber reinforced Engineered Cementitious Composites that provides the best compromise between durability performance and shear bond strength .

- To provide valuable data for the design and implementation of hybrid fiber reinforced ECC in practical construction applications.

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

A literature survey on Engineered Cementitious Composites (ECC) involves a comprehensive examination and analysis of existing research, publications, and scholarly works related to ECC. Such surveys are conducted to gather knowledge, insights, and trends in the field, offering a foundation for further research, innovation, and the application of ECC in construction and infrastructure projects. In this introduction, we will explore the significance and purpose of a literature survey on ECC.

2.2 Description

Due to the scarcity in the available land space, vertical growth is becoming unavoidable, resulting in high rise structures and sky scrapers which are increasing the demand for natural resources, high durable concrete, high workable concrete and high strength concrete. This increase in demand has given an opportunity for the use of mineral admixtures in High Strength Concrete. This research work would be an attempt to find the constraints on the use GGBS and Metakaolin in High Strength Concrete. This chapter presents a brief over view of the existing literature in the domain of use of GGBS and Metakaolin in High Strength Concrete. The major accomplishments and the results reported in the literature are highlighted. The over view of literature is presented in the following groups:

- Overview on use of GGBS and Metakaolin in High Strength Concrete;
- Overview on use of Metakaolin in High Strength Concrete;
- Overview on use of GGBS in High Strength Concrete.

2.2.1 Overview on use of GGBS and Metakaolin in High Strength Concrete

VishalKumar Milubhai Thakarya & Mahesh Patel [2023], stated that With time, the infrastructure is growing rapidly, and concrete has become one of its main components. Due to the adverse effects of cement production on the surrounding environment, utilizing cement in concrete can be a challenging job. Geopolymer concrete is gaining rapid recognition as an inventive construction material, serving as a great substitute for traditional Portland cement concrete and effectively contributing to the reduction of cement usage. In this research, pozzolanic substances including Ground Granulated Blast Furnace Slag (G.G.B.S.), Metakaolin (M.K.) as a binding agent, and sodium silicate and sodium hydroxide as alkali activators were employed. The proportion of alkali to binder remained constant at 0.45 throughout the study. The samples were casted for different mixes and tested for compressive strength and sulphate resistance. The results of the study indicated that the mix prepared with 14 molarity of alkali activators shows the better performance as compared to other mixes.

Mohammed Aasim Saeed & Nadeem Pasha [2022], have focused on the partial replacement of cement by Metakaolin which is produced by heat-treating kaolin, one of the most abundantly natural available mineral and also waste material GGBS obtained from ins manufacturing industries as by-product. In this attempt is made to reduce the production of green house gases and protecting environment and also the natural resources of calcareous material by reducing the production of Cement. In this study, concrete of M25 grade were considered for w/ ratio 0.50 for the replacement of cement by Metakaolin of 5% 10% 15%and 40% is tried and optimum parentages replacement is fixed. For this optimum percentage of Metakaolin, further. cement is replaced by different percentage of GCBS e. 6%, 9%, 12% is tried. Then the investigation revealed improvement in compressive strength, split tensile strength and flexural strength for various percentage replacement of cement by Metakaolin(MK) and GGBS. Based on the overall observation, it could be recommended that 15%MK and 9%GGBS replacement for cement be effectively utilized in all the concrete Works.

Krishna Nandanam et. al. [2021], In developing country such as India, due to the significant boom in the infrastructure development the virgin aggregates (VAs) resources are diminishing at a high pace and thus creating an ecological imbalance. In contrast, an immense quantity of recycled aggregates (RAs) is generated from construction and demolition waste. Thus, in view of sustainability, utilization of RA can be a great source of aggregate in the development of structural concrete. This paper outlines the development of self-compacting concrete (SCC) with full replacement of coarse VAs with coarse RAs. In addition, to make the SCC more sustainable, utilization of supplementary cementing materials such as coal GGBS (CFA), ground granulated blast furnace slag (GGBS), and metakaolin (MK) were used as cement replacement materials. Finally, the mechanical and durability performance of SCCs were examined to see whether they could be adopted for structural applications with greater confidence. A total of nine SCC mixes were designed containing GGBS, CFA, and MK content as cement replacement (by weight) with full replacement of VAs with RAs. Fresh performance of SCC mixes was scrutinized by slump flow, T_{500}, V-funnel, and L-box test.

Furthermore, compressive strength test, split tensile test, flexural test, and E-modulus test were performed to study the mechanical characteristics. Durability performance was examined by conducting water permeability, sorptivity, rapid chloride penetration test, surface resistivity, pH, and carbonation tests. The experimental results concluded that 15% replacement of cement with MK exhibited an excellent mechanical as well as durability performance of self-compacting recycled aggregate concrete with a ceiling strength of 75 MPa. The use of GGBS also yielded excellent durability performance. In contrast, the use of CFA exhibits moderate mechanical and durability performance. It can be inferred from the outcomes of this study that it is possible to develop high-performance SCC using 100% RA, by employing mineral admixtures such as CFA, GGBS, and MK.

O O Ofuyatan et. al. [2019], The experimental study of two supplementary cementitious material on self-compacting concrete was investigated. Three mixes were designed, the control mix without the supplementary cementitious material, second mix with metakaolin (MK) and third mix with ground granulated blast furnace slag (GGBFS) both at 5, 10, 15, 20 and 25% respectively. After each mix preparation, workability test was carried out and specimens of the three mixes were cast and cured in water for 7, 14, 21 and 28 days respectively. Tests on hardened concrete were carried out to know the compressive strength of the three-mix designs. The test results showed that a replacement of 5% of both admixtures GGBFS and Mk increased in the compressive strength compared to the control mix. Also observed was the presence of mineral admixtures that had a significant on the strength loss due to the sodium, calcium and magnesium sulphate attack. The best resistance was obtained for 5% MK and GGBFS at 28 days curing.

B. Sarath Chandra Kumar & K. Ramesh [2017], stated that Construction industry is dominated by new materials which are ecologically violable and feasible solution for ever growing architectural industry. Effort are in progress all over the world to develop environment friendly construction materials which minimizes the utility of natural resources and helps to decrease green house gas emissions in to the atmosphere. The green house gas releases in the atmosphere is increasing day by day due to ordinary Portland cement production. In this connection, Geopolymer is in need, where the binders used in the production of geopolymer concrete is inorganic polymers. Geopolymer concrete will be introduced as an alternative concrete which did not use any cement in its mixture and used Metakaoline and GGBS as alternative cement. NaOH and Na2SiO3 were used as activator solution. The fixed ratio of sodium silicate to sodium hydroxide is 2.5 and the concentration of sodium hydroxide is 8 Molar. The geopolymer concrete specimens are casted and tested in the laboratory for compressive strength, Split Tensile Strength and Flexural Strength for 3 Days, 7 Days and 28 days and cured at ambient temperature. This study helps in gaining knowledge about the morophological composition of geopolymer concrete which might result in path-breaking trends in research and construction industry.

K. Chandra Padmakar & B. Sarath Chandra Kumar [2017], studied the strength and durability properties of Metakaolin and Ground Granulated Blast Furnace Slag (GGBS) based Geopolymer Concrete mixes at various proportions. In this connection, Geopolymer is showing great potential and does not need the presence of Portland cement as a binder. Geopolymer concrete is prepared by using an alkaline solution of the suitable chemical composition. The ratio of the mixture is 2.5 and the concentration of sodium hydroxide is 10M. The geopolymer concrete specimens are cast and tested for different types of strengths for 3, 7, and 28 days and cured at ambient temperature. This study helps in gaining knowledge about the morphological composition of concrete which might result in path-breaking trends in the construction industry.

S. Mounika1 & S. K. Asha [2016], High strength concrete is defined as concrete with considered characteristic cube strength above 40 Mpa. Environmental concerns both in terms of damage caused by the extraction of raw material and carbon dioxide emission during cement manufacturing also reduce cement consumption by the use of supplementary materials. Applications of high strength concrete are bridges, aqueducts, high rise buildings, off shore structures, dams etc. The study involves the replacement of cement with ground granulated blast furnace slag, replacement of cement with metakaolin and also replacement of cement with ground granulated blast furnace slag & metakaolin .using different percentages of supplementary materials. A 15% replacement of the cement by metakaolin resulted in satisfactory mean target compressive strength and workability and durability, GGBS 40% replacement in cement is satisfactory target strength is achieved, for M-80 grade concrete with glenieum B233 as super plasticizer and the strength properties were studied after 7 days, 28 days.

2.2.2 Overview on use of Metakaolin in High Strength Concrete

D.G. Basavaraj & M.S. Ravikumar [2022], Cement has an unresolved problem of increased utilization of raw materials and energy consumption and also carbon dioxide emission during its production. Metakaolin is utilized as partial substitute to cement. It utilizes lime on hydration and causes an increase in the production of cementitious compounds leading to improved strength. The principal intention of this research activity is to find out the fresh (workability) and hardened properties (compressive, split tensile and flexure) of concrete by using metakaolin at varying percentages from 0%, 5%, 10%, 15% and 20% by weight of cement and again by incorporating various types of steel fibers in the limit of 2%, 2.5%, 3% and 3.5%. Concrete specimens were cast for a M40 grade of concrete. Cube specimens (150 × 150 × 150 mm), cylindrical specimens (300 × 150 mm) and prism specimens (100 × 100 × 500 mm) were tested and evaluated for strengths in direct compression, tension and bending for 7 and 28 days of curing span. The outcomes were compared with normal mix. The results have shown that the increase in compressive, tensile and flexure were 20.29%, 16.13% and 14.4% respectively.

Nabil Abdelmelek & Eva Lubloy [2020], presented a wide experimental study, in which it evaluates the performance of high-strength paste exposed to elevated temperatures up to 900 °C. Several factors have been investigated at the age of 90 days, i.e. metakaolin (MK) dosages, water to binder ratio (w/b) as well as elevated temperatures. Results proved that MK improves the relative residual compressive strength and relative residual bending strength showing a gain up to 52% and of 71% at 500 °C, respectively, compared to the pure cement paste in case of 0.3 w/b. The maximum use of MK is not more than 12%, and the optimum dosages were 9, 12, and 12% of MK replacements for 0.3, 0.35, and 0.4 w/b, respectively. The optimum dosage could change with changing w/b ratio and this up to the density of the microstructure which is controlled by the amount of w/b ratio and the packing effect of MK amount. In addition to the mechanical properties, the adoption of MK decreases the cracking of the specimens at elevated temperatures. SEM investigations show the positive physical morphology contribution of MK, specific surface area as well as its chemical composition for decreasing the $Ca(OH)_2$ effect. Different phases that formed during temperatures elevation are illustrated by TG analysis. Results showed the reason behind using MK on the cracking enhancement and mechanical properties improvement after high temperatures exposure. Meanwhile, the obtained optimum MK dosages at ambient temperature are not similar to that obtained at elevated temperatures.

Sunny A. Jagtap et. al. [2017], Concrete is widely used construction materials. However, the production of Portland cement releases significant amount of CO2 (carbon dioxide), a greenhouse gas. One ton of Portland cement clinker production releases approximately one ton of CO2 and other gases. Environmental issues are playing essential role in the sustainable development of concrete industry. Today many researches are ongoing for the replacement of Portland cement, using many waste materials like GGBS and GGBS. Like GGBS and GGBS a Metakaolin can also use as a binder with the partial replacement of cement which take some part of reaction at the time of hydration reaction. Cement replacement by glass powder in the range 5% to 25% with an interval of 5% is to be study. It was tested for compressive strength, Split tensile strength and flexural strength at the age of 7, 28 days and compared with the results of conventional concrete. The overall test results shows that Metakaolin could be used in concrete as a partial replacement of cement.

M Mohammed Ashik & D Gomathi [2017], stated that cement concrete is the most widely used material for various constructions. Properly designed and prepared concrete results in good strength and durability properties. Even such well designed and prepared cement concrete mixes under controlled conditions also have certain limitations because of which the above properties of concrete are found to be inadequate for special situations and for certain special structures. Hence variety of admixtures such as GGBS, Silica fume, rise husk ash and stone dust etc., are used along with cement in certain percentages to enhance the properties of the regular cement concrete.

Satyendra Dubey et. al. [2015], Metakaolin is a cementitious materials used as an admixture to produce high strength concrete and is used for maintaining the consistency of concrete. In the case where insufficient or poor curing concrete structure like the underground structure which undergo serve loss of compressive strength, use of metakaolin proves to be very useful to modify the properties of concrete. This paper deals with the properties of concrete with varying percentage replacement of metakaolin in M-25 greade of concrete. The mix M1,M2,M3 and M4 were obtained by replacing 0,5,10 and 15 percent mass of cement by Metakaolin. The test results indicated that admixture metakaolin when used at optimum quantity tend to increase the strength of the concrete mix when compared with conventional concrete.

Tsai-Lung Weng et. al. [2013], investigated the basic mechanical and microscopic properties of cement produced with metakaolin and quantified the production of residual white efflorescence. Cement mortar was produced at various replacement ratios of metakaolin (0, 5, 10, 15, 20, and 25% by weight of cement) and exposed to various environments. Compressive strength and efflorescence quantify (using Matrix Laboratory image analysis and the curettage method), scanning electron microscopy, and X-ray diffraction analysis were reported in this study. Specimens with metakaolin as a replacement for Portland cement present higher compressive strength and greater resistance to efflorescence; however, the addition of more than 20% metakaolin has a detrimental effect on strength and efflorescence. This may be explained by the microstructure and hydration products. The quantity of efflorescence determined using MATLAB image analysis is close to the result obtained using the curettage method. The results demonstrate the best effectiveness of replacing Portland cement with metakaolin at a 15% replacement ratio by weight.

P. Dinakar et. al. [2013], studied the effect of incorporating metakaolin (MK) on the mechanical and durability properties of high strength concrete for a constant water/binder ratio of 0.3. MK mixtures with cement replacement of 5, 10 and 15 % were designed for target strength and slump of 90 MPa and 100 ± 25 mm. From the results, it was observed that 10 % replacement level was the optimum level in terms of compressive strength. Beyond 10 % replacement levels, the strength was decreased but remained higher than the control mixture. Compressive strength of 106 MPa was achieved at 10 % replacement. Splitting tensile strength and elastic modulus values have also followed the same trend. In durability tests MK concretes have exhibited high resistance compared to control and the resistance increases as the MK percentage increases. This investigation has shown that the local MK has the potential to produce high strength and high performance concretes.

2.2.3 Overview on use of GGBS in High Strength Concrete

Sachin J et. al. [2023], In India, the annual production of GGBS is 15 million tons and only 55% of GGBS is used in the construction industry. It is therefore important to increase the use of industrial waste on a larger scale for environmental benefits in the concrete industry. Numerous studies have been performed on these SCMs to evaluate the properties of his GGBS-containing concrete in fresh and cured states. Using by-products of the slag industry to higher replacement levels for cement could significantly reduce the price of concrete. Paving economical and environmentally friendly concrete Green house gas (GHG) emissions are effectively reduced by 47.5% by using GGBS as a cement substitute. India is the largest producer of GGBS. In one year he produces more than 112 million tons of GGBS. 60-70% of the GGBS is consumed and the rest is spread over the ground. This is because the government encourages the use of his 100% GGBS to avoid landfills and create a greener environment.

Seelam Srikanth et. al. [2022], Utilization of various mineral admixtures in producing mortar decreases the porosity and capillarity, hence improves the durability in opposition to water and competitive solutions. In this research work, Ground Granulated Blast Furnace Slag is used to replace 30 percent, 60 percent, and 70% of ordinary Portland cement (OPC) (GGBFS). Mechanical property (compressive strength) and durability properties (permeability, porosity, and sorptivity) of high-performance concrete (HPC) are tested. Water permeability of M85 is measured using three cell permeability apparatus. Compressive strength, porosity, and sorptivity of the same mixes are also found. According to the test results of HPC, 30%

replacement level of GGBFS gives higher compressive strength than 60% and 70% replacement levels of GGBFS. An equation is developed for permeability of HPC based on mechanical strength and porosity. It is found that coefficient of permeability of water for HPC mixes ranges from 5.1 × 10-11 cm/sec to 7.8 × 10-11 cm/sec. It is concluded that 30% GGBFS used in HPC produces less porosity, less permeability, and less sorptivity than compared to other replacement levels

Adek Ainie Mat Dom et. al. [2021], Numerous infrastructures have been effectual on the list with the demands of Malaysia's economic growth due to the country's explosive growth. As a result, demand for cement has increased, prompting one of the country's largest cement producers to increase production. Cement production necessitates a significant quantity of finite supplies, such as stock and hydrocarbon deposit which is expected to produce 5-6 percent of all carbon dioxide greenhouse emissions. This paper emphasizes the viability of GGBS for certain value in cement, as implied by earlier studies. GGBS is a waste product deduced from the iron and steel industries. The use of GGBS as a cement replacement in concrete is desirable since it has equivalent cement fineness and cementitious properties. The specific gravity, specific surface, GGBS's chemical composition and impact of GGBS on water absorption were discussed in this study. Replacing GGBS in concrete production reduced the highest point heat of hydration rate and time. The use of GGBS as a partial cement substitute in the range of 30% to 60% developed strength at longer hardening periods.

M. N. Bajad et. al. [2018], Cement concrete is the most commonly used construction material in the world. The basic constituent materials are cement, aggregate and water. Nowadays these materials are not easily available. For the manufacturing of cement availability of limestone is very important. In these days it is seen that the availability of lime stone is very less. Further it also causes pollution to the environment and also the manufacturing cost of cement is high. So it is the need of time to replace cement with some other materials. After looking in that way it comes to know that Ground Granulated Blast Furnace Slag (GGBS) has somewhat similar properties to cement. So the replacement of cement by GGBS can be possible. In that way the properties of concrete containing GGBS has to be checked and its suitability for the replacement of cement is to be checked. In this investigation the effect of GGBS on properties of fresh (workability) and hardened concrete (Compressive strength) have been studied by varying percentage of GGBS by weight of cement. After that, comparison between the behavior of conventional concrete and concrete containing GGBS, under chemical attack such as sulphate, chloride, and acid attack has been studied at optimum replacement of cement with GGBS. These observations are being made in order to be able to replace the usage of conventional concrete with concrete containing GGBS in areas where the chemical damage of conventional concrete is high. In this investigation effect of GGBS on properties of fresh and hardened concrete are studied. The effect of chemicals attack also studied to know the effect of GGBS on durability of concrete. Higher strength and durability of concrete subjected to chemical attack was observed with partial replacement of cement by GGBS.

Thavasumony D et. al. [2014], Concrete is a brittle material when it undergoes heavy loads, cracks will form and to reduce this and improve high strength in concrete certain admixtures are used. To produce high strength concrete these Ground Granulated Blast Furnace Slag is used. It is obtained by quenching molten iron Slag (a by-product of iron and steel making) from blast Fornance in water or steam. GGBS is used to make durable concrete structure in combination with ordinary Portland cement and (or) other pozzolona materials. Concrete containg GGBS cement has a higher ultimate strength than concrete made with Portland cement. It has a higher portion of the strength enhancing calcium silicate hydrates (CSH) than concrete made with Portland cement only and a reduce content of free lime which does not contribute to concrete strength, concrete made with GGBFS continues to gain strength overtime, and has been shown to double its 28-day-strength over periods of 10 to 12 years. Our project is a testing project compared with the compressive strength of PCC and GGBFS, used concrete. Here the amount of cement is reduced and that amount is replaced with GGBS.

D. Suresh & K. Nagaraju [2015], Concrete is a mixture of cement, fine aggregate, coarse aggregate and water. Concrete plays a vital role in the development of infrastructure Viz., buildings, industrial structures, bridges and highways etc. leading to utilization of large quantity of concrete. On the other side, cost of concrete is attributed to the cost of its ingredients which is scarce and expensive, this leading to usage of economically alternative materials in its production. This requirement is drawn the attention of investigators to explore new replacements of ingredients of concrete. The present technical report focuses on investigating characteristics of concrete with partial replacement of cement with Ground Granulated Blast furnace Slag (GGBS). The topic deals with the usage of GGBS and advantages as well as disadvantages in using it in concrete. This usage of GGBS serves as replacement to already depleting conventional building materials and the recent years and also as being a byproduct it serves as an Eco Friendly way of utilizing the product without dumping it on ground.

A. Oner & S. Akyuz [2007], This paper presents a laboratory investigation on optimum level of ground granulated blast-furnace slag (GGBS) on the compressive strength of concrete. GGBS was added according to the partial replacement method in all mixtures. A total of 32 mixtures were prepared in four groups according to their binder content. Eight mixes were prepared as control mixtures with 175, 210, 245 and 280 kg/m^3 cement content in order to calculate the Bolomey and Féret coefficients (K_B, K_F). For each group 175, 210, 245 and 280 kg/m^3 dosages were determined as initial dosages, which were obtained by removing 30 percent of the cement content of control concretes with 250, 300, 350, and 400 kg/m^3 dosages. Test concretes were obtained by adding GGBS to concretes in an amount equivalent to approximately 0%, 15%, 30%, 50%, 70%, 90% and 110% of cement contents of control concretes with 250, 300, 350 and 400 kg/m^3 dosages. All specimens were moist cured for 7, 14, 28, 63, 119, 180 and 365 days before compressive strength testing. The test results proved that the compressive strength of concrete mixtures containing GGBS increases as the amount of GGBS increase.

2.3 Conclusion

In conclusion, the literature review on engineered cementitious composites proven to be a highly effective and durable material in various applications. Their exceptional crack control properties and high tensile strain capacity make them ideal for earthquake-resistant structures and infrastructure repair. Engineered cementitious composites has also shown promise in precast elements, architectural cladding, and sustainable construction. Overall, the use of engineered cementitious composites has greatly improved the performance and longevity of concrete structures. It’s an exciting development in the field construction.

CHAPTER-3

METHODOLOGY

3.1 INTRODUCTION

Engineered Cementitious Composites (ECC) represent a groundbreaking advancement in the world of concrete technology. Unlike traditional concrete, ECC is designed to have exceptional ductility, meaning it can bend and deform without fracturing, making it highly resistant to cracking. Additionally, ECC possesses the remarkable ability to autonomously heal microcracks, improving its long-term durability and minimizing maintenance requirements. The methodology behind ECC involves a systematic approach to designing, mixing, and utilizing this innovative material.

3.2 METHODOLOGY

The methodology of the project work is as shown . The project is carried out in three main stages

Stage 1: Collection of Materials

Stage 2: Mix proportions

Stage 3: Tests conducted on samples

In first stage, the materials to be used for the project work are characterized based on their usage and importance in the project work. It also involves procurement of the materials. The location details and the present retail market prices will be shared. The last step in the first stage is, testing of all the materials for their physical characteristics and also discusses already derived characteristics (physical & chemical) of the materials.

In second stage, using the material properties derived by conducting various tests, the mix design using IS10262-2019 is carried out. This stage also involves mix proportioning of GGBS and metakaolin in varying proportions and their nomenclature will be mentioned. The last step in the second stage is, upon successful mix designing, the samples are casted and cured for the time period to be further mentioned in the chapter 4.

In third stage, tests are conducted for the concrete samples. Firstly, before casting of specimens, workability tests are conducted on all the samples. After casting and curing of the concrete specimens they undergo compressive strength testing. The specimens after successful curing, durability test (water permeability test) is conducted on the specimens.

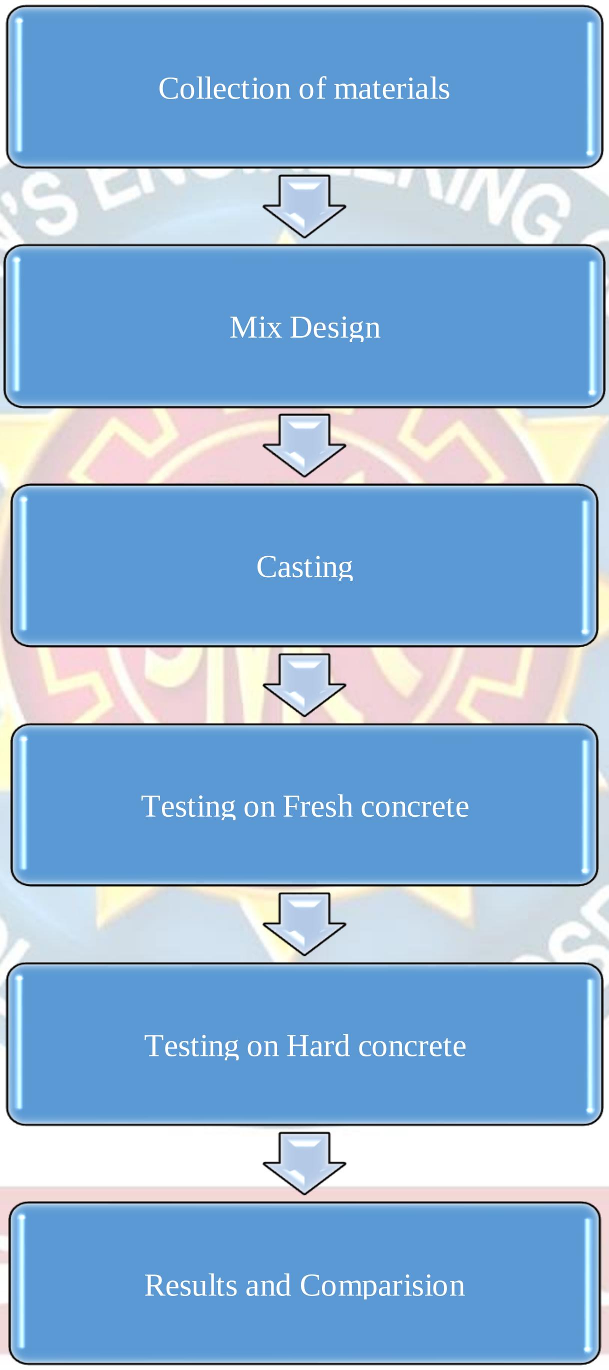

Figure:3.1 Methodology of project work

Objective 1: To evaluate and compare the long-term durability performance of hybrid fiber reinforced ECC with conventional concrete under various environmental conditions.

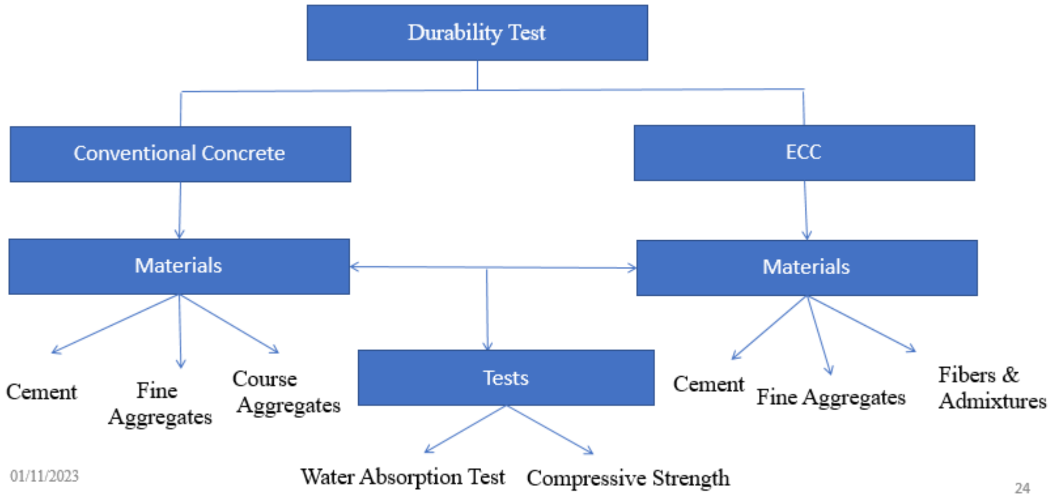

Fig :3.2 Durability test for conventional concrete and ECC

Evaluating and comparing the long-term durability performance of Hybrid Fiber Reinforced Engineered Cementitious Composites (ECC) with conventional concrete under various environmental conditions involves a systematic and comprehensive approach.

Objective 2: To examine the shear bond behaviour between HFCC and conventional concrete substrate by conducting pull-off tests or push-off tests. To determine the influence of hybrid fibers on the interfacial bond strength, crack propagation, and debonding mechanisms between the HFCC overlay and the base concrete.

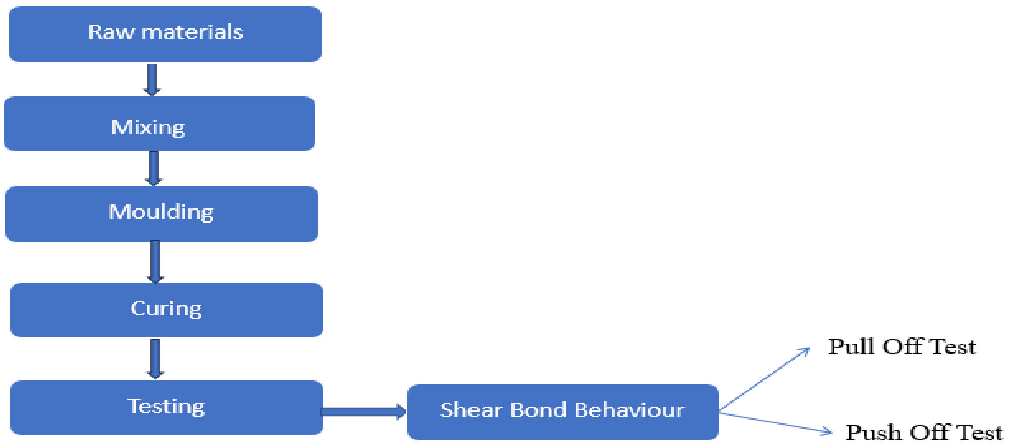

Fig :3.3 Steps involved in shear bond behaviour test

Examining the shear bond behavior between Hybrid Fiber Reinforced Cementitious Composites (HFCC) and a conventional concrete substrate is an important aspect of assessing the performance of such overlays. Pull-off tests and push-off tests can be used to determine the influence of hybrid fibers on the interfacial bond strength, crack propagation, and debonding mechanisms.

Objective 3: To identify the optimal combination of hybrid fiber types, content and mix proportions in hybrid fiber reinforced Engineered Cementitious Composites that provides the best compromise between durability performance and shear bond strength.

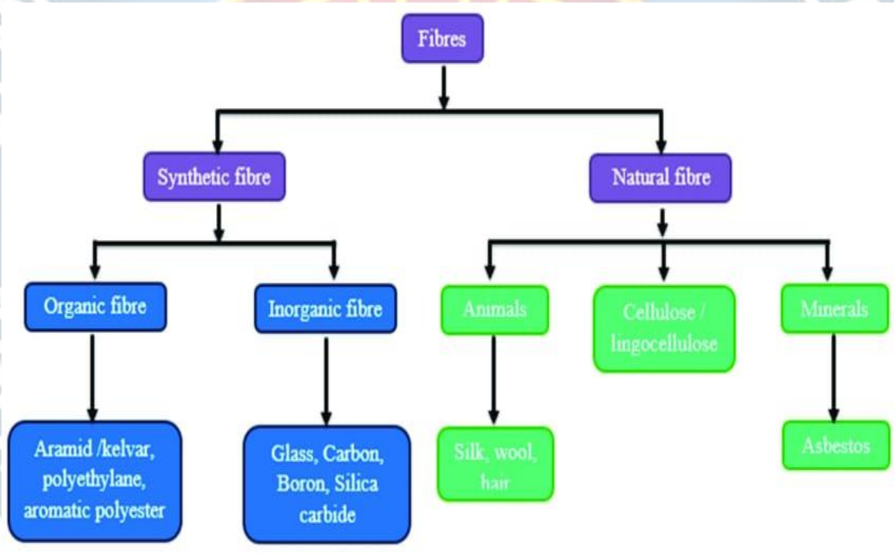

Fig :3.4 Different types of fibers

Identifying the optimal combination of hybrid fiber types, content, and mix proportions in Hybrid Fiber Reinforced Engineered Cementitious Composites (ECC) that strikes the best compromise between durability performance and shear bond strength requires a systematic and well-planned research approach.

CHAPTER-4

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