EXPERIMENTAL STUDY ON BENDABLE CONCRETE

Submitted in partial fulfillment of the requirements

For the degree of

Bachelors of Engineering

by

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2017-18

Certificate

This is to certify that the project report entitled as "**Experimental Study On Bendable Concrete"** submitted by the team of the above mentioned students studying in 'Anjuman-I-Islam's Kalsekar Technical Campus', New Panvel is an authentic work carried out by them under my guidance.

The report was submitted in partial fulfillment of the requirement for the award of the degree of Bachelor of Engineering in Civil Engineering.

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Project Report Approval for B.E.

This project report entitled "***Experimental Study on Bendable Concrete***" by "***M.Ahmed Noor M. Jalgaonkar (14CE17), Izhan Amiruddin Kazi (14CE20), Suhail Iqbal Khot (14CE36) and Ramish Ravish Majid (14CE37)"*** is approved for the degree of "***Bachelor of Engineering"*** in ***"Department of Civil Engineering***".

Examiners

1.______________________

2.______________________

Date:

Place:

Declaration

We declare that this written submission represents our ideas in our own words and where others' ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed

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Acknowledgement

Before we indulge into the things we would like to add a few unfeigned words for the people who are a part of our team as they have given everlasting contribution & support right from the genesis of the report till the end. Apart from our team we are indebted to a number of people who have assisted & furnished us with constructive guidance.

We acknowledge with deep sense of gratitude towards the encouragement in the form of substantial assistance provided by each member of our team.

We are grateful to Dr. Abdul Razak Honnutagi (Hon. Director, AIKTC) for his continuous encouragement throughout the course of this project and providing us with excellent facilities like well-equipped Lab which helped us immensely in the completion of this project.

We would like to express our sincere gratitude towards our H.O.D (Civil department) Dr. Rajendra Magar for providing us project lab & the needed assistance.

We would sincerely like to thank our project mentor Prof.Fauwaz Parkar for providing us the required technical guidance, stimulating suggestions and necessary cooperation in the process of preparing this report.

We also express our gratitude to Prof. Junaid Siddique & Prof. Junaid Maste for giving us their expertise & valuable time during the progress of this project.

Abstract

Reducing the brittle nature of concrete has opened a new world of possibilities to enhance the safety, durability and sustainability of the next generation of civil infrastructure. Tiny fibres partly account for its performance, and also the materials are designed for maximum flexibility, because of its long life, the Engineered Cement composites (ECC) is expected to cost less in the long run, as well. The ductile or bendable concrete is made of same ingredients as in regular concrete minus the coarse aggregate. It looks exactly like normal concrete, but under excessive strain, the ECC concrete allows, the specially coated network of fibre in the cement to slide within the cement, thus avoiding the inflexibility that causes brittleness and breakage. The key factor is that ECC is engineered, means in addition to reinforcing the concrete with micro scale fibers that act as ligaments to bond the concrete more tightly

As this is a special type of concrete there are no defined codes for it and also it is rarely developed in India hence no Indian Codes can be found related to this, thus for these reasons the parameters needed are to be obtained using trial and error method. This project includes different sets of tests such as marsh-cone test, slump test, sieve analysis, compression test, split tensile test and flexure test. To get the perfect dosage of admixtures marsh-cone test if well known for giving reliable results, similarly sieve analysis gives us the optimum sizes and proportion of the fine aggregates to be used in the making of this concrete. To determine the best possible water-cement and sand-cement ratio compression test was practiced and also it gives us the compressive strength of the concrete specimen. Finally the flexural strength of the concrete is determined by performing the flexural test on the specimen / member. Later on all the data is analysed and future predictions for flexural strength corresponding to different intermediate depths are made in regards to the results obtained. Also the ECC is compared with conventional concrete with regard to its weight and cost parameters.

Keywords: ECC, Bendable concrete

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Chapter 1

Introduction

1.1 Overview of Bendable Concrete

Concrete has always been a brittle material, and cracks easily when subjected to tensile loading. Recently, researchers have turned such conventional concrete into a new type of concrete that is more ductile than ordinary concrete. When ordinary concrete is subjected to tensile load, it tends to crack. For this reason, researchers have long been interested in making concrete more ductile, that is, more likely to bend than to break under load. Engineered Cementitious Composite (ECC) has proved to be 50 times more flexible and 40 times lighter than conventional concrete (Gandhiya,2015)[9]. Additionally, the excellent energy absorbing properties of ECC makes it especially suitable for critical elements in seismic zones. Researchers at the Advanced Civil Engineering Material Research Laboratory, in Ann Arbor, Michigan, have spent the past several years developing what they call an engineered cementitious composite, in essence a highly ductile type of fiber-reinforced concrete (Victor Li)[6].

.Figure 1. 1: Bendable Concrete, Conflex pave (Source:, www.weather.com)

1.2 Problem Statement

Bendable Concrete can bring a revolution because of its some special quality such as flexibility, self-healingness, lighter weight, etc. In some countries such as Japan, Korea, U.S.A, etc the flexible concrete is used in many structures. But in India, it is still an unexplored composite and requires thorough research for its use.

Concrete is widely used in today’s construction industry. It can take the compressive load very effectively. But the main problem with traditional concrete is that it cannot take much tensile stresses. It fails under the tensile load. The flexible concrete seems to be a good solution for this problem, if it can give the desired flexural strength.

1.3 Background

Engineered Cementitious Composites developed in the last decade, will contribute to safer, more durable, and sustainable concrete infra-structure that is cost-effective. This concrete has the strain-hardening property but can be processed with conventional equipment. This concrete has strain capacity of about 3 to 5% as compared to 0.01% of normal (conventional) concrete. ECC is a unique class of high-performance fiber-reinforced cementitious composites featuring high tensile ductility and durability. Flexural strength to the concrete is induced by the fibers admitted to the concrete. The concrete is produced with 2% of optimal volume of different fibers. ECC flexes without fracturing, due to the interaction between fibers, sand, and cement working in a matrix that binds everything together within the material. In addition to reinforcing, the concrete with fibers, acts as ligaments to bond it more tightly. Due to this instead of fracturing, the material undergoes a process called micro-cracking, wherein the energy of the tensile strain is diffused into a number of tiny cracks producing cracks of extremely small size, averaging less than 60 µm in width, roughly half the width of a human hair (Kalepalli,2006)[4]. Initially self-healing concrete costs roughly three times as much as conventional concrete. But its lower lifecycle cost is ascribed to lower repair frequency and lesser consumption of materials due to its higher ductility and durability which leads to savings in cost.

Further this technology is being advanced by using Iron Ore Tailings (IOTs) to develop greener engineered cementitious composites (ECCs). Due to the high cement usage in ECC limits the material greenness and increases the material cost compared with normal concrete. The replacement of cement with IOTs results in 10–32% reduction in energy consumption and 29–63% reduction in carbon dioxide emissions in green ECC compared with typical ECC (Xiaoyan et al).

1.4 Ingredients

Engineered cementitious composite is composed of:

- Cement (PPC)
- Sand
- Water
- Super-plasticizer (Supercon-100)
- Fibers (Polypropylene Fibres)

In concrete mix, coarse aggregates are not used because properties of engineered cementitious composite (ECC) is formation of micro-cracks with large deflection. Coarse aggregates increase crack width which contradicts the basic properties of ECC.

1.4.1 Cement (PPC)

Pozzolana is a natural or artificial material which contains silica in the reactive form. Portland Pozzolana Cement is cement manufactured by combining Pozzolanic materials. This cement comprises of OPC clinker, gypsum and pozzolanic materials in certain proportions. The Pozzolanic materials include fly ash, volcanic ash, calcined clay or silica fumes. These materials are added within a range of 15% to 35% by cement weight. Pozzolana cement is ecofriendly and made of natural recycled waste. It helps in making quality building materials with the efficient use of natural waste thus reducing environmental pollution. Pozzolano are siliceous materials which reduce the cost and make it economical without altering the properties of cement. After curing Pozzolana cement achieves the strength that is equivalent to Grade 33 Ordinary Portland Cement. This cement has a very low initial strength and they become stronger with curing time. Pozzolana cement has very good resistance against sulphate attack hence is used in hydraulic structures, marine structures, construction near the sea shore, dam construction etc.

1.4.2 Sand [Fine Aggregate]

Fine aggregate / natural sand is an accumulation of grains of mineral matter derived from the disintegration of rocks. It is distinguished from gravel only by the size of the grains or particles. But it is distinct from clays which contain organic materials. Sands that have been sorted out and separated from the organic material by the action of currents of water or by winds across arid lands are generally quite uniform in size of grains. Usually commercial sand is obtained from river beds or from sand dunes originally formed by the action of winds. The most commercially used are silica sands, often above 98% pure. Beach sands usually have smooth, spherical to ovoid particles from the abrasive action of waves and tides and are free of organic matter. The white beach sands are largely silica but may also be of zircon, monazite, garnet, and other minerals. Sand is used for making mortar and concrete and for also used for polishing and sandblasting. Sands containing a little clay are used for making molds in foundries.

1.4.3 Super Plasticizer

Super plasticizer used is Supercon-100 which is modified Melamine Formaldehyde Resin. This is used to control rheological properties of fresh concrete. Super plasticizers are additives to fresh concrete which help in dispersing the cement uniformly in the mix. This is achieved by their deflocculating action on cement agglomerates by which water entrapped in the groups of cement grains is released and it is available for workability. Typically super plasticizer increase slump from say 5 cm to about 18-20 cm without addition of water. When used to achieve reduction in mixing water they can reduce water up to 15-20% and hence decrease W/C ratio by same amount. This results in increase in strength and other properties like density, water tightness. Where thin sections are to be cast super plasticizer can increase workability to pumpable level and almost no compaction is required. This helps in avoiding honeycombing. The permeability of concrete is a guide to its durability. Gross porosity is usually due to continuous passage in the concrete due to poor compaction or cracks which can be minimized by the use of super plasticizer, the incorporation of which provides increased workability maintaining low w/c ratio. It is reported that coefficient of permeability of cement paste reduces considerably with the reduction in w/c ratio

1.4.4 Polypropylene Fibres

Polypropylene fibres are used. Their primary role is to modify the properties of the fresh concrete. They increase the homogeneity of the mix, stabilizing the movement of solid particles and blocking bleed water channels. This reduces the bleed capacity of the concrete and slows down the bleed rate, helping to reduce plastic settlement. The matrix of filaments also helps reduce plastic shrinkage cracking which can occur when the concrete surface is allowed to dry out rapidly.

1.4.5 Water

Water fit for drinking is generally considered fit for making concrete. Water should be free from acids, oils, alkalis, vegetables or other organic Impurities. Soft waters also produce weaker concrete. Water has two functions in a concrete mix. Firstly, it reacts chemically with the cement to form a cement paste in which the inert aggregates are held in suspension until the cement paste has hardened. Secondly, it serves as a vehicle or lubricant in the mixture of fine aggregates.

1.5 Aim and Objectives

Detailed study of properties of Engineered Cementitious Composites (ECC) in terms of compressive strength and flexural strength.

- To study the effect on flexural strength for varying depths of ECC by keeping water/cement ratio constant.
- To compare the weight and cost of ECC with the conventional concrete.
- To model the parameters for predicting flexural strengths for intermediate depths.

1.6 Expected Outcomes

Development of a special type of concrete i.e. ECC also known as Bendable Concrete which has very high flexural strength as compared to conventional concrete allowing the concrete to bend without cracking under heavy loads.

1.7 Self-Healing Property of ECC

For the most part, the self-healing process simply takes advantage of materials already present in conventional concrete, explains. Even in ordinary concrete a significant percentage of the cement grains remain unused and dormant because they are never hydrated. Cracks in the concrete expose these residual cement grains to the air and water in the surrounding environment. Under the right conditions, the unhydrated grains react chemically with water and the carbon dioxide in the air to form strong compounds known as calcium carbonates.

The fractures in conventional concrete are generally so wide that even when calcium carbonates do form they provide virtually no benefit. However, when the cracks are small enough no more than 50 µm these compounds can accumulate in such a way as to fill the cracks, thus repairing the concrete and leaving behind nothing but a scar. Most important of all, the self-healing concrete recovers its essential properties, including its ductility, its stiffness, and its ability to resist the intrusion of such corrosive agents as water and road salt, In general, the self-healing concrete consists of the same Portland cement, water, sand, and chemical admixtures that are already present in conventional concrete. The difference is that the chemical, mechanical, and geometric properties and proportions of these ingredients are fine-tuned to promote the self-healing process, Li says.

1.8 Advantages

Fibres are not as efficient in withstanding tensile stresses as compared to conventional steel reinforcement, but fibres are more closely spaced than steel which makes fibres better in controlling cracks and shrinkage. The following advantages of ECC are summarized,

- Increased crack resistance, more energy absorption capacity, increased toughness and long term ductility.
- Increased impact resistance and shear strength of concrete
- Fibres provides multidirectional reinforcements.
- Ultimate load carrying capacity in flexure is greatly enhanced.
- The weight of flexible concrete is approx. reduced by 20-40%.
- The use of steel reinforcement is reduced.

- It can be used as precast concrete.
- ECC incorporates high volumes of industrial wastes including fly ash, sands and wastes from metal casting processes, wasted cement kiln dust from cement production, which essentially reduces pollution.

1.9 Scope of the project

Scope of the project are limited to :

1. Preparation of cubes of different ratios and slabs of different depths with varying percentages of fibres.
2. Finding Compressive strength and flexural strength of various specimens.
3. Predicting the missing Values for compressive and flexural strength using XLSTAT.
4. Comparing the cost of ECC with the conventional concrete.
5. Applications of ECC.

1.10 Applications

ECC have found use in a number of large-scale applications, These include:

i. The Mitaka Dam near Hiroshima was repaired using ECC in 2003. The surface of the then 60-year-old dam was severely damaged, showing evidence of cracks, spalling, and some water leakage. A 20 mm-thick layer of ECC was applied by spraying over the 600 m^2 surface as seen in Fig. 1.2 and Fig.1.3

Figure 1. 2: Repair of Mitaka Dam by spraying water-tight ECC layer (Kunieda and Rokugo, 2006)

Figure 1. 3: Mitaka Dam, Hiroshima

(Source: www.damnet.or.jp)

ii. Also 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 cracking in 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.

iii. 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 mitigate earthquake damage as shown in Fig 1.4. The properties of ECC (high damage tolerance, high energy absorption, 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) shown in Fig 1.5

Figure 1. 4: Glorio Roppongi high-rise residential building, Tokyo (Source: www.cif.org)

Figure 1. 5: Nabeaure Tower, Yokohama (Source: www.kencorp.com)

iv. 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 behavior of ECC led to a 40% reduction in weight and 50% reduction in cost.

Figure 1. 4: Mihara Bridge, Hokkaido (Source: Kajima Corporation and Kuraray Co. Ltd)

v. 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 also used less material than a proposed deck made of ordinary portland cement. Both the University of Michigan and the Michigan Department of Transportation are monitoring the bridge in an attempt to verify the theoretical superior durability of ECC; after four years of monitoring, performance remained undiminished.

Figure 1. 5: ECC bridge deck on interstate 94, Michigan (Source: MDOT research, 2008)

Chapter 2

Literature Review

Li [2007] says that final failure of the specimen occurs when one of the multiple cracks forms a fracture plane. Beyond this peak load, ECC is no different than normal Fibre Reinforced Concrete, showing a tension-softening response. The high tensile ductility is of great value in enhancing the structural ultimate limit state (ULS) in terms of 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 µm. Further loading beyond 1% causes more multiple cracks to form, but with no additional crack opening beyond the steady state value of 60 µm. 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 eliminated in ECC.

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. 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 absence of coarse aggregates. The compressive strain capacity of ECC is slightly higher, around 0.45-0.65%. The post-peak behavior of ECC under compression tends to descend more gently than high strength concrete, accompanied by a gradual bulging of the specimen rather than explosive crushing failure. ECC has significant improvements in fatigue response over normal concrete and FRC.

Şahmaran et al.[2008] investigated the cracking behavior and residual flexural load capacities of reinforced ECC specimens, which have equal compressive strength to the ECC. During accelerated corrosion test at constant applied voltage, corrosion-induced crack width of the mortar specimens were found to increase with time as corrosion activity progressed. Larger crack widths up to 2.00 mm were observed at higher levels of corrosion. Moreover, corrosion of reinforced mortar beam specimens resulted in a marked reduction in stiffness and flexural load capacity. After 25 hours accelerated corrosion exposure, the flexural load reduced to about 34 % of the flexural capacity of the control mortar beam. On the other hand, crack widths (~ 0.1 mm) of ECC remained nearly constant with time as corrosion activity progresses, while the number of cracks on the surface of the ECC specimens increased. The results of this study also showed that ECC has significant anti-spalling ability compared with conventional mortar.

Şahmaran & Li[2009] have stated that in terms of transport properties, micro-cracks induced by mechanical pre-loading increase the permeability, the chloride transport. However, the risk of water transport by permeability and capillary suction, and chloride transport by diffusion in ECC, cracked or uncracked, is found to be comparable or lower with that in normal sound concrete without any cracks. Apart from the slight reductions in ultimate tensile strain and strength capacities and higher residual crack width, the results found in the studies summarized in this paper largely confirm the durability performance of ECC material under accelerated aging (exposure to freeze-thaw cycles with and without de-icing salts, continuous sodium hydroxide at 38°C and sodium chloride solutions at room temperature (marine environment and hot and humid environment) even in cases where the material experiences mechanical loading that deforms it into the strain-hardening stage prior to exposure. Healing of micro-cracks induced by the preload is evident from the microstructural studies and recovery of elastic stiffness of the exposed pre-cracked specimens on reloading.

Li [2009] after research has stated that as a structural material, ECC maintains all the advantages of concrete, but overcomes its familiar brittleness in tension. Experimental studies confirm that ECC is highly damage tolerant under extreme loading, including reverse cyclic loading and low velocity impact. Between first cracking strain (about 0.01%) and 1% strain, the micro crack opening increases from zero to about 60 µm. Further loading beyond 1% causes more multiple cracks to form, but with no additional crack opening beyond the steady state value of 60 µm. This unique characteristic is critically important for durability of both material and structure. The elastic modulus (around 20-25GPa) of ECC is typically lower than that of concrete due to the absence of coarse aggregates. The compressive strain capacity of ECC is slightly higher, around 0.45-0.65%. Apart from resisting earthquake loads, ECC will likely perform well under hurricane loading, although more studies need to be conducted to confirm this. The moderate fiber content (2% or less by volume) makes ECC easily adaptable to construction project execution in the field or to precast plant structural element production. Indeed, ECC has demonstrated to possess flexibility in processing routes, including on-site self-consolidating casting, and spraying, as well as off-site recasting and extrusion.

Zhou & Pan[2014] stated that Due to the lack of aggregate, the modulus of ECC is lower than concrete with similar strength. Based on the test results, a regression equation is proposed to obtain the elastic modulus of ECC from its compressive strengths. The strain at peak load is between 0.004 and 0.005 for the tested ECC compositions, and there is little correlation between the peak strain and the compressive strength. Moreover, addition of PVA fiber has little effect on the strain at peak stress. For ECC material, the Poisson's ratio increases slightly with the compressive strength when the strength is lower than 50 MPa. However, when the strength exceeds 50 MPa, the Poisson's ratio stays almost constant, at a value higher than that for concrete of similar strength. The toughness index of ECC decreases with compressive strength.

Gandhiya[2015] said that Compressive strength decreases with the increase in the cementitious material i.e. fly ash, silica fume, LP etc. Incorporation SL into matrix can effectively increase compressive strength at all ages, especially at early age. The water to cementitious material (w/c) ratio 0.27 gives the best result. The ductility in direct shear depends on the fiber orientation and is significantly improved when the fibers are perpendicular to the shear plane.

Ian et al[2016] have explained that Unconfined compressive strength on day 7 increases by 42%, unconfined compressive strength on day 28 increases by 13%, and unconfined compressive strength on day 90 increases by 26%. Thus, the compressive strength of PECR is superior to that of CCR. Apparent self-healing properties are hardly seen in the CCR, but the PECR has excellent performance in self-healing. Its compressive strength increases by 57. 3 % after self-healing.

Zhang et al[2017] have said that mechanical properties of PVA-steel hybrid fiber–reinforced engineered cementitious composite with a high strength cement matrix were experimentally investigated. Effects of additional steel fibers, apart from a constant content of PVA fiber in the composite, compressive, bending, and tensile behavior were studied. The cracking and tensile strength of the composites obviously increases with the addition of steel fiber. The additional steel fiber can also increase the tensile strain capacity of the composites. However, a moderate amount of steel fibers (1% in the present study) is needed to obtain a positive response on the tensile strain of the composites. The individual crack width in the multiple cracking period is significantly decreased with the steel fiber addition. A reduction in crack width of more than 50% with the achieved tensile strength is observed with the addition of steel fiber.

Chapter 3

Methods and Methodology

Following are the steps involved:

- Research and discussion for project selection.
- Finalizing a topic after discussion and advice of project guide.
- Collection of data for detailed study of the project.
- Interim presentations.
- Planning and scheduling of project tasks.
- Preparation of report and presentations.
- Conducting mix design and preparing concrete mix.
- Casting ECC as cubes and slabs of suitable dimensions.
- Testing the casted specimens and obtaining results from tests performed.
- Analysis of the results obtained through experimental observations.
- Preparation of final report, presentation and black-book.

3.1 Material and Specimen Preparation

1. Matrix preparation: The matrix was prepared in a concrete mixer.

- First, the cementitious material and silica sand were mixed together for 2 min at low speed.
- Then water with superplasticizer was gradually added, and mixing was continued for 2 min, which resulted in a uniform fluid matrix. Within this period, the bottom of the mixing bowl was scraped manually to ensure that no solid materials stuck to the bottom.
- After such scraping, the matrix was mixed at a higher speed for 1 min before the addition of fibres.

2. Addition of fibres: The fibres were gradually spread into the mixer by hand as the matrix was mixed at a slow speed. The fibres were added slowly to ensure homogeneous distribution with no fibres bundled together.
3. Casting and curing:
    - The composite material was carefully casted into the mould in two layers.
    - First about half of the material was placed.
    - Then the mix was vibrated for about 1–2 min to ensure that the material was well compacted. Next, the second half of the mould was filled by the composite in the same manner.
    - After levelling the surface, the specimens were covered with a polyethylene sheet to prevent loss of moisture and stored for 24 h at room temperature prior to demoulding or testing.

Table 3. 1:Testing Specimens

Sr.no	Specimen		Numbers	Dimensions
1.	Cubes		25	150 mmx 150 mmx 150 mm
2.	Slabs			
	a.	Type 01	09	700 mmx 150mm x 10mm
	b.	Type 02	09	700 mmx 150mm x 20mm
	c.	Type 03	09	700 mmx 150mm x 30mm
	d.	Type 04	09	700 mmx 150mm x 40mm
	e.	Type 05	09	700 mmx 150mm x 50mm

Figure 3.1 shows the methodology adapted for the project. Following are the steps involved,

Flow Chart

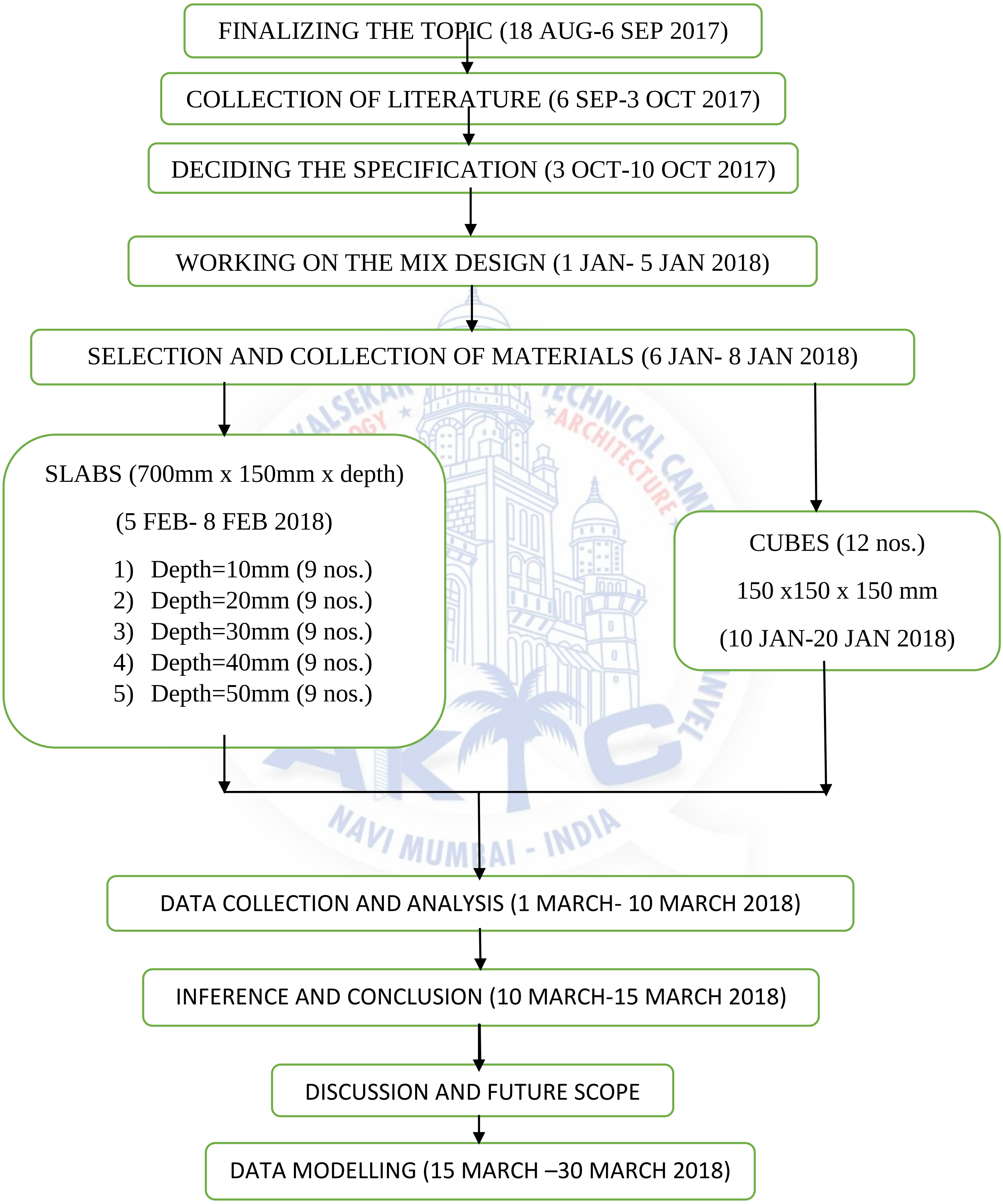

Figure 3. 1: Methodology Flowchart

3.2 Workability

The term workability is hard to define precisely, and Newman (1965) has proposed that it can define in three separate properties:

1. *Compatibility*. This means the 'ease and ability of the concrete can be compacted and the air voids are removed' (Murdock et. al, 1968).
2. *Mobility*. It terms as the 'ease and ability of the concrete can pour into the moulds, around the steel and be remoulded' (Murdock et. al, 1968).
3. *Stability*. It is the ability of the 'concrete to stay a stable coherent homogenous mass while handling and vibration' (Murdock et. al, 1968) without the constituents segregating.

3.3 Marsh Cone Test

Marsh cone test is reliable and simple method to study the rheological properties of cements and mortars. Flow time of cement/mortar through marsh cone is indicator of viscosity, which depends upon cement super plasticizer compatibility. It is widely used to study cement super plasticizer compatibility and to determine optimum super plasticizer dosage of a specific cement-super plasticizer combination. The time needed for a certain amount of material to flow out of the cone is recorded. This measured flow time is linked with the fluidity of the tested material. The longer the flow time, the lower is the fluidity. It is used in cement based materials mix design in order to define the saturation point, i.e. the dosage beyond which the flow time does not decrease appreciably. The saturation point is defined as the chemical admixture dosage beyond which the flow ti me dose not decrease appreciably.

Apparatus

a) Cone: It's a conical brass vessel with an orifice of 8mm at its bottom.
b) Stopwatch: to measure the time taken by cement mortar to flow out of orifice of cone.
c) Scoop
d) Mixer: for properly mixing matrix

Test procedure

1. 1L of cement paste is prepared in mortar mixer using 2 kg of cement and w/c ratio of 0.4. High strength Concrete designs typically have w/c ratios less.
2. Water is added in two steps- 70% of water is added in beginning of mixing and rest 30% of water is mixed with super plasticizer and added afterwards.
3. Mortar is properly stirred to ensure uniform distribution of super plasticizer.
4. Pour one liter slurry into marsh cone duly closing the aperture with a finger.
5. Start the stop watch and simultaneously remove the finger. Note the time taken for emptying the Marsh Cone. This time is called the "Marsh Cone Time".
6. Repeat the test for different mixes by increasing dosage of super plasticizer.
7. Optimum dosage is obtained from saturation point beyond which increase in super plasticizer dosage does not significantly decrease marsh cone time.

Figure 3. 2: Marsh Cone

(Source: www.indiamart.com)

3.4 Slump test

The slump test is a means of assessing the consistency of fresh concrete. It is performed to check the workability of freshly made concrete, and therefore the ease with which concrete flows. It can also be used as an indicator of an improperly mixed batch. The test is popular due to the simplicity of apparatus used and simple procedure. The slump may take one of three forms. In a true slump the concrete simply subsides, keeping more or less to shape. In a shear slump the top portion of the concrete shears off and slips sideways. In a collapse slump the concrete collapses completely.

After fully mixing, fresh concrete was used in slump test. The test was carried out in accordance with IS: 1199 - 1959. The apparatus of slump test is shown in figure.

Figure 3. 3: Slump Cone (Source: Aimil Ltd.)

Apparatus

The following apparatus and equipment complying with the relevant provisions of IS: 1199-1959 were used.

a) Mould: The mould for the test specimen shall be in the form of the frustum of a cone having the following internal dimensions:

Bottom diameter	=	200mm.
Top diameter	=	100mm.
Vertical height	=	300 mm.

The mould shall be constructed of metal (brass or aluminium shall not be used) of at least l-6 mm (or 16 BG) thickness and the top and bottom shall be open and at right angles to the axis of the cone. The mould shall have a smooth internal surface. It shall be provided with suitable foot pieces and also handles to facilitate lifting it from the moulded concrete test specimen in a vertical direction as required by the test. A mould provided with a suitable guide attachment may be used. A typical mould without the guide is shown

b) Tamping Rod: The tamping rod shall be of steel or other suitable material, 16 mm in diameter, 0.6 m long and rounded at one end.
c) Scoop: An appropriate size which large enough to accommodate the maximum size of aggregate in the concrete mix.
d) Base plate: Made of smooth, rigid and non-absorbent material.
e) Ruler: Appropriate steel ruler is required for measurement of slump height.

Test Procedure

The test procedure was in accordance to IS: 1199 - 1959. The procedure of the testing was as follow:

1. The internal surface of the mould was cleaned (free from set concrete) and moistened with a damp cloth immediately before beginning of each test.
2. The mould was placed on base plate. The mould was hold firmly by standing on the footpieces while the mould is being filled.
3. The mould was filled in four layers, each approximately 75mm of the height.
4. Each layer was tamped with twenty-five strokes of the rounded end of the tamping rod. The strokes were distributed in a uniform manner over the cross-section of the mould.
5. After tamping the top layer, the concrete was levelled with a trowel, so that the mould is exactly filled. Any mortar which may have leaked out between the mould and the base plate was cleaned away. A firm downward pressure was maintained at all times until the mould is removed.
6. The mould was immediately removed from the concrete by raising it's slowly and carefully in a vertical direction, allowing the concrete to collapse.
7. The mould was placed upside down next to the collapse concrete. The steel rod was positioned on to the mould.
8. The slump was immediately measured by determining the difference between the height of the mould (300 mm) and the average height of the top surface of the concrete.

3.5 Compressive Strength Test

compressive strength of a concrete is a measure of its ability to resist static load, which tends to crush it. Most common test on hardened concrete is compressive strength test. It is because the test is easy to perform. Furthermore, many desirable characteristic of concrete are qualitatively related to its strength and the importance of the compressive strength of concrete in structural design. The compressive strength gives a good and clear indication that how the strength is affected with the increase of fibre volume dosage rate in the test specimens.

This test was performed to find the increase and differences of strength according the cement to sand ratio in concrete. The compressive strength of concrete can be calculated using formula,

$$f_c = \frac{P \times 100}{A}$$

where, f_c = Compressive strength of concrete (MPa)

P= Maximum load applied to specimen (KN)

A= Cross sectional area of specimen (mm^2)

Apparatus

a) Machine: Compression Testing Machine

b) Mould size: 75mmx75mmx75mm

Figure 3. 4: Compression Testing Machine (Source: Aimil Ltd)

Test Procedure

The test procedure was in accordance to IS: 516 - 1959. The procedure of the testing was as follow,

1. Test was conducted immediately after removal of cubes from curing while they are still in wet condition.
2. Surface water was cleaned, grit and any projecting fins were removed.
3. The platens of the testing machine were cleaned to ensure it is free from films of oil and particles of grit.
4. The specimen was placed in the testing machine (between the two platens). The axis of the specimens was carefully aligned.
5. Load was applied without shock and increasing continuously at a rate of 140 kg/sqcm/min.
6. The compressive strength of the specimen was obtained from the machine directly.

3.6 Flexural Strength Test

Flexural strength of a concrete is a measure of its ability to resist bending. Flexural strength can be expressed in terms of 'modulus of rupture'. Concrete specimens for flexural strength were cross sectional area of 150mm width with 150mm depth and length of 700mm concrete beam. The specimen is subjected to bending, using four-point loading until it fails. The task of this test was performed to find the increase and differences of strength according the increasing percentage of fibre in the concrete, in both pre-crack and post-crack behaviour, as fundamental to assess and evaluate the effects of the additional of fibres on the behaviour of concrete. The flexural strength test was conducted in the concrete technology laboratory after the concrete specimens were cured for 28 days. The test procedure was carried out accordance with IS: 516-1959.

Apparatus

The following apparatus and equipment complying with the relevant provisions of IS: 516-1959 were used.

Machine: Universal Testing Machine.

Loading: 2 point loading using suitable attachment.

Calculation

The flexural strength of the specimen shall be ex- pressed as the modulus of rupture f_b. Flexural strength is calculated using below formulae,

$$f_b = \frac{p \times l}{b \times d^2}$$

when a is greater than 20cm for 15 cm specimen, or

$$f_b = \frac{3p \times l}{b \times d^2}$$

When a is less than 20cm but greater than 17cm for 15 cm specimen

Where,

a = distance between crack and nearest support

b = measured width in cm of the specimen

d = measured depth in cm of the specimen at the point of failure

l = length in cm of the span on which the specimen was sup- ported

p = maximum load In kg applied to the specimen

Test Procedure

The test procedure was in accordance to IS: 516 - 1959. The procedure of the testing was as follows:

1. Test was performed immediately after removal from water whilst specimens were still wet.

2. Any girt from the surface was removed and surplus water was wiped on the concrete specimen before commencing the test.
3. Gauge length was marked by using chalk, 300mm from centre on each side.
4. The specimen was placed on the supporting rollers. The two outer lines drawn on the specimen were aligned to the center of the supporting roller.
5. The loading rollers were brought in contact to the top of the specimen. Once the loading rollers reached the top surface, the uniformity of the rollers was checked. The positions of the loading rollers were aligned to the two inner lines drawn on the specimen.
6. Force was applied without shock and increase continuously at a constant rate, until the specimen can sustain no force. The maximum force applied to the concrete specimen was recorded through the software of the computerized test machine.
7. Cracking pattern was observed and value of ‘a’ was measured.
8. Final results along with graphs (load vs deflection and stress vs strain) were recorded in the computer linked to Universal Testing Machine.
9. Flexural strength was calculated using above mentioned formulae.

Figure 3. 5: Flexural Strength Test

Chapter 4

Data Collection and Analysis

4.1 Marsh Cone Test

Super plasticizer (Supercon-100) dosage was decided by this test. Table 4.1 shows the data acquired after performing test using 400gm of cement with varying plasticizer dosage. w/c ratio was kept as 0.4.

Table 4. 1: Marsh Cone Test Results

Cement (gm)	Water (ml)	Dosage (ml)	Marsh cone time (s)
400	160	10	30
400	160	11	27
400	160	12	26
400	160	13	24
400	160	14	22
400	160	15	17
400	160	16	17
400	160	17	16.5

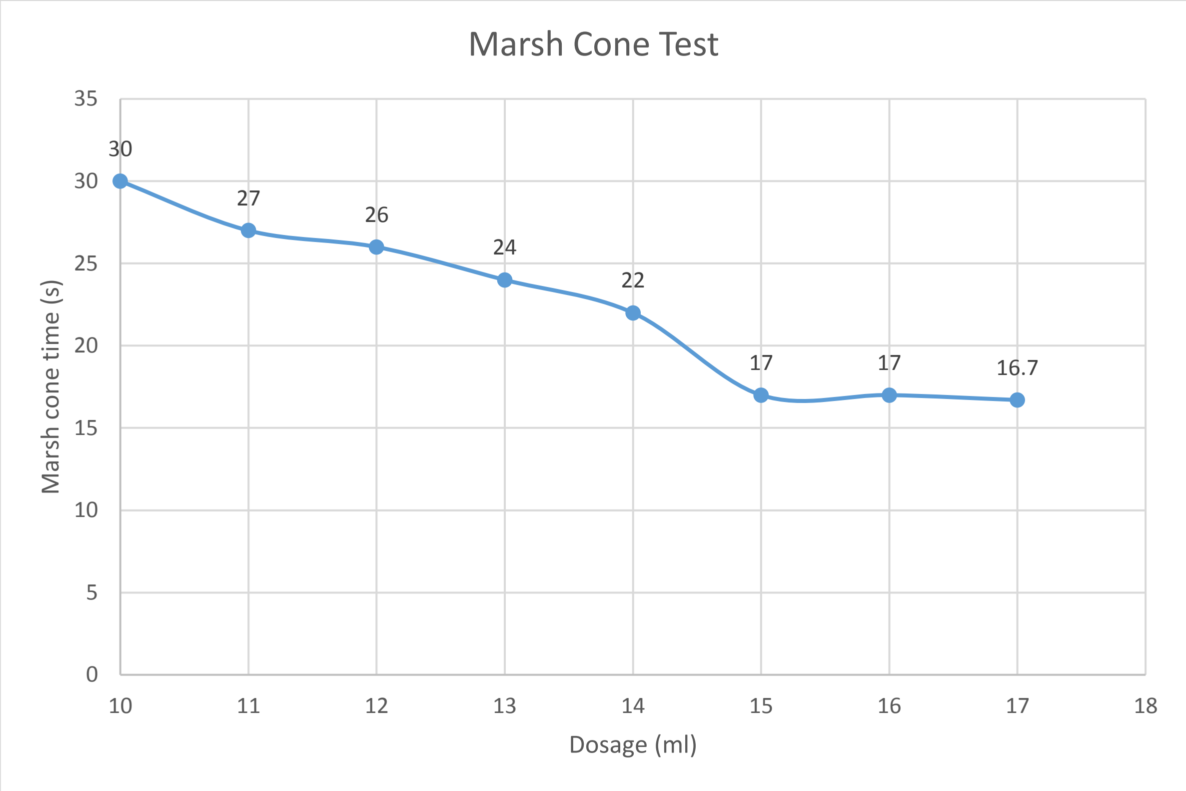

Figure 4. 1: Marsh Cone Test

The experimental results, as seen in Fig 4.1 indicate that marsh cone time has decreasing trend as the dosage of super plasticizer is increased. Once the dosage exceeds 15ml, marsh cone time remains constant. From the results super plasticizer dosage was fixed as 15ml.

4.2 Average Slump

The slump test indicates decreasing trend as the fibre percentage increases. Table 4.2 shows the slump height recorded during the test and the difference in percentage dropped for all mix batches compared to control batch.

Table 4. 2: Slump Cone Test Results (Average)

Type of mix	Slump (mm)	Percentage difference (%)
Plane (0%)	132	-
1.0% Fibre	63	52
1.25% Fibre	55	58
1.5% Fibre	46	65

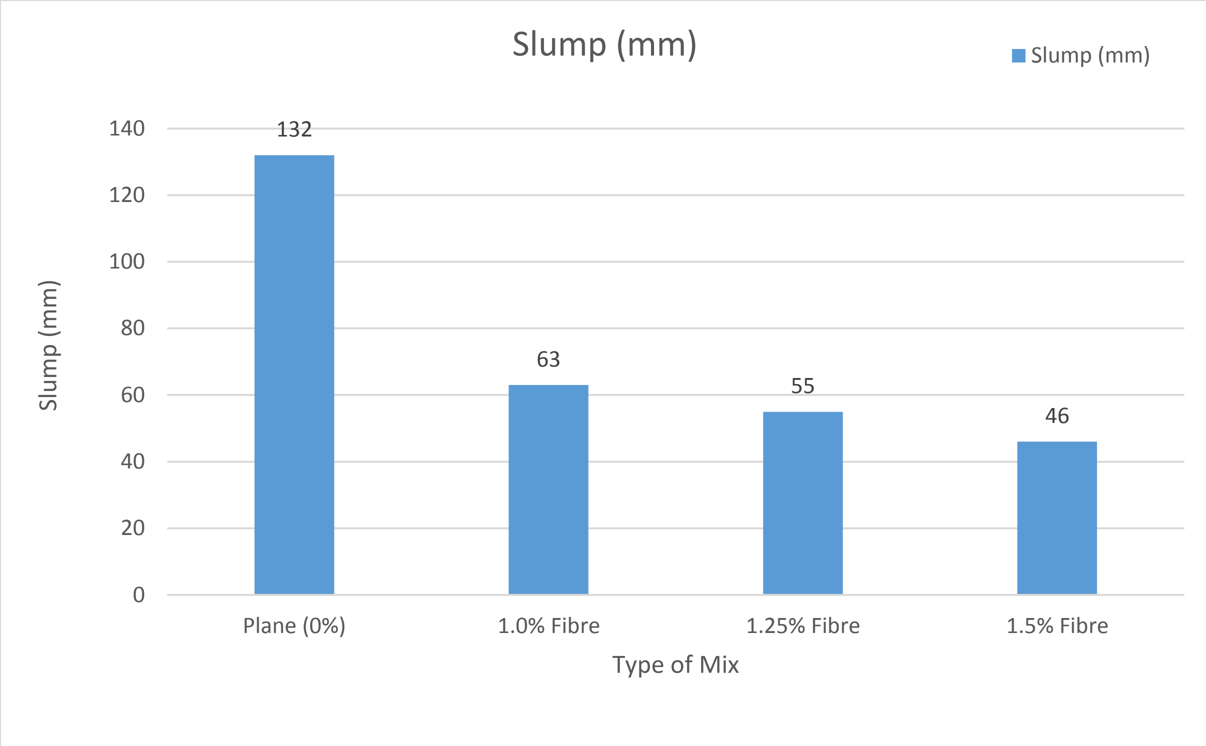

Figure 4. 2: Slump Test

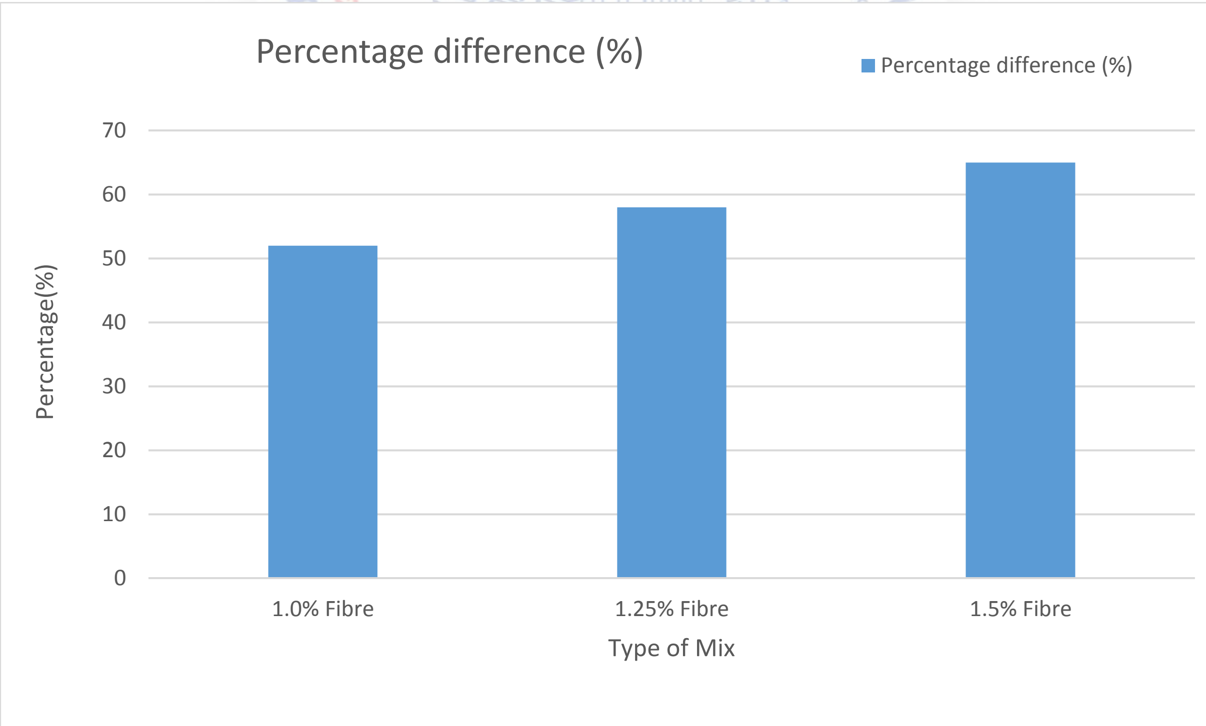

Figure 4. 3: Difference of Slump Test

Fig 4.2 shows comparison of fibres for varying percentage of fibres. The experimental observations as seen in Fig 4.3indicate that the slump value decreases rapidly with the increase in percentage of fibres.

4.3 Average Compressive Strength

The result of compression test shows that the strength decreases as cement/sand ratio decreases. Table 4.3 shows the average compressive strength recorded during test. Average strength of three tested specimens of each ratio was taken.

Table 4. 3: Compressive Strength (Average)

Specimen	Cement/Sand ratio	Average maximum load (KN)	Average compressive strength (MPa)
1	1:0.6	149.06	26.4
2	1:0.8	138.26	24.56
3	1:1.0	112.5	19.97
4	1:1.2	105.06	18.63

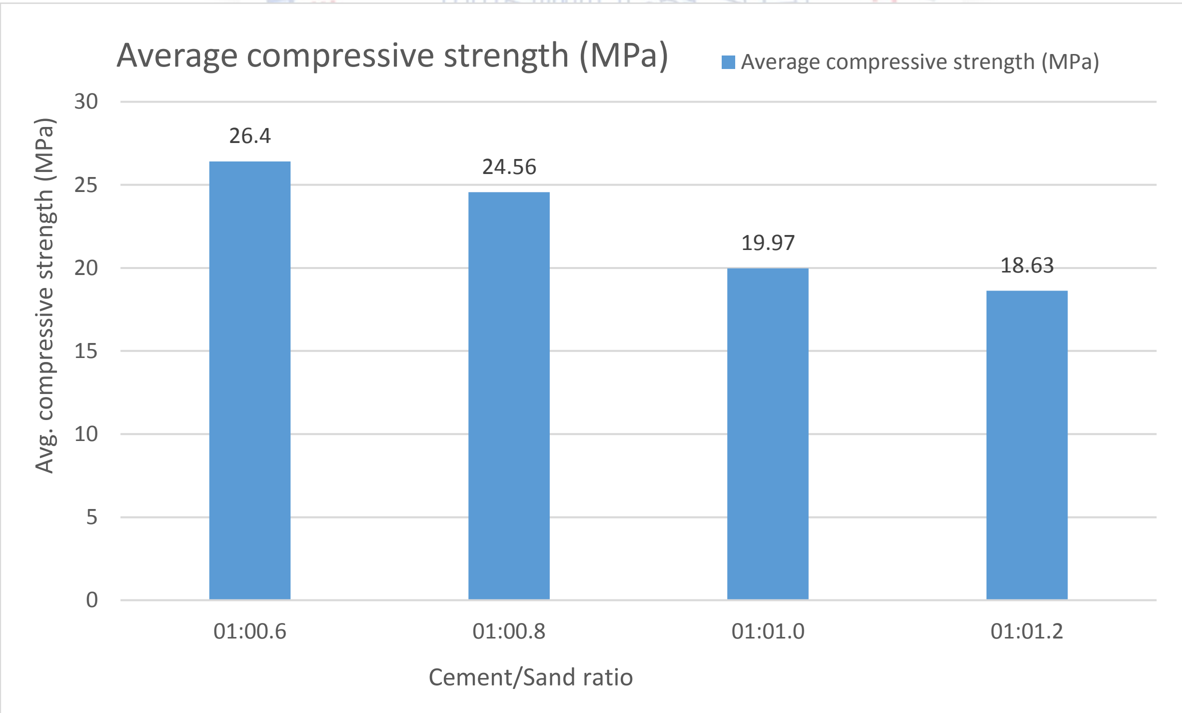

Figure 4. 4: Compressive Strength Test

Above results as seen in Table 4.3 and Fig 4.4 indicate that the compressive strength decreases as the sand quantity increases. There is not much difference in compressive strength of ratios 1:0.6 and 1:0.8. Hence economy point of view cement /sand ratio=1:0.8 was selected for further tests.

4.4 Average Flexural Strength

Flexural strength trend varies with the percentage of fibres. Table 4.4 shows the average flexural strength for the specimens having different fibre content and depth varying between 10mm to 50mm.

Table 4. 4: Flexural Strength (Average)

Depth (mm)	Strength (Mpa) for 1% fibre	Strength (Mpa) for 1.25% fibre	Strength (Mpa) for 1.5% fibre	Remark
5.000	**7.037**	**9.520**	**10.578**	**Predicted**
10.000	8.400	11.070	12.330	Tested
12.000	**6.195**	**8.264**	**9.159**	**Predicted**
15.000	**5.834**	**7.726**	**8.550**	**Predicted**
18.000	**5.474**	**7.188**	**7.942**	**Predicted**
20.000	4.480	6.830	7.400	Tested
25.000	**4.632**	**5.933**	**6.522**	**Predicted**
30.000	4.220	4.870	5.570	Tested
35.000	**3.430**	**4.139**	**4.495**	**Predicted**
40.000	3.330	3.500	3.690	Tested
45.000	**2.227**	**2.346**	**2.467**	**Predicted**
50.000	2.480	3.020	3.200	Tested

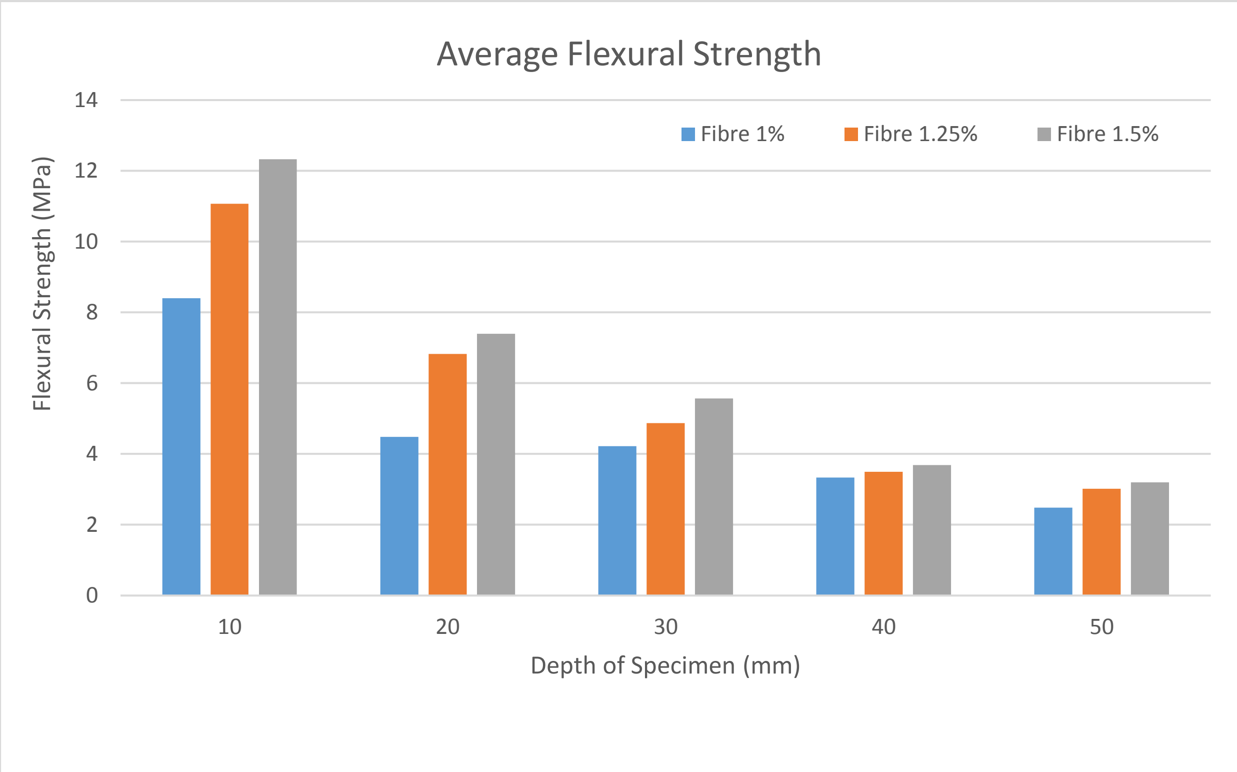

Figure 4. 5: Average Flexural Strength

Flexural strength test results as shown in Fig 4.5 indicate decreasing trend as the depth of specimen increases but it shows increasing trend as the fibre percentage increases for specific depth. As the depth increases, the flexural capacity of concrete decreases but at the same time for a specific depth, as the fibre content increases, flexural capacity of concrete increases.

Flexural strength for depths of 15mm and 25mm were calculated using XLSTAT.

4.5 Weight Analysis

Weight of different ingredients for 1m^3 of ECC:

1. Weight of cement = 856kg
2. Weight of sand = 710kg
3. Superplasticizer = 32.1l
4. Weight of fibres = 12.83kg

Total weight = 1610.93kg/m^3

4.6 Cost Analysis

4.6.1 Conventional concrete

For 1m^3 of M20 grade of concrete (1:2:4), cost analysis is as follows:

i. Quantity of cement = 5 bags

   Cost of cement = 5x350 = Rs.1750

ii. Quantity of fine aggregates =.286m^3

   Cost of fine aggregates = .286x3150 = Rs.900

iii. Quantity of coarse aggregates = .571m^3

   Cost of coarse aggregates =.571x1155 = Rs.660

Total cost of M20 Grade concrete for 1m^3 = Rs.3100

4.6.2 Engineered Cementitious Composites

For 1m^3 of ECC, cost analysis is as follows:

i. Quantity of cement = 18 bags

   Cost of cement = 18x350 = Rs.6300

ii. Quantity of fine aggregates = 0.444m^3

   Cost of fine aggregates = 0.444x3150 = Rs.1400

iii. Superplasticizer Quantity = 37.5ml/kg of cement x 856 = 32.1litres

   Cost of Superplasticizer = 60 x 32.1 = Rs.1926

iv. Quantity of Fibres = 1.5% by weight of cement

   = 1.5% of 856 kg of cement = 12.84kg

   Cost of Fibres = 12.84 x 228 = Rs.2928

Total cost of 1m3 of ECC = Rs.12554

Chapter 5

Results and Conclusion

Multiple tests were conducted and after detailed study of the test results following conclusions can be made,

1. The compressive strength of the concrete was found to be maximum when cement/sand ratio was 1:0.6. As the sand content was increased to 1:0.8 there was about 7% drop in compressive strength.
2. The flexural strength of the concrete was found to be maximum for specimen of 10mm depth at fibre content of 1.5%. From the Flexural strength test results it can be concluded that for length:breadth:depth ratio of 70:15:1 and fibre content = 1.5% the flexural strength is maximum.
3. Flexural strength of the concrete decreases as we increase the depth of the concrete specimen. For fibre content = 1.5% as the depth was increased from 10mm to 20mm, there was about 40% reduction in flexural strength.
4. Cost of 1m^3 ECC is found to be 4 times when compared to the cost of 1m^3 of conventional concrete.

Chapter 6

Discussion and Future Scope

6.1 Discussion of Results:

In line with the results obtained in chapter 5 and their succeeding analysis, it can be concluded that ECC has the following advantages over conventional concrete:

1. From the Results it can be concluded that for L:B:D ratio of 70:15:1 and fibre content =1.5%, the flexural strength was maximum. Hence, this ECC will last longer than conventional concrete as it is able to resist cracking.
2. It is observed that ECC has very high flexibility (strain=0.007) and hence is able to bend like a metal.
3. The ECC is about 32.8% lighter than conventional concrete. It is observed that for same section about 32.8% weight can be reduced. Hence, steel reinforcement can be reduced.
4. The ECC has very good self healing property as it can heal micro cracks itself because of excess free cement content which has not reacted during initial hydration.
5. Although the material component cost is increased, but due to lesser volume of structural members, the dead load of structure is decreased and the usable area is increased, thereby reducing the overall cost of project.
6. In road projects specially where huge volume of vehicles are plying, the life cycle is very short if constructed by conventional concrete. However, if ECC is used, due flexible nature the service life can be increased considerably. Hence, the replacement cost of the roads is eliminated. Also, the operation and maintenance cost is reduced.
7. ECC is more earthquake resistant due to its elastic nature. Hence, in earthquake prone regions ECC will provide an excellent solution to mitigate the risks of damage to the structures due to earthquake.

8. It can be easily used for structures having difficult architectural shapes like dome, inclined or slender members.
9. In case of roads and bridges, if ECC is used there is no need of providing joints as ECC itself has the ability to change shape

6.2 Limitations

1. Reduction in workability of concrete.
2. Initial cost is high, approximately 4 times as compared to conventional concrete.
3. It needs some special type of ingredients which can be difficult to find in some areas.
4. Its compressive strength is generally less than conventional concrete due to absence of coarse aggregate.
5. As the depth of member is increased, the flexural strength decreases, showing no major benefits.

6.3 Future Scope

1. ECC is a unique class of high-performance fiber-reinforced cementitious composites featuring high tensile ductility and durability. However, the high cement usage in ECC limits the material greenness and increases the material cost compared with normal concrete. Iron Ore Tailings in powder form can be used to partially replace cement to enhance the environmental sustainability of ECC.
2. More investigations and laboratory work to be done to find out Poisson's ratio. It is recommended that testing can be done on cylinders of concrete.
3. More investigations and studies required to find out shear resistance of concrete so that the application of concrete in earthquake resistant structures can be tested.
4. More laboratory work to be done to find out the corrosion resistance capacity of concrete. Therefore, it is recommended that the testing can be done by casting ECC Concrete beams with steel reinforcing bars.
5. The structure made with the flexible concrete can take more tensile stresses that it does not break down due to the vibration caused by the earthquake.

6. The concrete canvas can also be made with the flexible concrete. The concrete canvas is stronger and durable than the normal canvas. It can be used in the military area.
7. It can be used in roads and bridges. With the use of flexible concrete in roads and bridges there is no need of joints such as expansion joint, contraction joint as the concrete is itself have the ability to change its shape. Moreover the bridges and roads are more durable and has low repair cost.
8. Impact loading can be applied to such a slab of ECC and the behaviour can be studied & be compared to conventional concrete.
9. Effect of temperature stresses on ECC can be studied.

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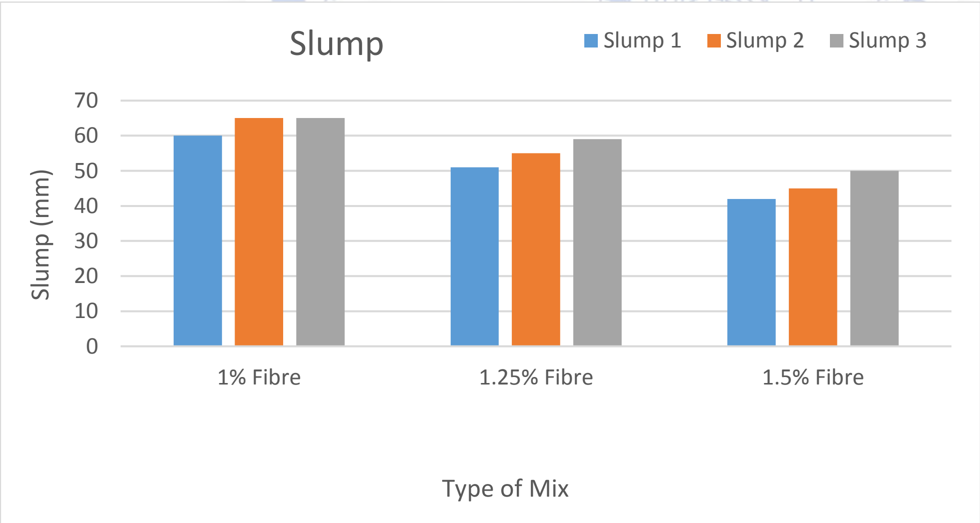
Appendix

Appendix "A"

Individual Test Result for Slump

Type of mix batch	Slump 1 (mm)	Slump 2 (mm)	Slump 3 (mm)	Average slump (mm)
1% Fibre	60	65	65	63
1.25% Fibre	51	55	59	55
1.5% Fibre	42	45	50	46

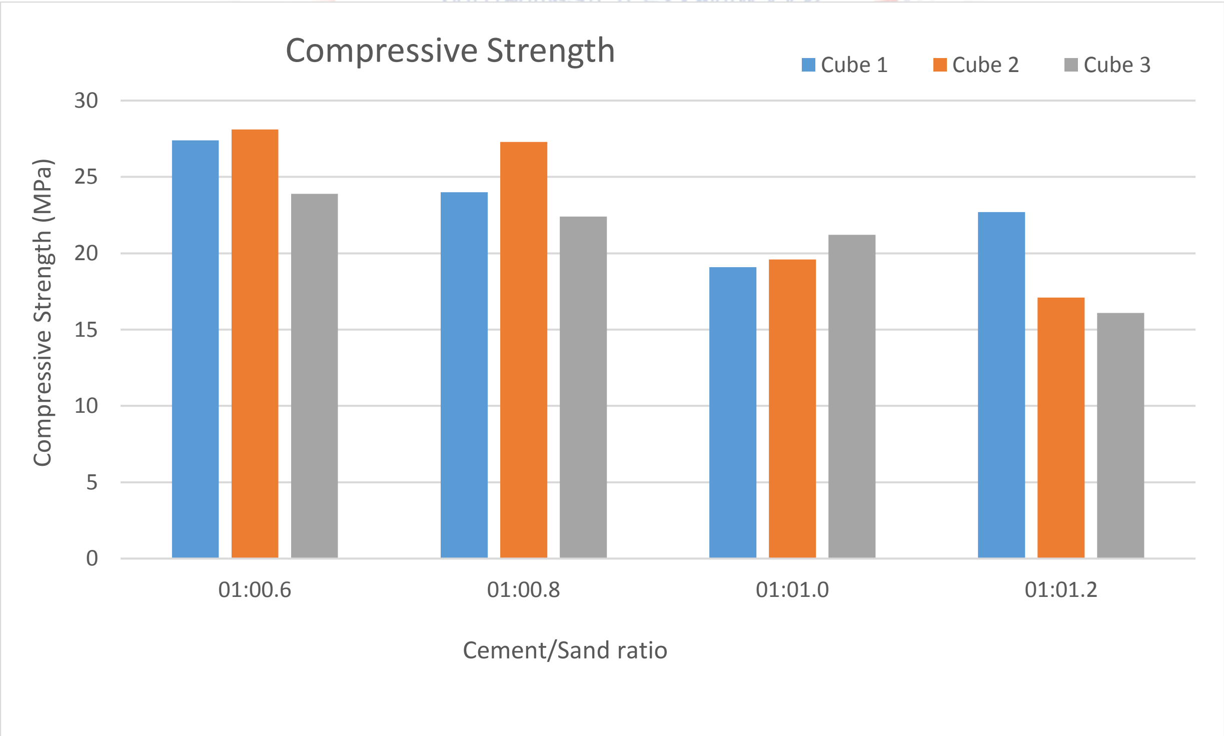


Above Table shows the individual slum test results for 3 trails of each fibre content. Above Fig graphically represents the results.

Appendix "B"

Individual Test Result for Compressive Strength

Cement/Sand ratio	Compressive strength (MPa)			Average compressive strength (MPa)
	Cube 1	Cube 2	Cube 3	
1:0.6	27.4	28.1	23.9	26.4
1:0.8	24	27.3	22.4	24.56
1:1.0	19.1	19.6	21.2	19.97
1:1.2	22.7	17.1	16.1	18.63



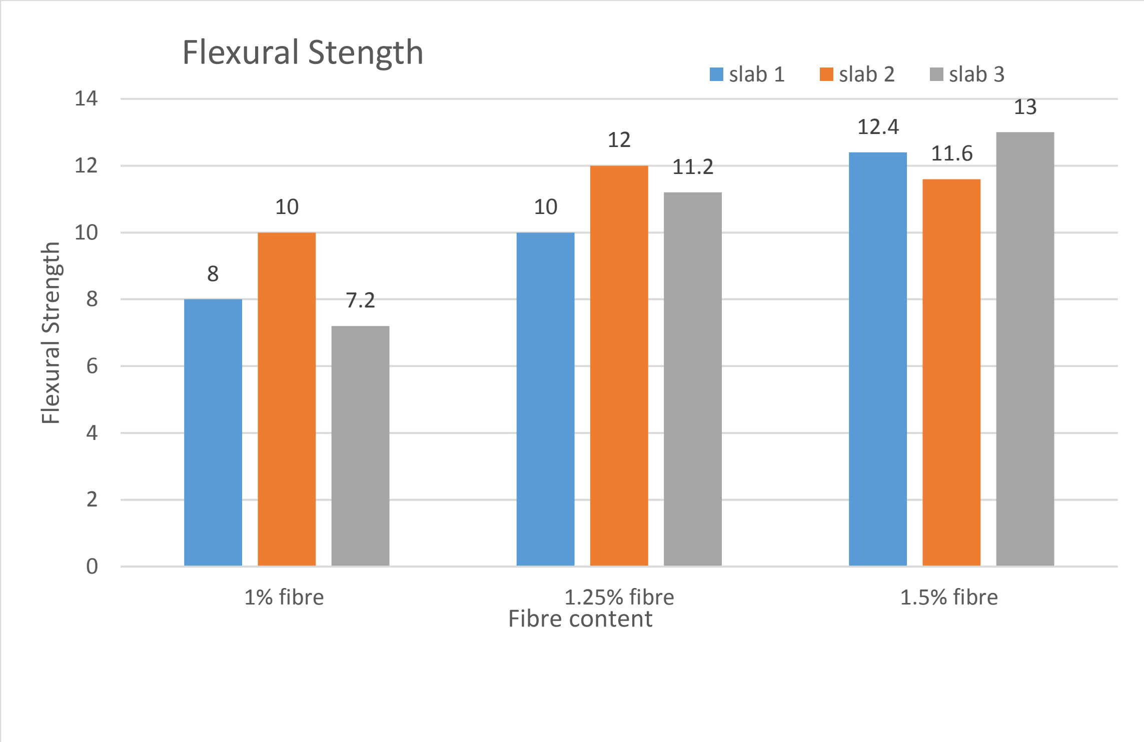
Appendix "C"

Individual Test Result for Flexural Strength

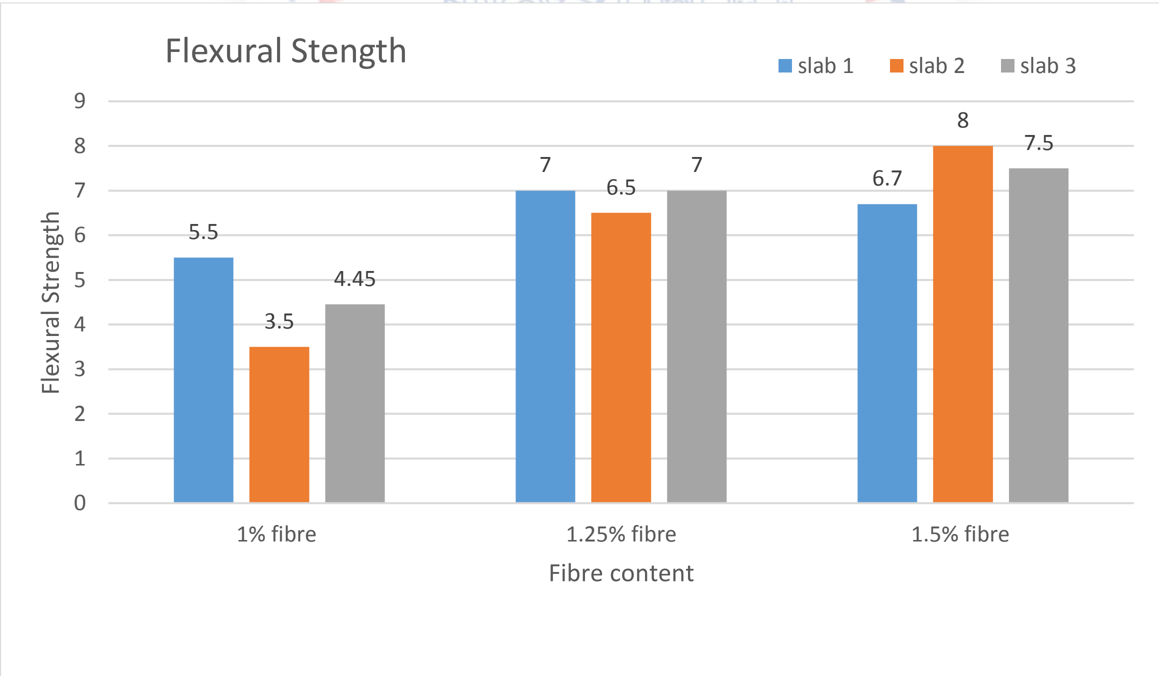
DEPTH (mm)	Fibre content (%)	Max. Force (N)	'a' (mm)	FLEXURAL STRENGTH(N/mm^2)	Mean Flexural Strength(N/mm^2)
10	1.0	200	310	8	8.4
		250	336	10	
		180	323	7.2	
	1.25	250	270	10	11.07
		300	281	12	
		280	279	11.2	
	1.5	310	305	12.4	12.33
		290	331	11.6	
		325	317	13	
20	1.0	550	199	5.5	4.48
		350	183	3.5	
		445	201	4.45	
	1.25	700	277	7	6.83
		650	248	6.5	
		700	312	7	
	1.5	670	272	6.7	7.4
		800	345	8	
		750	291	7.5	
30	1.0	1000	303	4.44	4.22
		900	309	4	
		950	300	4.22	

	1.25	1100	211	4.89	4.87
		1150	206	5.11	
		1040	210	4.62	
	1.5	1200	257	5.33	5.57
		1300	258	5.78	
		1260	237	5.6	
40	1.0	1250	290	3.13	3.33
		1340	293	3.35	
		1400	291	3.5	
	1.25	1445	233	3.61	3.5
		1400	251	3.5	
		1350	229	3.38	
	1.5	1470	224	3.68	3.69
		1505	215	3.76	
		1450	220	3.63	
50	1.0	1550	328	2.48	2.48
		1600	242	2.56	
		1500	300	2.4	
	1.25	1900	307	3.04	3.02
		1840	210	2.94	
		1930	289	3.09	
	1.5	2000	232	3.2	3.2
		1950	222	3.12	
		2050	226	3.28	

Above table shows the individual flexural test results for each depth and for each fibre content. Below Figures represent the variation of Flexural strength with the fibre content percentage for each depth.



Flexural Strength Results (slab depth=10mm)



Flexural Strength Results (slab depth=20mm)

Appendix "D"

Polypropylene Fibre (Properties)

Chemical and Physical Properties

Colour	: white
Shape	: Bunchy monofilament
Diameter	: 50μm
Specific Gravity	: 0.90 – 0.91 g/cm^3
Melting point	: 165°C
Elongation at break	: 30%
Tensile Strength	: ≥450MPa
Elastic modulus	: ≥4.0GPa
Flexibility	: Excellent low temp. flexibility
Alkali, Acid and Salt Resistance	: high
Electrical and Thermal Conductivity	: low
Effects on health	: safe and nontoxic

Appendix "E"

Super Plasticizer (Supercon-100)

SUPERCON 100 is a high range water reducing superplasticizer used to achieve impermeable, honeycomb free, high quality concrete. It is highly recommended for roof slabs, water tanks, basements, foundations, floorings, bridge decks, etc. It modifies the properties of concrete such as workability, strength, permeability, cohesion etc.

Supercon 100 is a pure melamine based superplasticizer which can be added in any dosage. It has no harmful effect on concrete in high dosages since it doesn't entrain excess air.

Physical and Chemical Properties :

Type	:	Modified Melamine Formaldehyde Resin
Dosage	:	0.5%-5% by wt. of cement
Appearance	:	clear to slightly hazy
Stability	:	12 month shelf life
Specific gravity	:	1.2 to 1.28
pH	:	minimum 7.0
chlorides & sulphates	:	negligible
water reduction	:	13%-20%

Appendix "F"

Data Modelling using XLSTAT

XLSTAT 2018.2.50731 - Missing data - Start time: 5/4/2018 at 4:16:14 PM / End time: 5/4/2018 at 4:16:14 PM
Data: Workbook = Book3.xlsx / Sheet = Sheet1 / Range = Sheet1!$A$1:$D$13 / 12 rows and 4 columns
Data type:
Quantitative data

Summary statistics(Before treatment):

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Depth (mm)	12	0	12	5.000	50.000	25.417	14.588
Strength (Mpa) for 1% fibre	12	7	5	2.480	8.400	4.582	2.275
Strength (Mpa) for 1.25% fibre	12	7	5	3.020	11.070	5.858	3.267
Strength (Mpa) for 1.5% fibre	12	7	5	3.200	12.330	6.438	3.689

Summary statistics(Post treatment):

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Depth (mm)	12	0	12	5.000	50.000	25.417	14.588
Strength (Mpa) for 1% fibre	12	0	12	2.227	8.400	4.812	1.857
Strength (Mpa) for 1.25% fibre	12	0	12	2.346	11.070	6.200	2.714
Strength (Mpa) for 1.5% fibre	12	0	12	2.467	12.330	6.825	3.067

Completed data:

	Depth (mm)	Strength (Mpa) for 1% fibre	Strength (Mpa) for 1.25% fibre	Strength (Mpa) for 1.5% fibre
Obs1	5.000	**7.037**	**9.520**	**10.578**
Obs2	10.000	8.400	11.070	12.330
Obs3	12.000	**6.195**	**8.264**	**9.159**
Obs4	15.000	**5.834**	**7.726**	**8.550**
Obs5	18.000	**5.474**	**7.188**	**7.942**
Obs6	20.000	4.480	6.830	7.400
Obs7	25.000	**4.632**	**5.933**	**6.522**
Obs8	30.000	4.220	4.870	5.570
Obs9	35.000	**3.430**	**4.139**	**4.495**
Obs10	40.000	3.330	3.500	3.690
Obs11	45.000	**2.227**	**2.346**	**2.467**
Obs12	50.000	2.480	3.020	3.200