BE CIVIL ENGINEERING

PROJECT REPORT

IMPACT RESISTANT AND DUCTILE CEMENTITIOUS MATRIX (IMDUC)

Project submitted in partial fulfillment of the requirements for the degree of

BE Civil Engineering

SUBMITTED BY

TC-1602 CSUO UMER ANJUM MINHAS 2011 NUST BE CE 51 (Syndicate Leader)

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This to certify that the

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Has been accepted towards the partial fulfilment of the requirements for

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LT COL DR MAQBOOL SADIQ AWAN

PROJECT ADVISORAND DIRECTING STAFF

Dedication

We dedicate this project to all those humble beings who have aided us in any way to become what we are today, whose sacrifices seeded our success; especially our parents who have felt our pain beyond us and showered us with their never ending prayers and support. We deem them as a divine source of inspiration.

For all support, encouragement and believe in us. Thank you so much.

ACKNOWLEDGEMENT

First of all thanks to Allah for his blessings, this has enabled us to complete our Bachelor's thesis. There are number of people without whom this might not have been written, and to whom we are greatly obliged.

Last but not least, our deepest gratitude goes to our beloved parents who have always been a symbol of encouragement and inspiration to us throughout our lives. Special thanks to our project advisor Lt Col. Dr Maqbool Sadiq Awan for his time, support and prayers. To those who in some way contributed in this research, your kindness means a lot to us. Thank you very much.

All Syndicate members

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LIST OF ABBREVIATIONS/SYMBOLS

ECC	Engineered Cementitious Composites
PP	Poly propylene
ASTM	American Society for Testing and Materials
CMF	Carbon Micro Fiber
GF	Glass Fiber
FRC	Fiber Reinforced Concrete
IMDUC	Impact Resistant and Ductile Cementitious Composite
AR	Alkali Resistant
GFRCC	Glass Fiber Reinforced Cementitious Composites
CFCC	Carbon Fiber Cement Concrete
PAN	Poly acrylonitrile
LDPE	Low-Density Poly Ethylene
HDPE	High-Density Poly Ethylene
UTM	Universal Testing Machine

EXECUTIVE SUMMARY

In normal use conventional concrete, micro-cracks develop before structure is loaded because of drying shrinkage and other causes of volume change. When the structure is loaded, the micro cracks open up and propagate. Because of development of such micro-cracks, it results in inelastic deformation in concrete. As to remedy it fiber reinforced concrete or cementitious matrix is used. Fiber reinforced concrete (FRC) is cementing concrete reinforced mixture with more or less randomly distributed small fibers. In the FRC, a numbers of small fibers at a percentage of base material or the cementitious material is added and dispersed and distributed randomly in the concrete at the time of mixing, and thus it improves concrete properties in all directions. These fibers have many benefits. Like they help in reducing the steel reinforcement as they impart flexural strength as compared to normal matrix. Impact resistance of the matrix is improved. Compressive strength of the concrete is improved Durability of the concrete is improved to reduce in the crack widths. The fibers added were from 30-50 microns in diameter and 12 -15 mm in length. Polypropylene, glass and carbon micro fibers were compared and their comparison led to polypropylene being the best in flexure performance and hence it led to the use of poly propylene to produce ECC (Engineered Cementitious Composite) also known as bendable concrete. As for improvement in impact properties the MCE impact machine manufactured, helped to compare the effect of fiber reinforcing on plates hence improving the impact resistance.

The fibers help to transfer load from the internal micro cracks hence reducing stresses and their propagation. FRC is cement based material manufactured to cater for these problems. It has been successfully used in construction with its excellent flexural-tensile strength, resistance to spitting, impact resistance and excellent permeability and frost resistance. It is an effective way to increase toughness (area under load deflection curve) and resistance to plastic shrinkage cracking of the mortar.

Chapter 1

INTRODUCTION

1.1 Background

It is well known that one of the problems of a cement-based material is the intrinsically brittle type of failure owing to low tensile strength and poor fracture toughness that impose constraints in structural design and long-term durability of structures. In order to satisfy the performance of cement-based matrices, incorporation of fibers is getting growing interest to increase the toughness, impact resistance, fatigue endurance, energy absorption capacity as well as tensile properties of the basic matrix.

Both the development and propagation of cracks of cement-based composite are resisted through stress-transfer bridges and crack tip plasticity mechanisms due to the presence of fibers. As a result of the above advantages, fiber reinforced cement-based composites are steadily used in hydraulic structures, tunnel linings, highway and airfield pavements and tensile skin in concrete beams and slabs.

Extensive literature review indicates that several types of fibers such as steel, asbestos, glass, metallic glass ribbons, polymeric, carbon, natural fibers and textile reinforcements were being used to reinforce cement matrix and considerable works have been done on the mechanical properties of these types of cement-based materials.

Among the different types of fibers used in cement-based composites, carbon micro fibers, glass woven fibers and poly propylene fibers were sought as they are available in Pakistan and tend to have a more drastic effect on the said properties of Cementitious matrix like compressive, flexure and impact. And once the flexure property is improved it may lead us to think upon the use of fibers to produce an ECC (Engineered Cementitious Composite).

1.2 Problem Statement

Failure in cement based materials is a gradual multi-scale process. When loaded, initially short and discontinuous micro cracks are created in a distributed manner. These micro cracks coalesce to form large macroscopic cracks, known as macro cracks. These cracks tend to drastically affect the cementitious matrix and reduce the life and strength. Hence in order to increase the strength which is flexural strength, there was a need to compare the different fibers that impart strength to the mortar and hence the mortar becomes more resistant to flexural stresses and it also makes it more resistant to impact loads. As for the present standards we don't have an ASTM impact testing machine so a machine needed to be designed and manufactured so that the impact numbers of the samples is studied properly and the concerned problem be addressed properly. The increase in flexural reinforcement has led to cause a considerable decrease in steel reinforcement and hence the term ECC is to be coined. These all things are to be manufactured and compared using materials that are locally available.

1.3 Objective of the Study

The objectives of study were:

- To compare the engineering properties of suitable mortar with high medium and low modulus fibers.
- Development of IMDUC using the fibers with best performance characteristics, hence tending to produce a ductile cementitious matrix.
- Selecting the fiber giving the best ductility to produce an ECC.

1.4 Scope of the Study

In this study of different fibers we have selected some suitable fibers which are available in Pakistan and we have incorporated them in mortar (Cementitious matrix). We have not used coarse aggregate because our aim is to see the effect of fibers in the reinforcement of cementitious matrix.

The increase in compressive, flexural and impact properties (basic engineering properties) is observed which has led to the selection of a specific fiber for the increase in flexure property to a considerable level and hence tending to produce a cementitious matrix which is called ECC. The probable reason that we have selected a mortar is because the ECC developed by Prof Victor Li is based on mortar and hence it led us to the use of mortar as our cementitious matrix. The ECC is a patented technology and without the adequate formula and mix proportions available, we tried our best to make a local matrix for ECC. Though we were not successful in it but we did increase the ductility of our cementitious matrix with the help of a local oiling agent.

Compressive tests which were conducted were on 2 inch cube samples. Flexural loading was a two point loading test and hence the both tests compressive and flexure were performed in SOM lab using UTM (Ultimate Testing Machine).

For impact tests a MCE impact machine was designed in which a mass of known quantity was dropped from variable height and the height at which the sample cracked, was taken and computed to give an impact number.

1.5 Organization of the Report

The thesis is ordered in five chapters; brief description of each is as follows:

- Chapter 1 elaborates a short overview to the impact resistant and ductile cementitious matrix, its introduction and what is the problem which we are addressing. It also included the scope of our FYP.
- Chapter 2 comprises of review of the past researches carried out regarding the fiber reinforced Cementitious matrices, their role in improving the flexural, compressive and impact properties and the use of different fibers and techniques in producing ECC(engineered Cementitious composite). It also reviews different modulus fibers and their comparative properties which they impart to the composite.
- Chapter 3 includes the research methodology adopted in this thesis to achieve the objectives, the source of materials used in this research, and characterization of materials. It also includes the details of testing for fiber selection, and various steps leading to ECC.

- Chapter 4 includes materials and matrix selection and it explains different materials including base materials and fibers. Fibers properties and their characteristics are also mentioned in this chapter.

- Chapter 5 includes Preparation of samples, mould sand MCE Impact machine. The different molds manufactured for the project and the experimental work done. It also includes the MCE impact machine design and use.

- Chapter 6 includes Material testing and results which are done to ascertain how the basic engineering properties have improved with the reinforcement of cementitious matrix. It includes compressive, flexural, toughness and impact testing results and comparisons of different fibers.

- Chapter 7 shifting towards ECC is basically the ambitious approach which we have made in shifting the IMDUC cementitious matrix towards ECC (Engineered Cementitious Composites). It also explains the different oiling agent's trials and selection.

- Chapter 8 summarizes the findings and conclusions of testing results. The recommended work for future and suggestions.

Chapter 2

LITRATURE REVIEW

2.1 Introduction

This chapter includes a summary of the studies and researches that are already carried. A brief review of background, properties, composition and researches on Glass fibers, Polypropylene fibers and Carbon fibers is narrated below.

2.2 Overview on Fibers

The idea of incorporating fibers into binding material to improve its properties originates back in early days of human civilization. The use of straw in sun baked clay bricks was widespread in early civilization. It was followed on with use of small branches, leaves and other naturally abundant available materials. Asbestos was used to reinforce clay posts around 2500 B.C. In more recent time's horse - hair has been added to plaster mixes.

2.2.1 Need of Fibers

Cement paste is not used as a material for construction as it cracks easily due to dimensional instability which may be caused by changes in environmental conditions (variation in temperature). Naturally available stone was introduced to improve the properties of mortar (cement). Aggregate (crushed stone) was used to reduce that effect and the resulting product (mortar) possesses many advantage including low cost, high strength and load bearing capability, general adaptability and utilization under different environmental condition. It greatly enhanced the compressive strength of cement (mortar). But in spite of all that mortar is fundamentally weak in tension and have comparatively low ductility and little resistance to impact loading. Fibers were introduced to cement matrix basing on the role performed in the past.

2.2.2 Role of Fibers

Researchers have been conducting series of experiments by introducing several different types or fibers available to overcome these disadvantages which offer a convenient and practical means of achieving improvements in many of the engineering properties of the material such as fracture toughness, fatigue resistance, impact resistance and flexural strength. Various fibrous composite materials both natural and man-made have been used and are being used as building materials. Glass fibers, Steel fibers, Carbon fibers and Polypropylene are example of materials of this type.

Research on fiber reinforced mortar revealed that the properties of mortar such as strength and deformation are improved when fiber are added to the mortar. Such improvements are caused by transfer of load from mortar to the fibers, thus controls the crack growth. The load is transferred by interfacial shear stress and longitudinal tensile stress developed on the fibers.

2.2.3 Behavior of Fibers

Fiber reinforced cement is a mortar made of hydraulic cements containing fine aggregate and discontinuous discrete fiber. It may contain pozzolans and other admixture (Fly ash). The main emphasis on research and practical application of fiber in cement paste has been concerned with the behaviour of the fibers in ordinary Portland cement. The physical performance of the fibers in this matrix and as a result, the performance of composite is critically dependent on the microstructure of the matrix and of the fibers in the interfacial region where the fibers and matrix make contact.

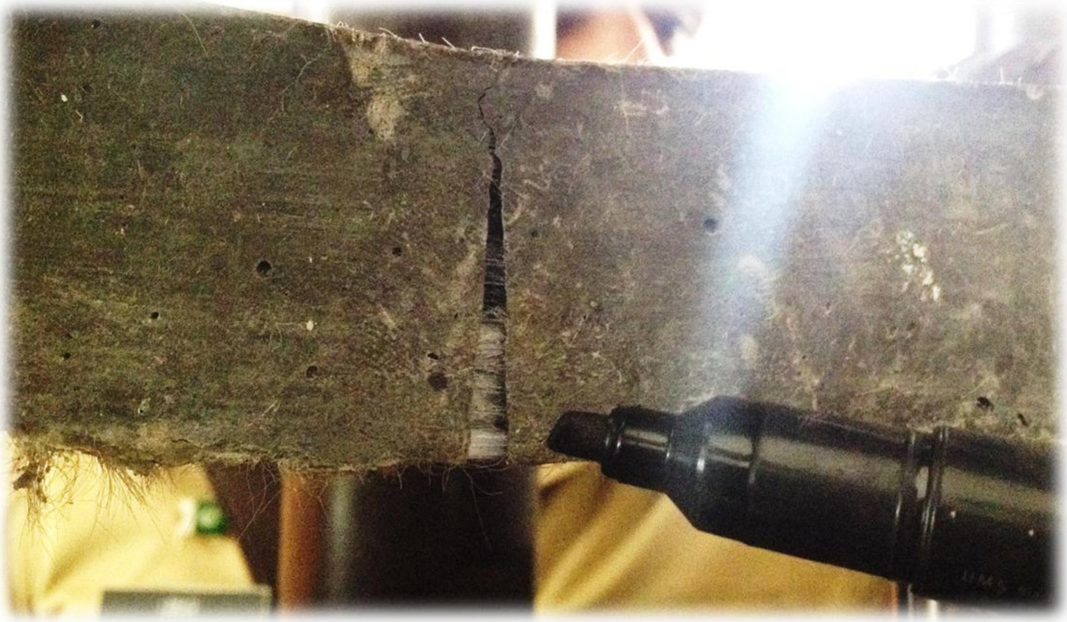

Figure 2.1 Behaviour of Fibers

This region is important not only on the external surface of the fibers but also between the fibers itself.

The transfer of load from mortar to fibers depends on the following two considerations:-

1- Critical fiber length or the fiber transfer length, that if the fiber length is greater than the critical length, fiber should yield at the failure of the composite.

$$lc = \frac{\sigma ult.d}{2\tau}$$

Where;

Lc: Critical length,

d: Fiber diameter ,

σult.d: Ultimate tensile strength of the fiber,

τ: Interfacial shear stress.

2- The interfacial bonds between fibers and mortar in the vicinity of the crack increase to maximum and then decrease with increasing distance from crack edge as shown

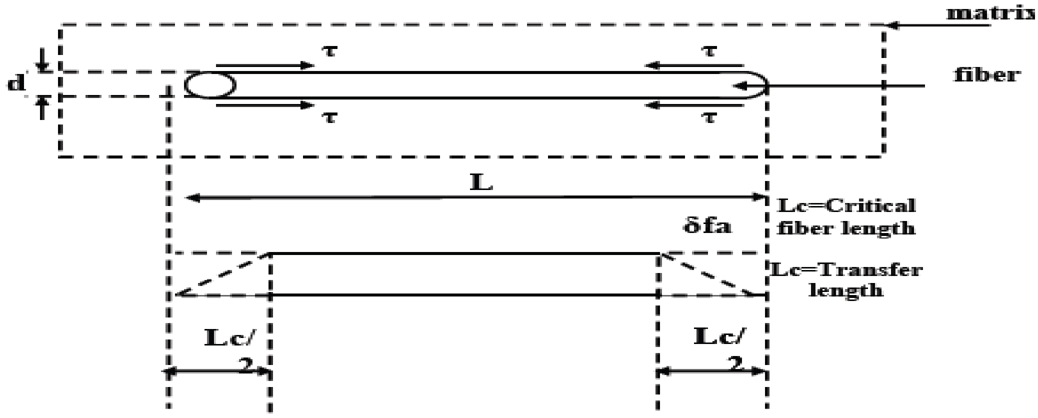

Fig.(2): Stress distribution for fiber in a discontinuous, aligned fiber composite(Ghazy,2000).

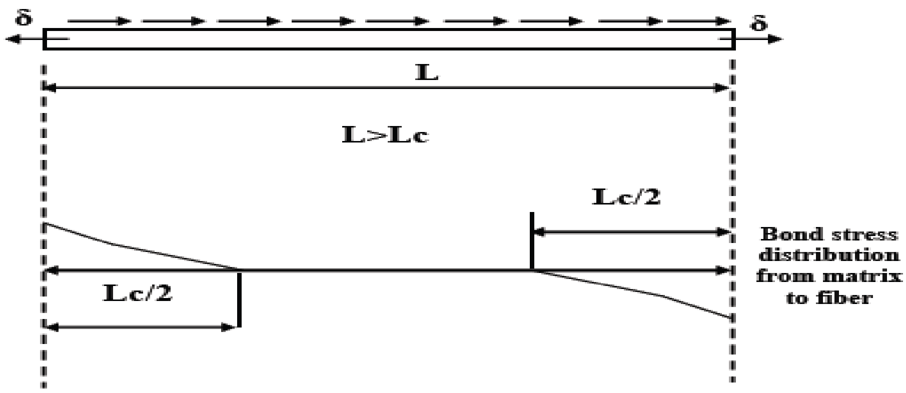

Fig.(3): Bond stress distribution at fiber – matrix interface (Ghazy,2000)

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Fig.(3) shows that the failure of the fiber reinforced mortar occurs either by simultaneous yielding of the fiber and crashing of mortar or by bond failure at the mortar – fiber interface.

Short fibers are used as admixtures in cement-based materials for the purpose of decreasing the drying shrinkage, increasing the flexural toughness and in some cases increasing the flexural strength as well as **impact resistance of mortar.**

In the case that the fibers are electrically conductive, the fibers may also provide non-structural functions, such as self-sensing, for sensing the strain, damage, or temperature, self-healing and electromagnetic reflection, for electromagnetic interference shielding, i.e., EMI shielding.

Although continuous fibers are more effective than short fibers as reinforcement, they are not amenable to incorporation in a mortar mix and they are relatively expensive.

2.3 Detail on Fibers

This includes a detail on the fibers that are being used in the market and were used in the research work. It includes Glass Fibers, Carbon Fibers and Polypropylene Fibers. The last part includes an overview on ECC (Engineered Cementitious Composites).

2.4 Glass-fiber reinforced cement composites (GFRCC)

Glass-fiber reinforced cement composites (GFRCC) is a material made up of a cementitious matrix composed of fine aggregates, cement, water and admixtures, in which glass fibers are dispersed. GFRCC exhibits many favourable characteristics such as being lightweight, durable, aesthetically pleasing with adequate strength. An investigative report backed by existing experimental findings is presented to showcase the various applications of GFRCC as a viable alternative construction material.

2.4.1 Introduction

Cement-based materials are characterized by very good properties in compression but their brittle manner of failure under tensile or impact load was a limiting factor for their applicability range from the very beginnings. Fiber reinforcement is a traditional and effective method how to improve the toughness and durability of cement based products. The steel rod reinforcement became very popular during the whole last century and remains the most frequently used type of cement reinforcement until now. However, in the second half of the 20th century, an application of uniformly dispersed short fibers strengthening the brittle cementitious matrices appeared with an increasing frequency. In the current practice, steel, glass, carbon and various polymeric fibers such as polyethylene, polypropylene, nylon, polyester, polyurethane, cellulose, etc., are commonly used in cement-based materials.

Glass-fiber reinforced cement composites (GFRCC) are produced by incorporating a small amount of alkali-resistant glass fiber in cement to overcome the traditional weakness of inorganic cements, namely poor tensile strength and brittleness. The length and content of the glass fiber reinforcement can be chosen to meet the strength and toughness requirements of the product. Also, the type of aggregates can be varied in order to control thermal properties.

Figure 2.2 Glass-fiber

GFRCC have found their place as versatile and commercially viable materials for use in construction industry in the beginning of 1970s. Currently, they are frequently applied in wall systems, utilized in form work, pipe work, used for surface bonding and rendering, etc. They can also replace asbestos cement products as fire protection Undoubtedly one of the most important materials vastly used in the global construction industry is Cement, thanks to the hardened uniform structure, the ability to take any shape and most importantly the capability of quality improvement by incorporating composites and admixtures. One such form of modified cement is

Glass-fiber reinforced cement composites (GFRCC) whose constituent material properties, production technologies, resulting matrix properties and field applications are dealt in detail.

2.4.2 Constituent material properties

- **Typical chemical composition**

SiO_2 (silica)	70 – 74 %
Na_2O (sodium oxide)	12 – 16 %
CaO (calcium oxide)	05 – 11 %
MgO (magnesium oxide)	01 – 03 %
Al_2O_3 (aluminum oxide)	01 – 03 %

Table 2.1 Chemical properties of GFRCC

- **Mechanical Properties**

Specific Gravity	2.7 – 2.74
Tensile Strength, Mpa	1700
Elastic Modulus, Gpa	72
Strain @ Break, %	2

Table 2.2 Mechanical properties of GFRCC

2.4.3 General Properties

1) Normal glass fibers react with the alkali present in cement and deteriorate with time. Hence Alkali Resistant (AR) fibers are used.
2) Fibers ranging from 25 to 50mm are preferred over very short fibers.
3) Individual fibers are typically <10μm in dia. and maybe bundled together to form wires up to 1.5mm in diameter.
4) The Outermost fibers chiefly contribute to the bond strength in the matrix. The fiber wires behave as an elastic component even after 28 days of curing due to the effect of Inner strands which are not in contact with the cementitious matrix.
5) Easy to cut but very difficult to break.
6) Inorganic in nature and thus reduce the Fire Loading on the Structure.

2.4.4 Production technology:

The following four steps are involved in the production of fibers.

1. **Premix process:** Fibers are treated simply as an extra ingredient in the most common method of producing a cementitious mix. However, because the fibers reduce the workability, only up to about 2% fibers by volume can be introduced in the mix by this method.
2. **Spray-up process:** Chopped glass fibers and cement slurry are sprayed simultaneously on to the forming surface, to produce thin sheets. With this technique, substantially higher fiber volumes, up to about 6%, can be incorporated.
3. **Hand lay up or Hybrid Method :** In this method, layers of fibers in the form of mats or fabrics can be placed in moulds, impregnated with a cement slurry, and then vibrated or compressed, to produce dense materials with very high fiber contents. This technique can also be used with glass fiber roving already impregnated with cement slurry.
4. **Pulp type process:** The fibers are dispersed in cement slurry, which is then dewatered to produce thin sheet materials. These can be built up to the required thickness by layering. This process yields fiber content ranging from 9% to over 20% by volume.

2.4.5 GFRCC matrix properties:

1. GFRCC exhibits synergism i.e. the combined effect of the glass fibers and the cementitious matrix is better than the algebraic sum of the strength of the constituents.
2. Randomly distributed fibers expand the loads in a wide range and let the complete matrix behave cohesively.
3. The Glass fibers act as an effective crack arresting system i.e. after the onset of micro cracks; the strong fibers resist the loads thereby stopping the propagation of the existing micro cracks but rather induce fresh cracks.
4. Failure in GFRCC is similar to a gradual plastic failure, except for the fact that the glass fibers do not break but it is elongated and pulled out of the matrix that leads to failure.
5. The major Factors affecting the properties of GFRCC are fiber content, W/C ratio, porosity, composite density, orientation of fibers, fiber length and type of curing.
6. The coefficient of Thermal Expansion of GFRCC is in the range of (10.8 – 16.2) x $10^{-6}/^{\circ}C$ (roughly 1/3rd of steel).
7. The Thermal conductivity of GFRCC is also very low (0.5 – 1.05) W/m.K i.e. 2 to 4 times that of Air.

2.4.6 Applications of GFRCC:

1. **Decorative Architectural Panels or Cladding:**

   Due to the light weight of GFRCC panels, thinner structural members provide enough stability. Transportation costs are also reduced. GFRCC panels also provide good resistance to fire and extreme weather conditions thereby making it an ideal material for exterior use. Also GFRCC is a versatile material that provides great design flexibility by offering a plethora of colors, textures, patterns and surface finishes. Spray-up and pulp type production are the commonly used methods of production.

2. **Noise Protection Barriers:**

   GFRCC has been used for making noise protection barriers. The main reason is that theoretical values have suggested that GFRCC panels with a thickness of 10mm and surface mass of 20kg/m^2 will achieve a sound reduction of about 30dB. Production technology is the same as in Architectural cladding.

3. **Interior usage:**

   GFRCC is more stain resistant than granite and more scratch resistant than marble. Kitchen counters tops, commercial and Industrial tops etc. Premix method is best suited for these purposes.

4. **Column Strengthening by GFRCC layers:**

   Used for retrofitting of existing compression members to improve ductility. Also the strength is increased by confining the columns in Glass Fiber Reinforced Polymer wrapping. Spray up is the preferred method of execution.

5. **Retrofitting of Masonry walls with Glass Fiber mesh:**

   Since masonry walls offer poor resistance to dynamic forces, existing masonry construction are strengthened by application of Glass fiber mesh beneath a layer of cement or cement slurry by spray up or Hybrid Method.

6. **Ducts, Channels and Sewer lining:**

   GFRCC offers good resistance against impact, acid, salt, lime and water. The major problems encountered in channels and sewers are abrasion due to flow of liquid, corrosion due to chemicals present in waste water, temperature of water and humid conditions. Hence GFRCC provides a safe composite that serves well in many environmental issues related to cement and its poor strength in extreme conditions. All types of Production technologies are used depending on the site requirement.

7. **Exact Replicas of historical buildings:**

   The versatility of GFRCC in terms of colures, textures, patterns and surface finishes make it a good choice for the repair and rehabilitation of historical structures and extensions to old buildings using the same design features.

2.4.7 Advantages & limitations

The main advantages of GFRCC in comparison to cement are as follows:

- Higher flexural strength, tensile strength and Impact Strength than plain cement due to the presence of the glass fibers.
- No cover requirement to be provided thus resulting in thinner sections.
- Fibers are lightweight that minimizes the load added to existing structures.
- Improved Chemical Resistance, for example GFRCC exhibits better chloride penetration resistance than steel.
- It does not rust or corrode.
- Good acoustic properties.
- Low permeability that increases water or air pollution resistance
- It is recyclable and environment friendly.

Some of the main limitations of GFRCC are:

- It is more expensive than plain cement.
- GFRCC can lose some of its initial strength over long periods of time and this has to be taken into consideration during the design stage.

2.4.8 Conclusion

The following conclusions can be summarized:

- GFRCC can be used wherever a light, strong, weather resistant, attractive, fire retardant, impermeable material is required. It is characterized by many useful properties.
- GFRCC possesses higher tensile strength than that of steel. Modulus of elasticity is higher in steel bars but low modulus glass fibers stretch and allow cement to crack, but nevertheless do not allow the crack to propagate hence, a new crack in different position appears.
- Use of fiber produces more closely spaced cracks and reduces crack width. Fibers bridge cracks to resist deformation.
- Fiber addition improves ductility of cement and its post-cracking load-carrying capacity.

- Like most composites GFRCC properties are dependent on the quality of materials and accuracy of production method.
- Fracture energy of cement based materials is significantly increased by adding glass fiber to the mix composition.

2.5 Carbon Fibers:

Carbon fiber, alternatively **graphite fiber** or **CF**, is a material consisting of fibers about 5–10 μm in diameter and composed mostly carbon atoms to form long chains. The fibers are extremely stiff, strong, and light, and are used in many processes to create excellent building materials. The properties of carbon fibers, such as high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion, make them very popular in the field of Civil Engineering. Carbon fiber material comes in a variety of "raw" building-blocks, including yarns, uni-directional, weaves, braids, and several others, which are in turn used to create composite parts.

2.5.1 History

Carbon fibers, under industrial production now, are classified into PAN-based, pitch-based and rayon-based. Among them, PAN (Poly acrylonitrile) based carbon fiber is in the largest production and best used in volume.

In the beginning of 1970’s, commercial production of PAN-based and isotropic pitch-based carbon fibers was started on a large scale in Japan. In the latter half of 1980’s, anisotropic pitch-based carbon fiber manufacturers broke into the market. As the fruit of tireless technological improvement and business expansion, Japanese carbon fiber manufacturers have been keeping their position as world number one at quality and production volume of carbon fibers.

2.5.2 Manufacturing

Carbon fibers are manufactured by carbonizing suitable organic materials in fibrous forms at high temperatures and then aligning the resultant graphite crystallites by hot-stretching. The fibers are manufactured as either Type I (high modulus) or Type II (high strength) and are dependent upon material source and extent of hot stretching for their physical properties. . The Type I and II carbon fibers produced by carbonizing suitable organic materials other than petroleum-based materials are 20 to 40 times stronger and have a modulus of elasticity up to 100 times greater than the pitch-based carbon fiber.

2.5.3 Properties

Carbon fibers are usually combined with other materials to form a composite. When combined with a plastic resin and wound or moulded it forms carbon-fiber-reinforced polymer (often referred to as carbon fiber) which has a very high strength to weight ratio, and is extremely rigid although somewhat brittle. However, carbon fibers are also composited with other materials, such as with graphite to form carbon-carbon composites, which have a very high heat tolerance. Carbon fiber is extremely strong. It is typical in engineering to measure the benefit of a material in terms of strength to weight ratio and stiffness to weight ratio, particularly in structural design, where added weight may translate into increased lifecycle costs or unsatisfactory performance. The stiffness of a material is measured by its modulus of elasticity. The modulus of carbon fiber is typically 20 Msi (138 Gpa) and its ultimate tensile strength is typically 500 Ksi (3.5 Gpa).

High stiffness and strength carbon fiber materials are also available through specialized heat treatment processes with much higher values. The properties of a carbon fiber part are close to that of steel and the weight is close to that of plastic. Thus the strength to weight ratio (as well as stiffness to weight ratio) of a carbon fiber part is much higher than.

Figure 2.3 Carbon fibers

2.5.4 Applications:

Usage of carbon fiber by itself is not the rule. Commonly, customers apply carbon fibers for reinforcement and / or functionality of composite materials, made with resin, ceramic or metal as matrix. Carbon fibers are extensively applied to a large variety of applications with supreme mechanical characteristics (specific tensile strength, specific modulus) and other characteristics due to carbon matter (low density, low coefficient of thermal expansion, heat resistance, chemical stability, self-lubricity, etc.).

The use of short and chopped carbon fibers in concrete makes it carbon fiber cement concrete (CFCC) or carbon fiber reinforced concrete (CFRC). CFCC has little resemblance to conventional concrete. It contains no coarse aggregate and typically contains between 1 to 15 percent by volume chopped and short carbon fiber elements when we add carbon micro fibers the properties of mortar changes.

The effect of carbon fiber addition on the properties of mortar increases with fiber volume fraction unless the fiber volume fraction is so high that the air void content becomes excessively high. (The air void content increases with fiber content and air voids tend to have a negative effect on many properties, such as the compressive strength.) In addition, the workability of the mix decreases with fiber content. Moreover, the cost increases with fiber content. Therefore, a rather low volume fraction of fibers is desirable. A fiber content as low as 0.2 vol. % is effective, although fiber contents exceeding 1 % by volume are more common. The required fiber content increases with the particle size of the aggregate as the flexural strength decreases with increasing particle size .The improved structural properties rendered by carbon fiber addition pertain to the increased tensile and flexible strengths ,the increased tensile ductility and flexural toughness, the enhanced impact resistance, the reduced drying shrinkage and the improved freeze thaw durability. Carbon fibers are advantageous in their superior ability to increase the tensile strength of concrete, even though the tensile strength, modulus and ductility of the carbon fibers is less than other fibers.

2.5.5 Use in concrete

Carbon fibers can be used in concrete together with steel fibers, as the addition of short carbon fibers to steel fibers reinforced mortar increases the fracture toughness of the interfacial zone between steel fiber and the cement matrix. Carbon fibers can also be used in concrete together with steel bars or together with carbon fiber reinforced polymer rods .In relation to most functional properties, carbon fibers are exceptional compared to the other fiber types. Carbon fibers are electrically conducting, in contrast to glass and polymer fibers, which are not conducting. Steel fibers are conducting, but their typical diameter (60 mm) is much larger than the diameter of a typical carbon fiber (15 mm).

The combination of electrical conductivity and small diameter makes carbon Fibers superior to the other fiber types in the area of electrical conduction. However, carbon fibers are inferior to steel fibers for providing thermoelectric composites, due to the high electron concentration in steel and the low hole concentration in carbon.

Although carbon fibers are thermally conducting, addition of carbon fibers to concrete lowers the thermal conductivity, thus allowing applications related to thermal insulation. This effect of carbon fiber addition is due to the increase in air void content. The electrical conductivity of carbon fibers is higher than that of the cement matrix by about eight orders of magnitude, whereas the thermal conductivity of carbon fibers is higher than that of the cement matrix by only one or two orders of magnitude. As a result, the electrical conductivity is increased upon carbon fiber addition in spite of the increase in air void content, but the thermal conductivity is decreased upon fiber addition.

2.5.6 Other applications

Several structural engineering applications utilize carbon fiber reinforced polymer because of its potential construction benefits and cost effectiveness. The usual applications include strengthening structures made with concrete, steel, timber, masonry, and cast iron; Retrofitting to increasing the load capacity of old structures like bridges; to enhance shear strength and for flexure in reinforced concrete structures. Other applications include replacement for steel, pre stressing materials and strengthening cast-iron beams.

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2.6 Polypropylene

Polypropylene also known as PP, is a thermoplastic polymer used in a wide variety of applications. Phillips Petroleum chemists J. Paul Hogan and Robert L. Banks first polymerized propylene in 1951. Polypropylene is a synthetic hydrocarbon polymer, the fiber of which is made using extrusion processes by hot-drawing the material through a die. Polypropylene fibers are produced as continuous mono-filaments, with circular cross section that can be chopped to required lengths, or fibrillated films or tapes of rectangular cross section. It was first used to reinforce concrete in the 1960s.

2.6.1 Properties:

Most commercial polypropylene is isotactic and has an intermediate level of crystallinity between that of low-density polyethylene(LDPE) and high-density polyethylene (HDPE). Polypropylene is normally tough and flexible, especially when copolymerized with ethylene. This allows polypropylene to be used as an engineering plastic. Its specific gravity ranges from 0.90 – 0.91 gm/cm3.

Polypropylene fibers are hydrophobic and therefore have the disadvantages of poor bond characteristics with cement matrix, a low melting point, high combustibility and a relatively low modulus of elasticity. Long polypropylene fibers can prove difficult to mix due to their flexibility and tendency to wrap around the leading edges of mixer blades. Polypropylene fibers are tough but have low tensile strength and modulus of elasticity; they have a plastic stress-strain characteristic.

Monofilament polypropylene fibers have inherent weak bond with the cement matrix because of their relatively small specific surface area. Fibrillated polypropylene fibers are slit and expanded into an open network thus offering a larger specific surface area with improved bond characteristics. Polypropylene fiber contents of up to 12% by volume are claimed to have been used successfully with hand-packing fabrication techniques, but volumes of 0.1% of 50-mm fibers in concrete have been reported to have caused a slump loss of 75 mm. Polypropylene fibers have been reported to reduce unrestrained plastic and drying shrinkage of concrete at fiber contents of 0.1% to 0.3% by volume. Moreover this material is often chosen for its resistance to corrosion and chemical leaching, its resilience against most forms of physical damage, including impact and freezing, its environmental benefits, and its ability to be joined by heat fusion rather than gluing.

2.6.2 Role in cementitious matrix:

Fibers are increasingly being used for the reinforcement of cementitious matrix to enhance the toughness and energy absorption capacity and to reduce the cracking sensitivity of the matrix. Cement-based composites exhibit the general characteristics of brittle matrix composites; that is, the failure of the matrix precedes the fiber failure, thus allowing the fibers to bridge the propagating crack. The toughening effect is the result of several types of fiber/matrix interactions, which leads to energy absorption in the fiber-bridging zone of a fiber-reinforced matrix. These processes include fiber bridging, fiber de-bonding, fiber pull-out (sliding) and fiber rupture as a crack propagates across a fiber through the matrix as shown in Fig 2.4.

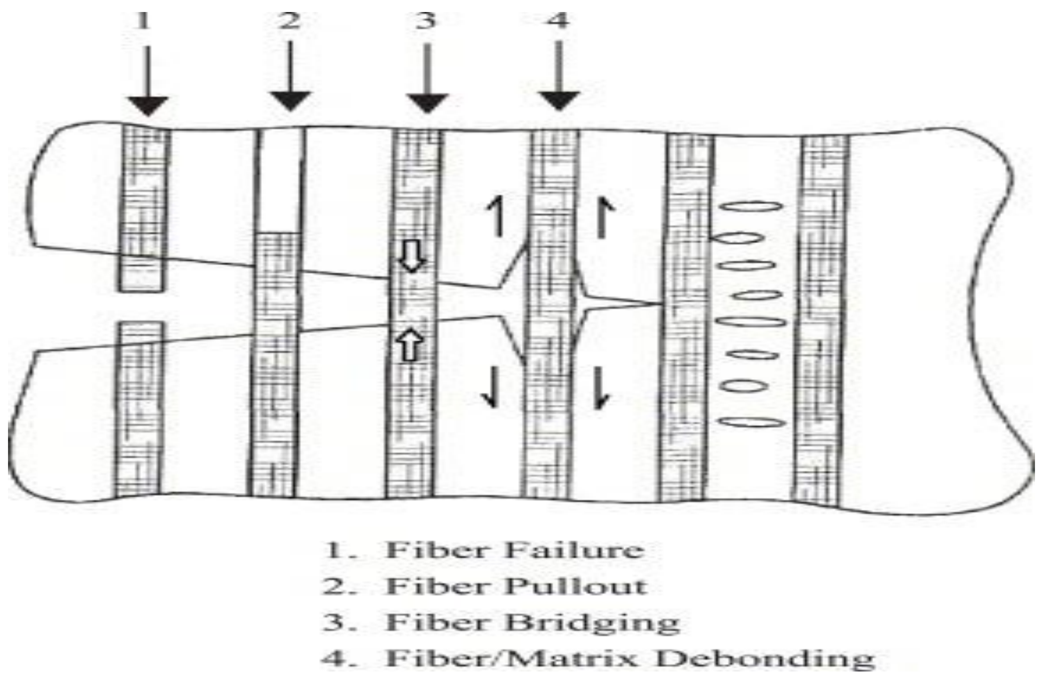

Figure 2.4 Fiber bridging, de-bonding, pull-out and rupture.

Although the amount of energy absorption associated with each mechanism for individual fiber may not be significant, a large number of fibers bridging over an extended length can contribute an enormous toughening effect to the composite. Fiber bridging results in crack closure and a reduction in stress intensity factor at the crack tip. Fiber de-bonding and pull-out (sliding) at the interface have a significant influence on total energy absorption during crack propagation. Thus, the fiber/matrix bond strongly affects the ability of fibers to stabilize crack propagation in the matrix. Many researchers have investigated and modelled the effect of the interfacial bond on composite properties such as crack resistance and durability. Cracks play an important role as they change matrix structures into permeable elements and consequently with a high risk of corrosion. Cracks not only reduce the quality of cementitious matrix and make it aesthetically unacceptable but also make structures out of service. If these cracks do not exceed a certain width, they are neither harmful to a structure nor to its serviceability.

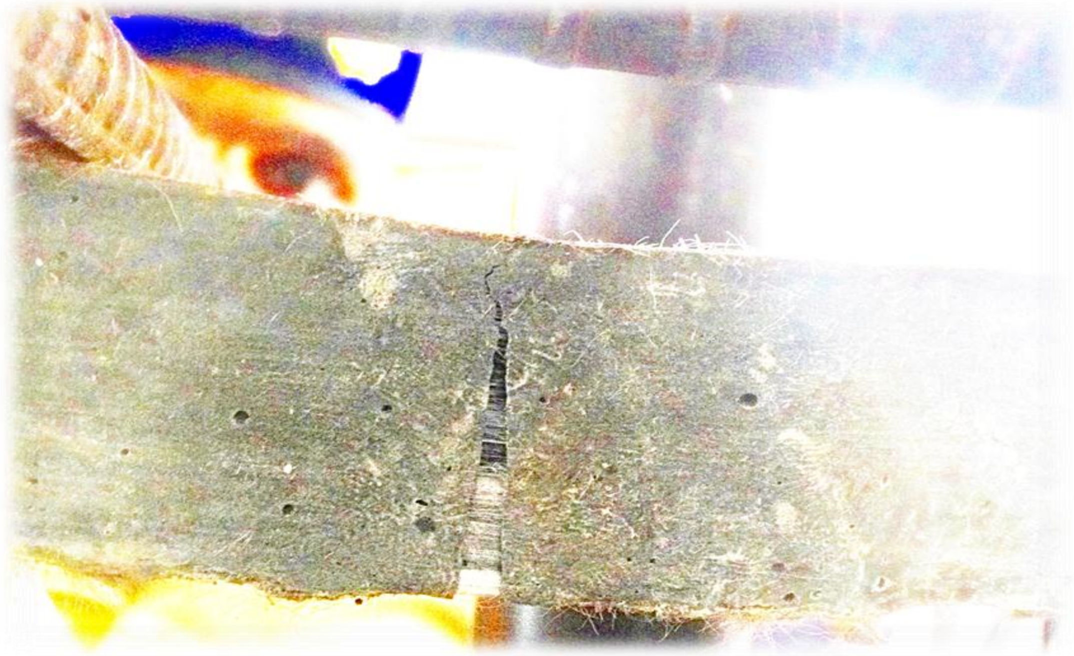

Figure 2.5 Role Polypropylene Fibers in cementitious matrix

Therefore, it is important to reduce the crack width and this can be achieved by adding polypropylene fibers to cementitious matrix.

2.6.3 Creep and shrinkage properties of cementitious matrix

Fibers reduce creep strain, which is defined as the time-dependent deformation of a matrix under a constant stress. Compressive creep values, however, may be only 10 to 20% of those for plain cementitious matrix. Shrinkage of cementitious, which is caused by the withdrawal of water from matrix during drying, is also reduced by fibers. The reduction in shrinkage due to the presence of fibers is expected from number of viewpoints. First, the fibers do not exhibit any shrinkage, thus reducing overall shrinkage of the mix. In addition the fibers have a role in retaining the water in the mix up to a certain limit which helps to delay the shrinkage. Therefore addition of fibers to the cementitious matrix is always advantageous in reducing shrinkage deformation.

2.6.4 Plastic shrinkage

It occurs when surface water evaporates before the bleed water reaches the surface. Polypropylene fibers reduce the plastic shrinkage crack area due to their flexibility and ability to conform to form. The addition of 0.1% by volume of fibers is found effective in reducing the extent of cracking by a factor of 5-10. The extent of crack reduction is proportional to the fiber content in the matrix**.**

2.6.5 Bond between Polypropylene Fibers and Cementitious Matrix

Polypropylene fibers have a weak bond with cementitious matrix because of smooth surface of fibers, which does not allow for sufficient friction to develop between the two. It is generally accepted that there is no physiochemical adhesion between polypropylene and cement, since polypropylene has a hydrophobic surface. It has been suggested that the use of chopped polypropylene fibers with their open structure has remedied the lack of interfacial adhesion by making use of wedge action at the slightly opened fiber end and also by mechanical bond between fibers and cement.

2.6.6 Pull-out behavior of polypropylene fibers from cementitious matrix:

The pull-out tests of polypropylene fibers from cement matrix were carried out to investigate the effect of embedded length on the pull-out characteristics and the development of the interfacial bond with the age of curing of matrix on the interfacial bond. The bond strength was calculated from the peak load and the embedded area of the fiber. The area under the pull-out curve up to 5 mm pull-out displacement was calculated to obtain the interfacial toughness. This corresponds to the energy absorbed in the pull-out process up to a pull-out displacement of 5 mm. The energy absorbed was calculated up to 5 mm pull-out displacement because a 5- to 10-mm crack opening is far beyond the acceptable limit for most practical structures. A typical pull-out curve of the fibers used in this study is shown in Fig. 2.2. It can be seen from this plot that the pull-out load initially increases almost linearly with the slip. The nonlinear region indicates the start of de-bonding of the fiber from the matrix. The interfacial de-bonding can be considered as fracture. This interfacial crack stably propagates up to peak load; that is, the crack propagates only when the pull-out load increases. After the peak load, unstable crack growth occurs, which means that the crack grows even though the pull-out load decreases. Finally, the fiber starts slipping out of the matrix.

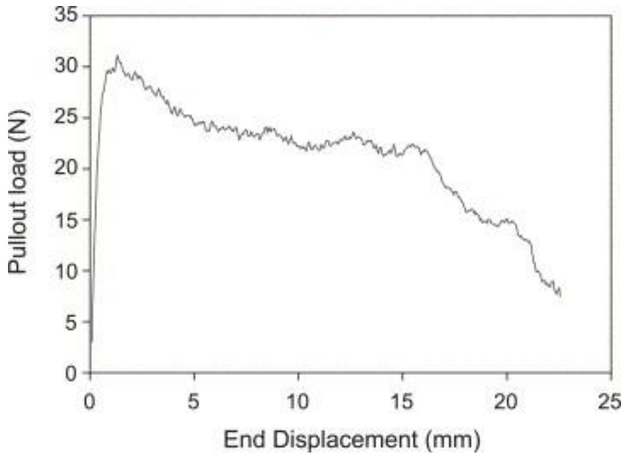

Figure 2.6 Pull-out curve of the fiber

2.7 Summary

The literature review explain different fibres and their role in different aspects which have been used in daily life focusing basically on the modulus of fibres which we have used specifically for our project and it involves the basic properties description and their role.

Chapter 3

RESEARCH METHODOLOGY

3.1 Introduction

In the project we have basically worked on fiber reinforced cementitious matrix to improve the matrix properties and to make it an IMDUC. The procedure was simple as it involved the use of some suitable fiber reinforced in the matrix and the strength imparted to it due to the interaction between the mortars and the fiber which gave the requisite strength to get the required improvement in basic engineering properties in the cementitious matrix.

Step by step methodology is shown below in the figure which takes us to different procedures which had been adopted to perform the project and to achieve an IMDUC Cementitious matrix.

3.2 Research methodology

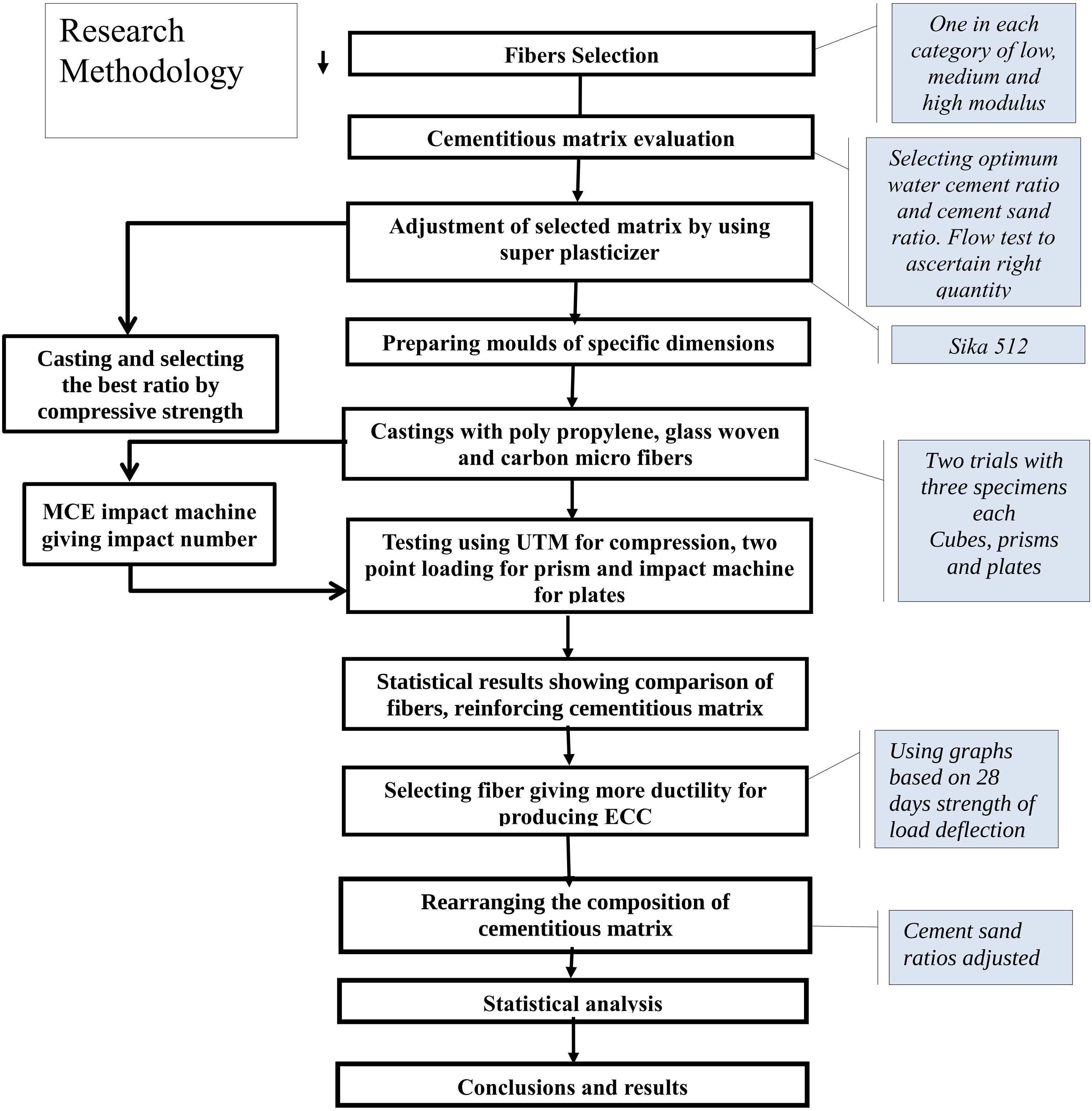

Figure 3.1 Flow chart for Research Methodology

3.3 Frame work of Research methodology

- In the research methodology the foremost aim was to select the different grade fibers and a cementitious matrix. Once the Cementitious matrix was selected it would be tested for engineering properties. Then the reinforced matrix was tested for the improvement in engineering properties like compression , flexure, impact , toughness and it was observed how each fiber behaved and rendered which specific properties to the Cementitious matrix.

- When the role of fibers was well established then a suitable fiber giving a considerable increase in ductility and flexure was selected and it was then used to produce ECC (Engineered Cementitious Composites). But that process was preceded by the re-evaluation of the matrix and imparting a suitable oiling agent on fibers.

3.4 Summary

This chapter explains the general methodology which had been employed in carrying out the project and it has been presented in tabulated form for the convenience of the readers for the purpose of understanding it. The research methodology is basically the step wise approach which had been made in the fulfilment of the project. The methodology generally had to do with the selection of the correct matrix and to establish the role of different modulus fibres incorporated into it.

Chapter 4

MATERIALS AND MATRIX SELECTION

4.1 MATERIALS

The materials selected for this process were:-

4.1.1 Cement

Cement selected was from Askari cement with fineness of Blaine (452m^2/kg). The chemical composition of cement is shown below:-
its density was 1.42g/cm^3.

Table 4.1 Chemical composition of cement

C_3S (%)	C_2S (%)	C_3A (%)	C_4AF (%)	CaO (%)	$Si0_2$ (%)	Al_2O_3 (%)	Fe_20_3 (%)	MgO (%)	$S0_3$ (%)	Loss on ignition (%)	Alkalies (%)
63	13	6	11	65.4	21.1	4.44	3.68	0.9	2.7	1.61	0.38

Properties of cement used are shown below

LAB TEST	VALUES	ASTM SPECIFICATIONS
Standard Consistency	24	20-26%
Initial Setting Time	120	60 Min (min)
Final Setting Time	480	375 Min (max)
Fineness	99	90% (min)
Soundness	5.33	10mm (max)
Specific Gravity	3.12	3-3.15

Table 4.2 Properties of cement

4.1.2 Sand

Sand used was from river Kabul sand bed and it was then sieved using #50 sieves (0.3 mm) and #200(0.075 mm) sieves. The retained material between the two sieves was taken as the constituent material for the production of the required cementitious matrix. The retained material between the two sieves was finer than 0.3 mm and hence the sand was fine grained. It was taken as such with the aim that the fine aggregate used in the production of ECC was very fine i.e. of the size less than 0.250 mm and hence in doing so we kept the size of fine aggregate as such. The fineness modulus of the sand selected was found to be 2.54 (ASTM C 33 requires the FM of fine aggregate to be between 2.3 and 3.1). its density was 1.26g/cm^3. The other properties of the sand are as mentioned:-

PROPERTIES	JALBAI SAND
FINENESS MODULUS	2.83
BULK SPECIFIC GRAVITY (SSD)	2.655
BULK SPECIFIC GRAVITY OVEN DRY	2.612
WATER ABSORPTION	1.5
APPARENT SPECIFIC GRAVITY	2.23

Table 4.3 Properties of sand

4.1.3 Super plasticizer

Super plasticizer selected was SIKAMENT 512 PK having densities of 1.18kg/lt. the super plasticizer was a poly carboxylate based super plasticizer. It also acted as water reducer. Its dosage was 660 ml per bag of cement.the dosage of super plasticizer is calculated in appendix A.

4.1.4 Water

Ordinary water of Risalpur was used in specimen preparation and their curing.

4.1.5 Fibers

We have used primarily three fibers for the IMDUC cementitious matrix. These fibers are from the category of low, medium, and high modulus fibers.

- The fiber selected in low modulus category is poly propylene fiber also known as fiber 12 from SIKA Pakistan.
- The fiber selected in medium modulus category is glass fiber.
- The fiber selected in high modulus category is carbon micro fiber.
- The selection of fiber was made on this prospect that we have to produce a local ECC (engineered Cementitious composite). So the different fibers will be tested and the fiber giving the best result will be selected. ECC is not the inclusion of fiber in the cementitious matrix. It also involved the re-evaluation of cementitious matrix and oiling the fibers with a specific oiling agent.

4.2 Aspect ratio

Fiber is a small piece of reinforcing material possessing certain characteristics properties. They can be circular or flat. The fiber is often described by a convenient parameter called "aspect ratio". The aspect ratio of the fiber is the ratio of its length to its diameter. Typical aspect ratio ranges from 30 to 500.

In general, the smaller the fiber diameter relates to a higher aspect ratio and more difficult the fiber dispersion. Similarly smaller the fiber length relates to a lower aspect ratio and easier fiber dispersion. This is due to the tendency for fibers of a small diameter or a long length to cling to one another.

4.3 Fiber details

4.3.1 Carbon micro fibers

TC-36s 12K poly acrylonitrile (PAN) carbon fibers were procured from SIKA PAKISTAN. The properties of fibers are shown below.

Length (average) (mm)	Diameter (µm)	Yield Tex (g/1000m)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation (%)	Density (g/cm^3)
15	10	800	4,900	250	2	1.81

Table 4.4 Properties of Carbon micro fibers

Figure 4.1 Dispersion of carbon micro fiber

The quantity of carbon micro fiber is added as a percentage by weight of the quantity of cementitious materials added. The concerned calculations are shown in APPENDIX B where the fibers are calculated as a perentage of cementitious materials. The percentage for PAN CMF is 1%.

4.3.2 Glass fibers

Glass fibers are among the most versatile industrial materials known today. They are made of silica. The basis of textile-grade glass fibers is silica, SiO_2. They are readily produced from raw materials, which are available in virtually unlimited supply. Over 90% of all glass fibers are general-purpose products. These fibers are known by the designation E-glass. They were also bought from SIKA PAKISTAN.

Their properties are shown below

Length (average) (mm)	Diameter (µm)	Yield Tex (g/1000m)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation (%)	Density (g/cm^3)
15	30	800	3445	180	2	2.58

Table 4.5 Properties of Glass fibers

The quantity of glass woven fibers is added as a percentage by weight of the quantity of cementitious materials added. The concerned calculations are shown in APPENDIX B where the fibers are calculated as a perentage of cementitious materials.

Figure 4.2 Dispersion of Glass fiber

4.3.3 Poly propylene fibers also known as SICA fiber 12

Sika® Fiber-12 is a high quality, 100% virgin polypropylene fiber that reduces the occurrence of plastic shrinkage and plastic settlement cracking whilst enhancing the surface properties and durability of a cementitious matrix

The main advantages are

- Reduced plastic shrinkage cracks
- Alternate to using crack control reinforcing mesh
- Reduced water and chemical permeability
- Increased abrasion properties
- Better finishing
- Reduces future repair costs due to cracking
- Better resistance against thermal movement.
- Better bonding

The fibers were bought from SIKA Pakistan and they were used as low modulus fibers as reinforces in the making of IMDUC Cementitious matrix. The different properties of the fibers are shown below:-

Length (average) (mm)	Diameter (µm)	Yield Tex (g/1000m)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation (%)	Density (g/cm^3)
12	18	650	4000	210	2	0.91

Table 4.6 Properties of Poly propylene fibers

4.3.4 Why poly propylene is used

The poly propylene fibers generally added were 2% of the base materials. The reason for the addition of such number of fibers is the study of professor victor Li of Michigan University. He has taken this number of fibers for producing ECC. We had the aim in the start that we will go for the manufacturing of ECC using locally available materials and for that we had kept the study of Prof Victor Li at hand and selected the optimum quantity of fibers required for this.

4.4 Exclusion of coarse aggregate

Perhaps one of the most daunting tasks in the preparation of IMDUC was to exclude the coarse aggregate. The coarse aggregate makes up approximately 50-70 %

of the volume of concrete or any cementitious matrix. The coarse aggregate was not included in the preparation of IMDUC due to following reasons:-

- As at the start of our study we had focused on the production of ECC, so in going to that step the selection of fiber and the cementitious matrix had to be such that which favors the production of ECC. The literature available by Victor Li, as he is the pioneer in this field has not taken the coarse aggregate, as it tends to adversely inhibit the ductility as proposed by Victor Li.
- The second most important reason is "The effect of coarse aggregate is more pronounced as compared to the fine aggregate on the concrete matrix (its volume in concrete affects as it is present in large quantities) and hence the properties vary with the variation of coarse aggregate. So in order to establish the general principles and evaluate different fibers for the novel medium i.e. ECC, the coarse aggregate was not included in the cementitious matrix and hence the matrix was generally a mortar.

4.5 Matrix selection

In making of the cementitious matrix, the first step was the selection of the ratios of cement and sand. As per the study of Prof Victor Li the ratio of cement to sand was taken as 2 as or more than that in the production of ECC. But our first step was the selection of fiber then the production of ECC so we had kept the ratios within the range of ratios specified for ECC. Hence the selected ratio was nearer to those of ECC which had cementitious content double or more than that. But firstly to evaluate fibers we have used ordinary use mortar.

- The cement to sand ratio selected was **1:2**.
- With the induction of water reducer and that too high range poly carboxylate based, we have reduced the water cement ratio from **0.35 (initially)** to **0.28**. The matrix selected had water cement ratio of 0.28 with the super plasticizer dosage of 660ml/bag of cement used in the mix. This was calculated using the flow test performed using ASTM standards C 1437-01 and hence the water cement ratio was brought down from 0.35 to 0.28 at this water cement ratio , the flow obtained was 31 cm and hence it meant that it possessed enough

consistency for compaction, mixing and casting. The different calculations done have been shown in Appendix A.

- The super plasticizer dose as mentioned above is taken as 660 ml per bag of cement. It has been specified by the SIKA company log book on **SIKAMENT 512** super plasticizer.

4.6 Mixing procedure

The mixing was done using a **12L HOBART** mixer for a better consistency of mix and the following sequence was adopted:-

1. Super plasticizer was added to the water.
2. Cement and sand were mixed together and they were introduced into the mixer.
3. The fibers were gradually introduced into the cement – sand mix and they were mixed in dry form so that the fibers are more dispersed in the matrix.
4. Once the fibers are introduced in the mix, water was slowly added in it to make it into slurry. A small amount of water was kept aside.
5. To obtain a better consistency the material was mixed at three different speeds i.e. 3 minutes at each speed.
6. Finally after making sure that the constituents have mixed well the remaining water was added and mixed again for a few minutes.

4.7 Summary

This chapter basically includes the properties of the material and their general quantities and characteristics which have in any way have influenced the samples. Also it included different variables like exclusion of coarse aggregate into the mix. This chapter also includes the mixing procedures and the matrix selection.

Chapter 5

PREPARATION OF MOULDS, SAMPLES AND MCE IMPACT MACHINE

5.1 Preparation of samples

For the sample preparation and as per the testing of the basic engineering properties, three different types of castings were to be done. These three types of castings are:-

1. Cubes of dimension 2”x2”x2” for mortar’s compressive strength testing.
2. Prisms of dimensions 16”x4”x1.5” for mortars flexure strength testing and measuring deflections with loading (for toughness curve).
3. Plates of dimensions 6”x6”x0.5” for the impact test performed using MCE impact machine.

The samples which were rectangular prims were manufactured from the local market area and they were of stainless steel. These have helped us in castings of the concerned samples and hence the evaluation of flexural strength test, toughness curves and impact strength parameters is aided.

There were two mixes for each cast to ascertain whether the results obtained areconsistent or not, which were done as per ASTM standards. In each mix there were three specimens. Hence we had casted 3 cubes, 3 prisms and 3 plates for mix 1. Then

3 cubes, 3 prisms and 3 plates for mix 2 for each fiber matrix.

Figure 5.1 cast samples

5.1.1 Curing of samples

The specimen casted were left in the casts for a day and then put in water at room temperature at 25'C so that the curing period starts and hence they were cured for 28 days and subsequent tests were made at 7 day, 14 days and 28 days.

5.2Preparation of special molds

- Special molds were made for the prisms as our matrix did not include coarse aggregate and hence the volume required for the conventional casts for prisms required was more than the amount which could be mustered at a single time in the Hobart mixer. Also the prisms casted by the Victor Li for ECC were less deep as compared to conventional prisms of size 16"x4"x4". Hence the prisms were casted exclusively for the project of the size mentioned above i.e. **16"x4"x1.5".**

Figure 5.2 special mold 16”x4”x1.5”

- For the impact test, to prove the adequacy and to check the impact strength of samples, special plates were needed to be cast.. Hence an impact machine was designed which has been mentioned later in the report. For this, special plates were required and plates designed were of the size **6”x6”x0.5**”. These plates were tested for impact for evaluating IMDUC cementitious matrix

.

Figure 5.3 special mold 6”x6”x0.5”

5.3 MCE Impact machine design

During service life, a structure may be subjected to various environmental and loading conditions. However, in general, the properties determined under one set of conditions may not be used to determine the behaviour of the material under a different set of conditions. For example, it is well known that concrete is a strain rate sensitive material; therefore, its properties determined under conventional static loading cannot be used to predict the performance of concrete subjected to high strain rates. The problem is serious because these high strain rate loadings are associated with large amounts of energy imparted to the structure in a very short period of time, and concrete is a brittle material. Since the strain rate sensitivity of concrete prohibits the use of its statically determined properties in assessing its behaviour under dynamic conditions, high strain rate tests are required. Impact tests were carried out for this purpose. An instrumented drop weight impact machine is generally used.

Figure 5.4 MCE Impact machine

5.3.1 Why impact test is done

Impact test is basically done to see the response of a material to impact loadings. Impact loadings are frequent in structures which are made for machinery and other sensitive areas and houses industrial or military equipment. Therefore in order to produce an IMDUC, there was a strong need to check that the concerned material should possess excellent impact resisting qualities. And for that impact test was to be conducted on mortars reinforced with fibers. Impact strength evaluation was an important parameter to see how different fibers behave in a cementitious matrix and how they reinforce the matrix to cater for impact. The machine was developed to determine the resistance of cementitious matrix subjected to low velocity single- and repeated-impacts to failure, and to higher velocity small projectiles. These performance tests were used to evaluate the effects of reinforcing concrete with one or more of the following reinforcement types: carbon micro fibers, glass fibers and poly propylene fibers.

5.3.2 Grabbing the idea

Idea was taken from **drop weight impact machine** which had a mass of known quantity dropped from a known height till the specimen is fractured or cracked. In literature we have an IZOD impact test, CHARPY impact test and PENDULUM impact tester similar to IZOD.

But as the later are for metallic materials and for notched bars and with the absence of drop weight impact machine for impact strength evaluation for Cementitious matrix, an impact machine known as MCE impact machine was designed for the concerned test. It followed the same principle as drop weight impact machine i.e. a mass of known quantity dropped from a known height till the specimen is fractured or cracked.

5.3.3 Specifications of the machine

- The machine designed had the variable height as it could be increased up to 6 feet.

- The mass of known quantity which was 250 gm. was dropped from different heights and the drop height was calculated at that height when the sample cracked. This in turn led to the calculation of impact number. Formula for impact number is shown below :-

Impact number = drop height/ plate thickness.

- Plate thickness was kept constant as 0.6”, hence the only variable thing is drop height and hence the drop number or impact number depends upon it.

5.3.4 MCE impact machine geometry and design

- The machine was of cast iron and it composed of a rectangular base with an impression of the plate size on it.
- The angled iron bars were screwed with base at bottom and with the plate at top and the third iron angled bar had a scale to measure the drop height.
- The drop height could be made variable with the help of angled iron bars held at top of each other.
- The mass was of the shape of a plumb bob with pointy end and it was also made of iron.

5.4 Summary

This chapter explains the different testing which we will do on the project and their deliberate improvisations depending upon the scope of our project and it has included a self-improvised impact test using a machine designed especially for this purpose.

Chapter 6

MATERIAL TESTING AND RESULTS

In order to conduct tests on the IMDUC, for the improvement of basic engineering properties, the different specimen were taken and they were tested for:-

- Compression so that we may know how the fibers reinforce the cementitious matrix in compression.
- Flexural strength and toughness by plotting a curve between load and deflection using dial gauges.
- Impact number so that we may know how it behaves to an impact loading and hence knowing the effect of fiber onto it.

6.1 Compressive strength

Compressive strength of the mortar cubes of 2" was done using UTM. UTM is a Universal Testing Machine and it has the concerned mechanism to load the sample and to put load on the sample. The samples were loaded and the load was calculated at which the samples sheared or broke. The loading was in tons and the load was converted into stress by the following relation:-

Figure 6.1 Compressive strength of the mortar cubes of 2”

Stress = load*2240/4

(Where 4 is the surface area of loaded cube and hence stress is calculated by dividing the load with the area.)

6.1.1 Compressive strength results

MIX 1

Compressive strength performed had the following results through the formula calculated. They are shown below. These results are for mix 1 and then the comparative graph is shown which depicts how they improve the compressive strength with respect to other fibers.

fiber type	Mix	load(ton)	stress (7-day)	stress (14-day)	stress (28-day)
Mortar	1	4.9	2744	3156	3629
	1	5.5	3080	3542	4073
	1	5.8	3248	3735	4295
Average			3024	3478	3999
carbon microfiber	1	7.5	4200	4830	5555
	1	9	5040	5796	6665
	1	8.3	4648	5345	6147
Average			4629	5324	6122
percent increase					**53**
poly propylene	1	7.7	4312	4959	5703
	1	7.7	4312	4959	5703
	1	7	3920	4508	5184
Average			4181	4809	5530
percent increase					38
glass woven	1	5.8	3248	3735	4295
	1	6	3360	3864	4444
	1	6.2	3472	3993	4592
Average			3360	3864	4444
percent increase					**11**

Table 6.1 Compressive strength of Mix 1

The different values of fibers of 3 specimens of each fiber are shown below. With the help of this the comparison becomes more visible. It shows that high modulus fibers have contributed more to the increase in compressive strength as compared to other fibers.

Days	Mortar	Carbon microfiber	Poly propylene	Glass fibers
0	0	0	0	0
7	3024	4629	4181	3360
14	3478	5324	4809	3864
28	3999	6122	5530	4444

Table 6.2 7, 14 & 28 days strength of Mix 1

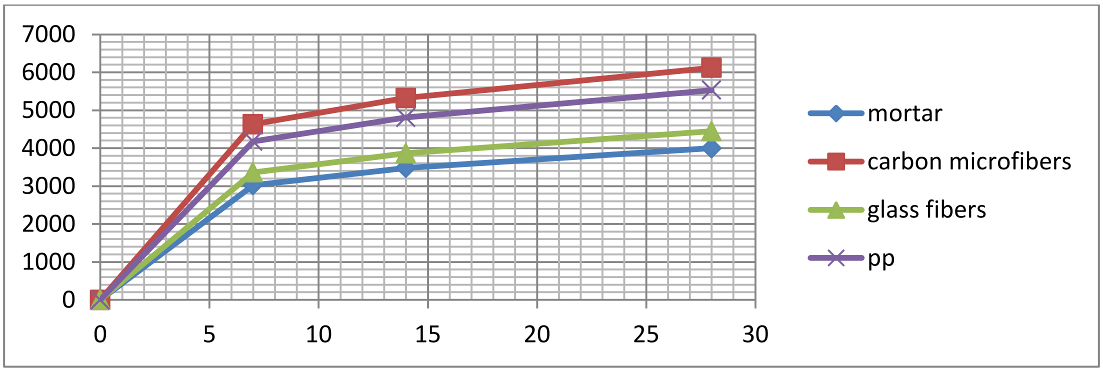

Figure 6.2 7, 14 & 28 days strength of Mix 1 plotted on graph

The bar chart showing the comparison also indicates that the compressive strength increase is more prominent in high modulus fibers i.e. carbon micro fibers.

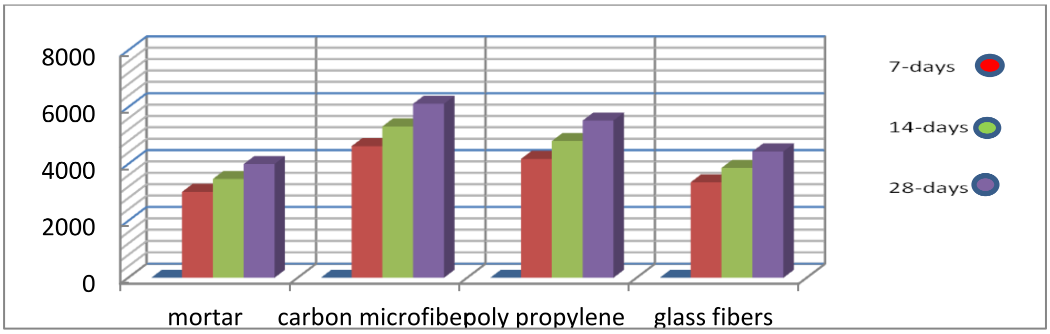

Figure 6.3 7, 14 & 28 days strength gain comparison of Mix 1

Mix 2

For the mix 2 the concerned tables and graphs are shown below:-

fiber type	mix	load(ton)	stress (7-day)	stress (14-day)	stress (28-day)
mortar	2	5.2	2912	3349	3851
	2	5.3	2968	3413	3925
	2	5.5	3080	3542	4073
Average			2987	3435	3950
carbon microfiber	2	6.9	3864	4444	5110
	2	7.6	4256	4894	5629
	2	8	4480	5152	5925
Average			4200	4830	5555
percent increase					**41**
glass woven	2	4.3	2408	2769	3185
	2	6.6	3696	4250	4888
	2	6.9	3864	4444	5110
Average			3323	3821	4394
percent increase					**11**
Polypropyle	2	6.2	3472	3993	4592
	2	6.3	3528	4057	4666
	2	5.9	3304	3800	4370
Average			3435	3950	4542
percent increase					**15**

Table 6.3 Compressive strength of Mix 2

The different values of fibers of each specimen are shown below. With the help of this the comparison becomes more visible. It shows that high modulus fibers have contributed more to the increase in compressive strength as compared to other fibers

days	mortar	carbon microfiber	polypropylene	glass woven
0	0	0	0	0
7	2987	4200	3435	3323
14	3435	4830	3950	3821
28	3950	5555	4542	4394

Table 6.4 7, 14 & 28 days strength of Mix 2

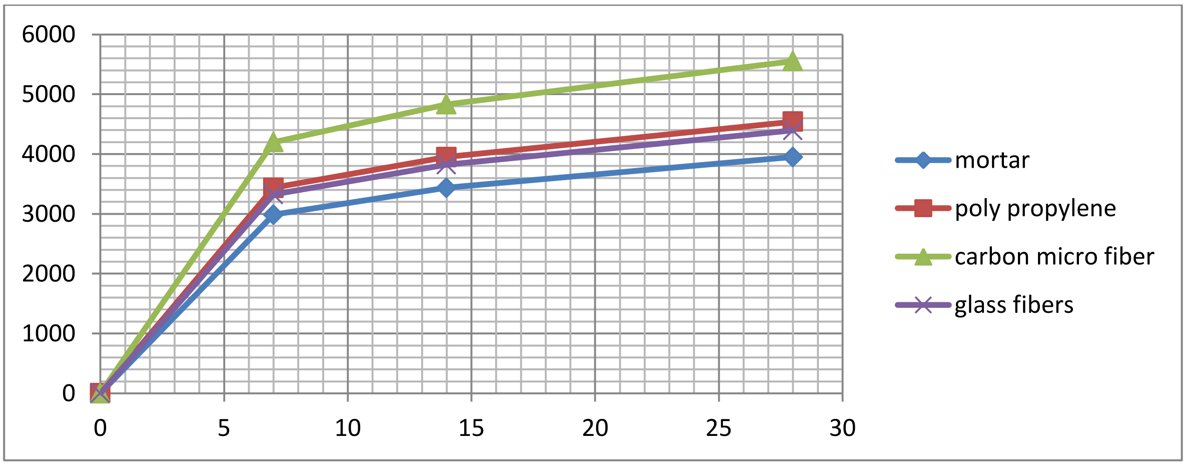

Figure 6.4 7, 14 & 28 days strength of Mix 2 plotted on graph

The bar chart showing the comparison also indicates that the compressive strength increase is more prominent in high modulus fibers i.e. carbon micro fibers. The graph shows the relation of the compressive property at 7, 14 and 28 days strength.

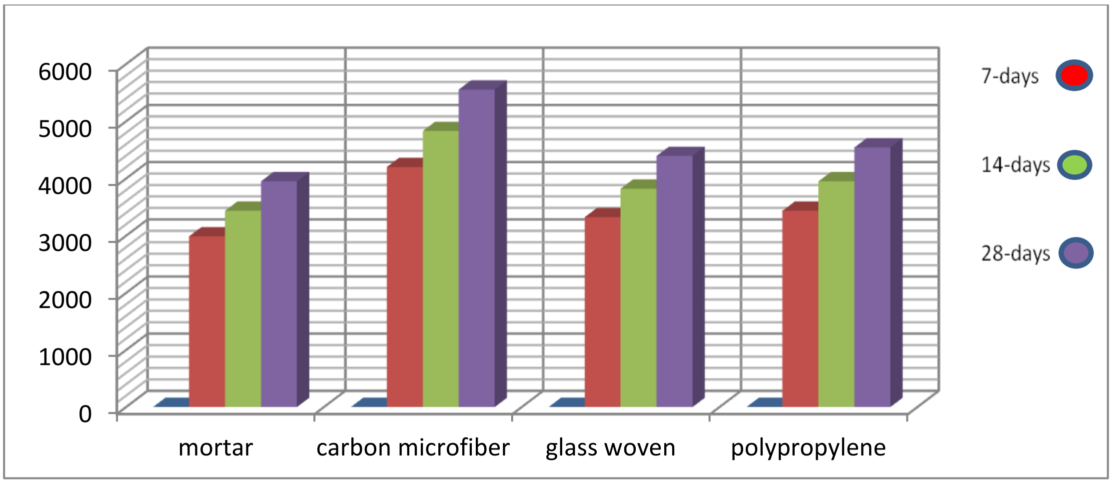

Figure 6.5 7, 14 & 28 days strength gain comparison of Mix 2

6.1.2 Cumulative comparison of compressive strength

Cumulative comparison of mix 1 and mix 2 is as shown below.

Mix 1

Days	Mortar	carbon microfiber	poly propylene	glass fibers
0	0	0	0	0
7	3024	4629	4181	3360
14	3478	5324	4809	3864
28	3999	6122	5530	4444

Table 6.5 7, 14 & 28 days of Fiber reinforced mortar of mix 1

Mix 2

Days	Mortar	carbon microfiber	polypropylene	glass woven
0	0	0	0	0
7	2987	4200	3435	3323
14	3435	4830	3950	3821
28	3950	5555	4542	4394

Table 6.6 7, 14 & 28 days of Fiber reinforced mortar of mix 2

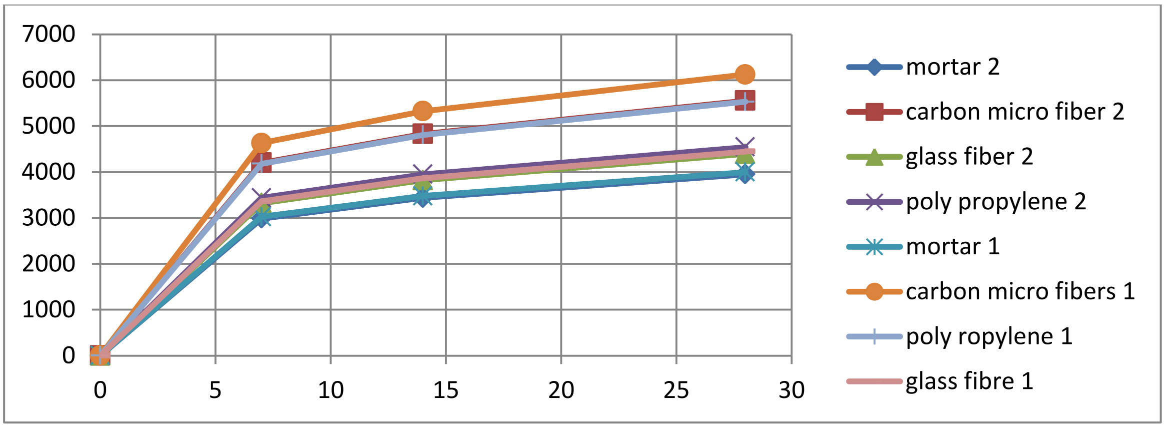

Figure 6.6 7, 14 & 28 days of Fiber reinforced mortar

6.2 Flexural strength test and toughness results:-

The flexure test was performed using a two point loading using UTM machine. The two point loading mechanism is shown in the figure. The test was done and the load at which the samples cracked is calculated. This load is then used to calculate the flexural strength. In calculating the load at cracking, the load was calculated at an interval of 0.02 ton and the deflections using the dial gauge are calculated at that specific load. These deflections and load is used to plot a load deflection curve also known as toughness curve.

Following formula was sued for calculating flexural strength

$$f = \frac{2PL}{3BD^2} * 2240$$

Where f = flexural strength in pounds per square inch

P = load in tons calculated from UTM

L = length of specimen in inches

B = width of specimen in inches

D = depth of specimen in inches

Mix 1 and mix 2

For the mix 1 and mix 2 the results are as shown. The table also shows the per cent increase in the flexural strength at the 28 days.

fiber type	**Mix**	**stress (7-day)**	**stress (14-day)**	**stress (28-day)**
mortar	1	584	637	796
	2	531	637	796
average		558	637	796
polypropylene	1	743	796	955
	2	743	796	1008
average		743	796	982
percent increase				23
glass woven	1	690	849	955
	2	637	796	903
average		663.5	823	929
percent increase				17
carbon micro	1	637	743	849
	2	637	690	743
average		637	717	796
per cent increase				0

Table 6.7 Cumulative results of compressive strength

The following table shows the increase in flexure strength of concrete at 7, 14 and 28 days. This table and the subsequent graph shown are for mix 1. The graph which is shown explains that poly propylene results in more increase in flexural strength of cementitious matrix as compared to other fibers.

Mix 1

	mix 1 for flexure			
days	**mortar**	**PP**	**GF**	**CMF**
0	0	0	0	0
7	584	743	690	637
14	637	796	849	743
28	796	955	955	849

Table 6.8 Increase of flexure strength of Mix 1

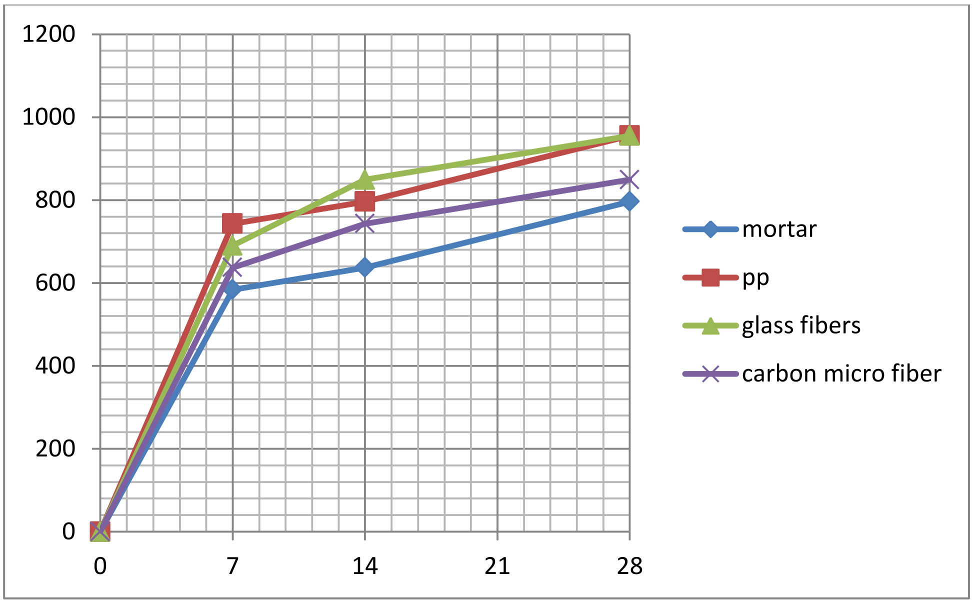

Figure 6.7 Increase of flexural strength plotted on graph of Mix 1

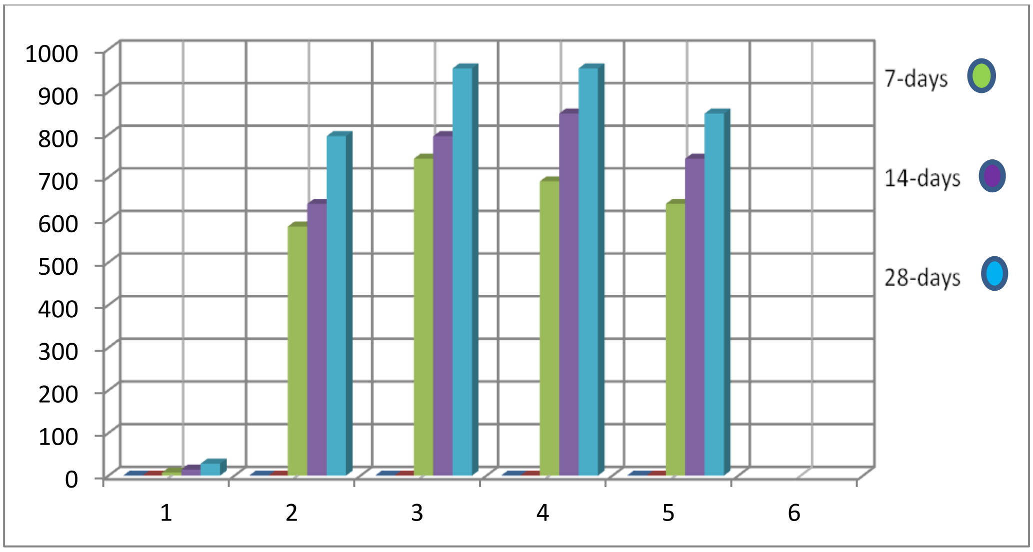

Figure 6.8 Increase of flexural strength plotted on bar graph

MIX 2

For mix 2 the flexural strength calculated is shown below. It also delineates the same fact and regresses to the conclusion that poly propylene fibers result in more increase in flexural strength as compared to high and medium modulus fibers.

	mix 2 for flexure			
days	**mortar**	**PP**	**GF**	**CMF**
0	0	0	0	0
7	531	743	637	637
14	637	796	796	690
28	796	1008	903	743

Table 6.9 Flexural strength of Mix 2

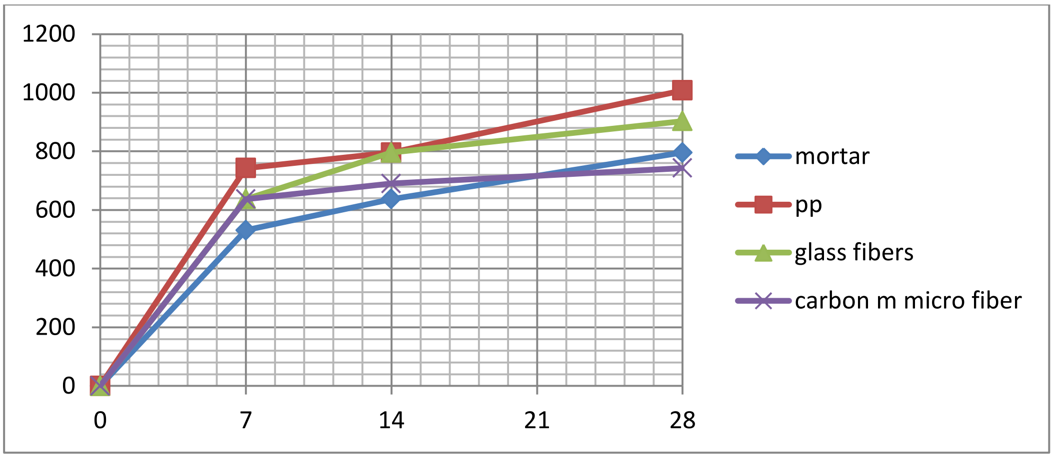

Figure 6.9 Flexural strength of Mix 2 plotted on graph

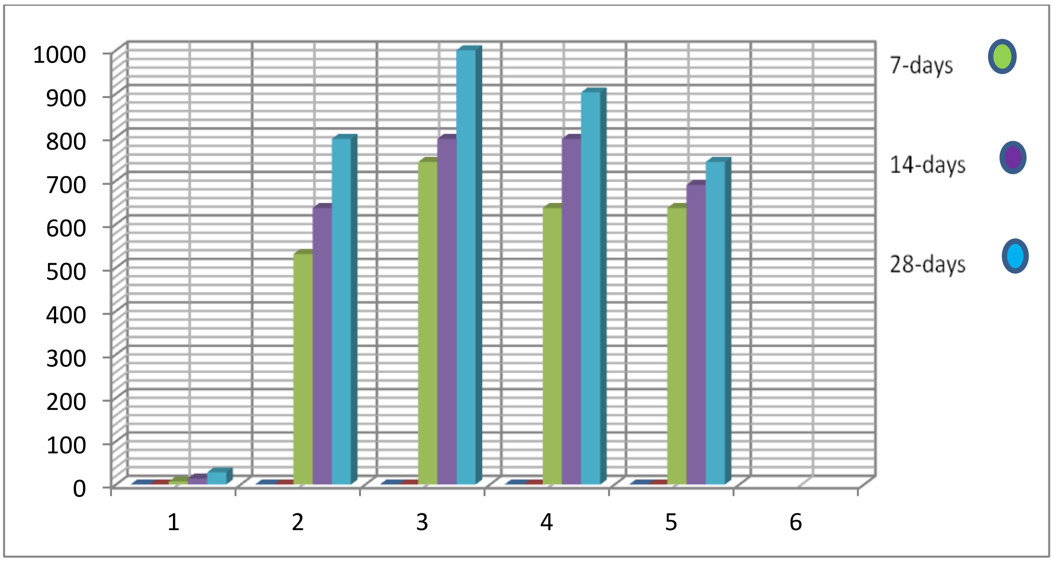

Figure 6.10 Increase in Flexural strength of Mix 2 plotted on bar graph

6.2.1 Cumulative comparison of flexural strength:-

The cumulative increase in the flexural strength is as shown. It is also the comparison of cumulative flexural strength of the cementitious matrix at 7, 14 and 28 days .

	mix 1					mix 2			
Days	**mortar**	**pp**	**glass fiber**	**carbon microfiber**	**days**	**mortar**	**Pp**	**glass fiber**	**carbon microfiber**
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
7	584	743	690	637	7	531	743	637	637
14	637	796	849	743	14	637	796	796	690
28	796	955	955	849	28	796	1008	903	743

Table 6.10 Cumulative comparison of Flexural strength

The graphs of the cumulative strength of flexure are shwn below. these graphs are for mix 1 and mix 2. The graphs explain the different roles of fibres and their trends.

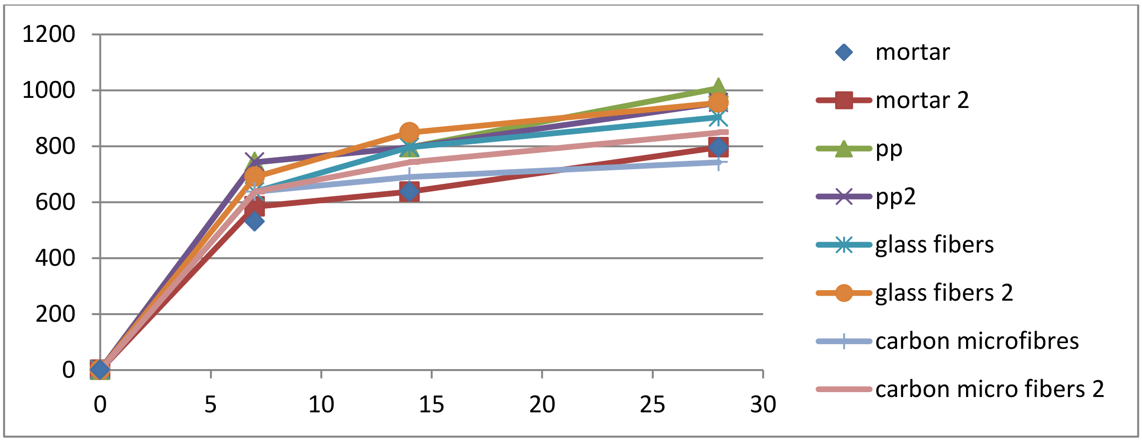

Figure 6.11 Cumulative comparison of Flexural strength plotted on graph

6.3 Toughness

The area under the load deflection curve is a very important parameter as it tells us about the toughness of a material. Toughness is basically the area under the curve of load and deflection plotted. It tells us how much a material is ductile under the load. The slope of the line calculated is basically the response which a material gets under load. When the slope is steep it shows that with the load the deflections observed are less and hence the material is less ductile. When slope is not steep it shows that with the load the deflections observed are more and the material is comparatively more ductile.

6.3.1 Procedure

In calculating toughness readings from UTM were taken at 0.02 ton interval and the subsequent deflections were measure using the dial gauges. The dial gauge readings were multiplied with least count and hence the load and deflection points were plotted and the line was drawn. As we had two mixes and three specimen at each 7, 14 and 28 days hence the 28 day specimen results of mix 1 and mix 2 along with their curve whose area under the curve is toughness are as shown below:-

For mix 1poly propylene

Mix 2		28 days		Poly propylene		
S/no.	**Load(tonnes)**	**Trial 1**	**Trial 2**	**Trial 3**	**Mean**	**Deflection**
1	0.02	6	7	5	6	0.06
2	0.04	9	8	7	8	0.08
3	0.06	11	9	10	10	0.1
4	0.08	12	10	11	11	0.11
5	0.1	15	11	13	13	0.13
6	0.12	18	12	15	15	0.15
7	0.14	19	14	15	16	0.16
8	0.16	21	15	17	17.6666666	0.17666666
9	0.18	24	16	20	20	0.2
10	0.2	26	18	23	22.33333333	0.223333333
11	0.22	28	20	24	24	0.24
12	0.24	31	22	29	27.33333333	0.273333333
13	0.26	33	27	32	30.66666667	0.306666667
14	0.28	38	37	38	37.66666667	0.376666667
15	0.3	42	43	43	42.6666666	0.42666666
16	0.32	45	45	46	45.3333333	0.45333333
17	0.34	49	48	48	48.3333333	0.48333333
18	0.36	54	54	53	53.6666666	0.53666666
19	0.38	57			57	0.57
	FLEXURE	955				

Table 6.11 Deflection reading for PP sample

The curve of load and deflection curve is shown below for mix 1

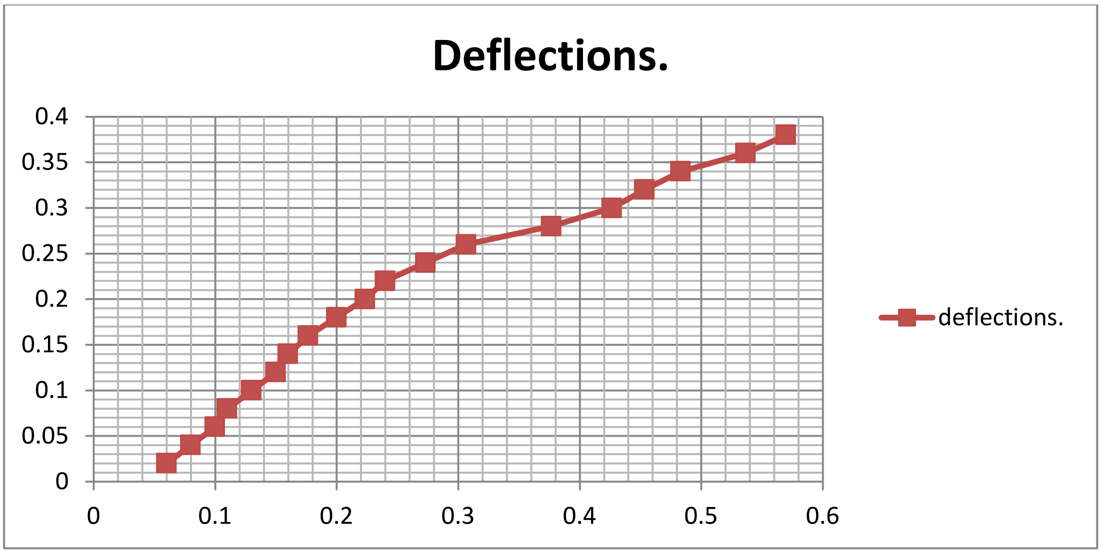

Figure 6.12 Load and deflection curve

For mix 2poly propylene

The results of specimen are shown below for 28 days strength:-

Mix 2		**28 days**		**Poly propylene**		
S/no.	**Load(tonnes)**	**Trial 1**	**Trial 2**	**Trial 3**	**Mean**	**Deflection**
1	0.02	7	6	5	6	0.06
2	0.04	9	9	8	8.6666667	0.0866667
3	0.06	10	10	10	10	0.1
4	0.08	12	11	11	11.333333	0.1133333
5	0.1	15	13	12	13.333333	0.1333333
6	0.12	17	14	14	15	0.15
7	0.14	20	14	14	16	0.16
8	0.16	21	17	16	18	0.18
9	0.18	24	18	19	20.333333	0.2033333
10	0.2	27	19	21	22.333333	0.2233333
11	0.22	29	21	22	24	0.24

12	0.24	30	25	28	27.666667	0.2766667
13	0.26	32	28	32	30.666667	0.3066667
14	0.28	37	37	39	37.666667	0.3766667
15	0.3	44	42	43	43	0.43
16	0.32	47	44	46	45.666667	0.4566667
17	0.34	50	49	47	48.666667	0.4866667
18	0.36	53	55	53	53.666667	0.5366667
19	0.38	58	57		57.5	0.575
Flexure		1008				

Table 6.12 Deflection reading for PP samples Mix 2

The curve of load and deflection for mix 2 at 28 days strength is shown below

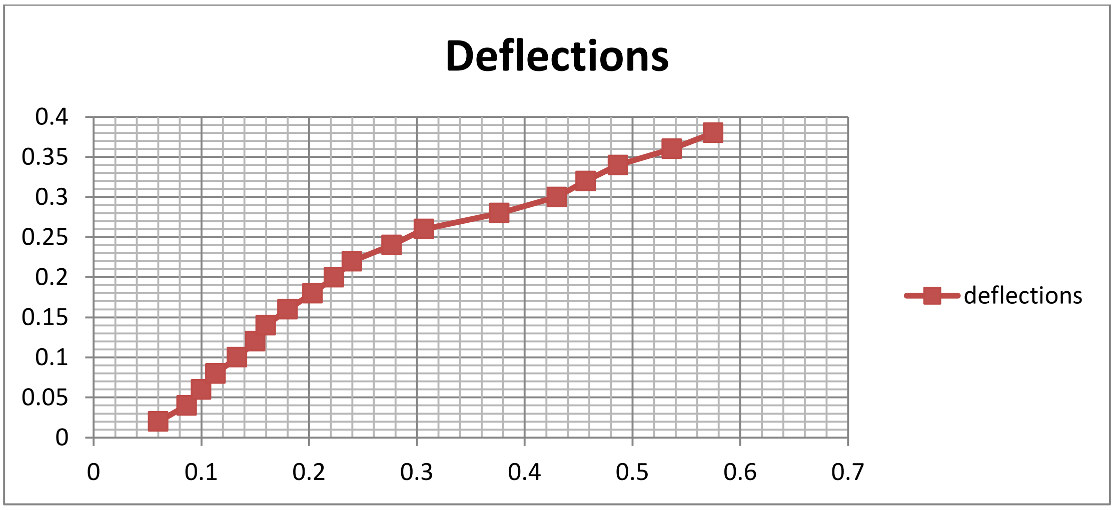

Figure 6.13 Load and deflection curve of Mix 2

6.3.2 Cumulative results

The cumulative comparison of the load and deflection curves of all the fibers and mortar are shown below for 28 days strength. These values are then plotted to get the idea of toughness (area under the load and deflection curve) given by the maximum fibers.

Mix 1

Mix 1	**Mortar**	**Column1**	**PP**	**Column2**	**CMF**	**Column3**	**GF**	**Column4**
28 days	**Load**	**Deflection**	**Load**	**Deflection**	**Load**	**Deflection**	**Load**	**Deflection**
	0.02	0.06	0.02	0.06	0.02	0.046666667	0.02	0.04
	0.04	0.09	0.04	0.08	0.04	0.063333333	0.04	0.06
	0.06	0.103333333	0.06	0.1	0.06	0.08	0.06	0.07
	0.08	0.126666667	0.08	0.11	0.08	0.09	0.08	0.08
	0.1	0.14	0.1	0.13	0.1	0.116666667	0.10	0.09
	0.12	0.156666667	0.12	0.15	0.12	0.15	0.12	0.12
	0.14	0.186666667	0.14	0.16	0.14	0.193333333	0.14	0.13
	0.16	0.206666667	0.16	0.176666667	0.16	0.226666667	0.16	0.17
	0.18	0.223333333	0.18	0.2	0.18	0.253333333	0.18	0.20
	0.2	0.236666667	0.2	0.223333333	0.2	0.29	0.20	0.23
	0.22	0.27	0.22	0.24	0.22	0.316666667	0.22	0.24
	0.24	0.293333333	0.24	0.273333333	0.24	0.346666667	0.24	0.27
	0.26	0.32	0.26	0.306666667	0.26	0.376666667	0.26	0.30
	0.28	0.333333333	0.28	0.376666667	0.28	0.416666667	0.28	0.32
	0.3	0.343333333	0.3	0.426666667	0.3	0.44	0.3	0.34
			0.32	0.453333333	0.32	0.48	0.32	0.36
			0.34	0.483333333			0.34	0.37
			0.36	0.536666667			0.36	0.38
			0.38	0.57				

Table 6.13 Cumulative comparison of the load and deflection

The table for the mix 2 is shown below. after that the curve showing its trend is also shown

	Mortar	**Column1**	**PP**	**Column2**	**CMF**	**Column3**	**GF**	**Column4**
Mix 2	**Load**	**Deflection**	**Load**	**Deflection**	**Load**	**Deflection**	**Load**	**Deflection**
28 days strength	0.02	0.0866666	0.02	0.06	0.02	0.073333333	0.02	0.04
	0.04	0.11	0.04	0.086666667	0.04	0.09	0.04	0.06
	0.06	0.1233333	0.06	0.1	0.06	0.1	0.06	0.07
	0.08	0.13	0.08	0.113333333	0.08	0.12	0.08	0.08
	0.1	0.1566666	0.1	0.133333333	0.1	0.1533333	0.10	0.09
	0.12	0.1833333	0.12	0.15	0.12	0.17333333	0.12	0.12
	0.14	0.21	0.14	0.16	0.14	0.19666666	0.14	0.13
	0.16	0.2333333	0.16	0.18	0.16	0.22	0.16	0.17
	0.18	0.25	0.18	0.203333333	0.18	0.24666666	0.18	0.20
	0.2	0.2833333	0.2	0.223333333	0.2	0.27666666	0.20	0.22
	0.22	0.32	0.22	0.24	0.22	0.31666666	0.22	0.25
	0.24	0.3333333	0.24	0.276666667	0.24	0.35333333	0.24	0.27
	0.26	0.35	0.26	0.306666667	0.26	0.38333333	0.26	0.30
	0.28	0.36	0.28	0.376666667	0.28	0.38333333	0.28	0.32
	0.3	0.3666666	0.3	0.43			0.3	0.34
			0.32	0.456666667			0.32	0.36
			0.34	0.486666667			0.34	0.38
			0.36	0.536666667			0.36	
			0.38	0.575				

Table 6.14 Load and deflection of Mix 2

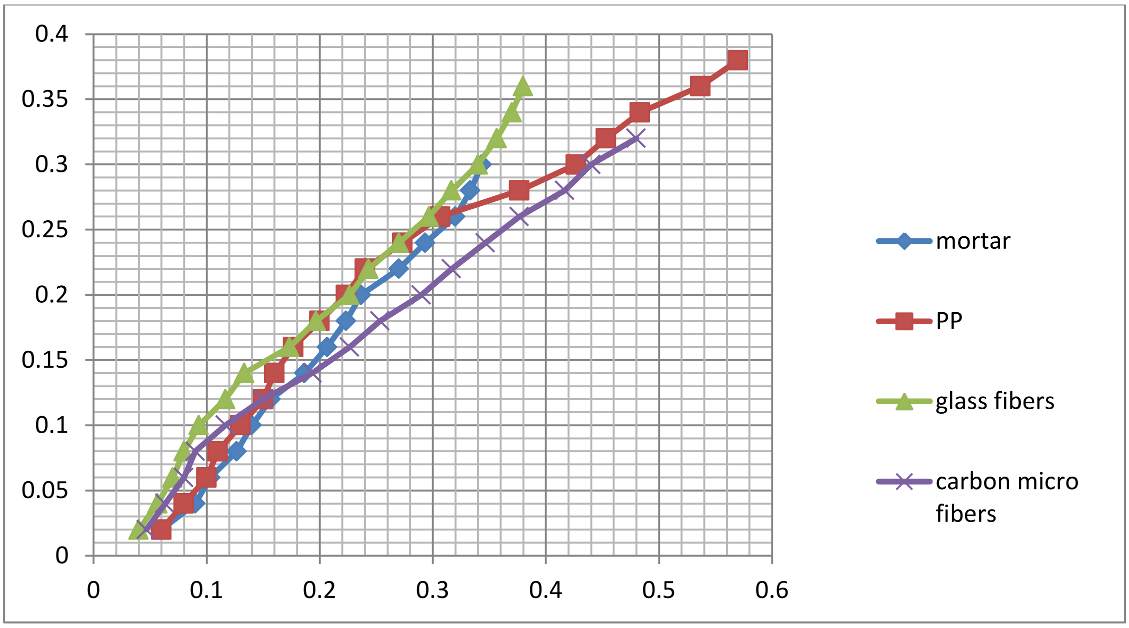

Figure 6.14 Load and deflection graph of mix 2

The graph clearly depicts that the load deflection curve of poly propylene has the maximum area under the curve. Hence the poly propylene fibers contribute more to the toughness then other fibers. This is the reason these fibers have been selected to produce IMDUC.

Mix 2

Similarly for mix 2 of all the mortars and mortars reinforced with fibers the values of load and the deflection are shown below.

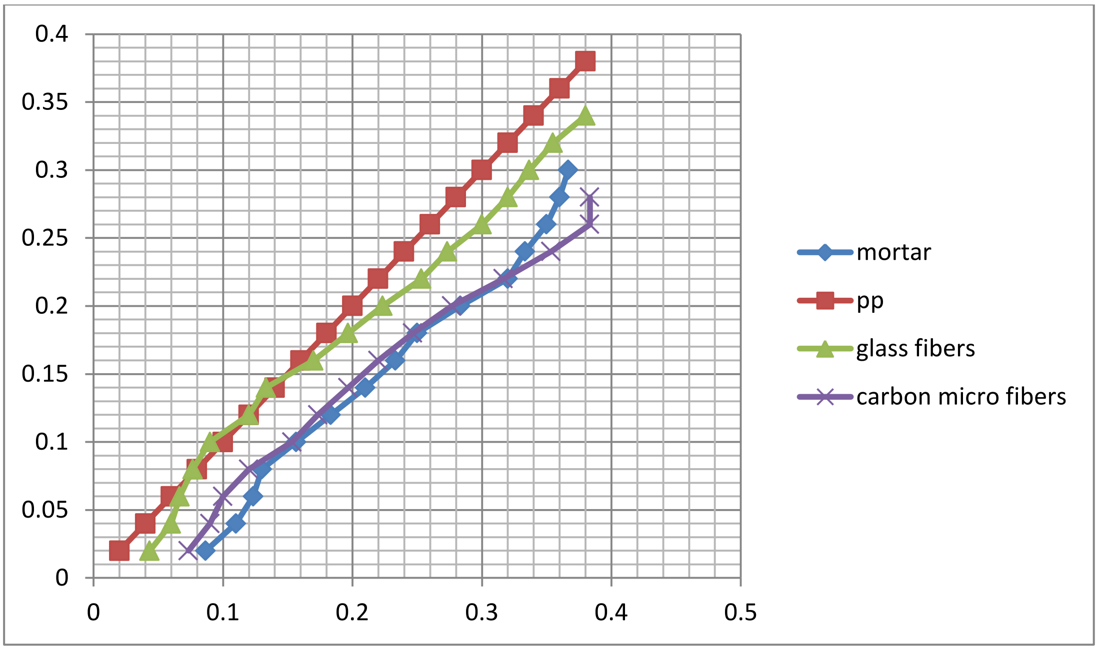

Figure 6.15 Load and deflection Curves

Their graph also clearly depicts that the load deflection curve of poly propylene has the maximum area under the curve. Hence the poly propylene fibers contribute more to the toughness then other fibers. This is the reason these fibers have been selected to produce IMDUC.

The results of the fibers of mix 1 and mix 2 in relation to toughness are shown below. In these two mixes the load- deflection curves of both the mixes are drawn. Both mixes include simple mortar and mortar reinforced with the three fibers i.e. carbon micro fibers, poly propylene fibers and glass woven fibers.

These curves are obtained by plotting the tabular data of 28 day strength of mix 1 and mix 2 simultaneously. The 28 day strength tests of mortars and mortars reinforced with fibers is given above. The curves are shown below:-

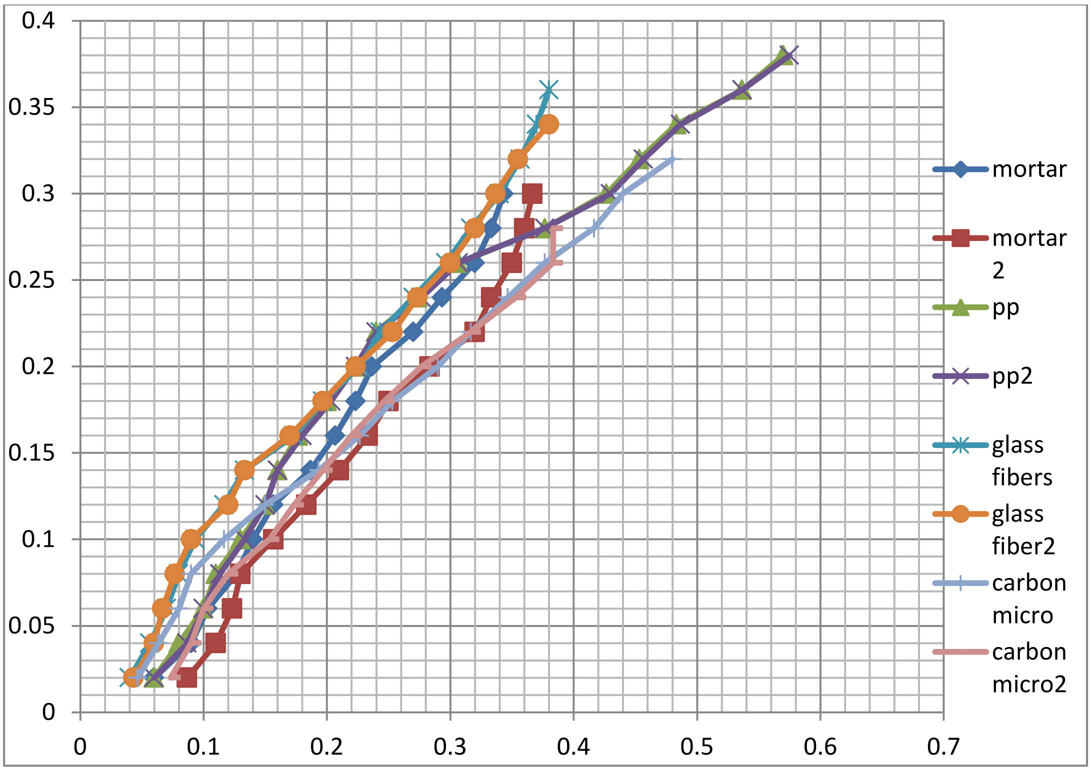

Figure 6.16 28-day strength load and deflection Curves

6.4 IMPACT TEST

6.4.1 Introduction

Impact test is basically done to see the response of a material to impact loadings. Impact loadings are frequent in structures which are made for, machinery and other sensitive areas and houses industrial or military equipment. Therefore in order to produce an IMDUC, there was a strong need to check that the concerned material should possess excellent impact qualities. And for that impact test was to be conducted on mortars reinforced with fibers.

Impact strength evaluation was an important parameter to see how different fibers behave in a cementitious matrix and how they reinforce the matrix to cater for impact. The machine was developed to determine the resistance of cementitious matrix subjected to low velocity single- and repeated-impact to failure, and to higher velocity small projectiles. These performance tests were used to evaluate the effects of reinforcing concrete with one or more of the following reinforcement types: carbon micro fibers, glass fibers and poly propylene fibers.

6.4.2 Impact mechanism

MCE Impact machine was used to calculate impact number of plates especially casted using molds made for this purpose. Idea was taken from **drop weight impact machine** which had a mass of known quantity dropped from a known height till the specimen is fractured or cracked. In literature we have an IZOD impact test, CHARPY impact test and PENDULUM impact tester similar to IZOD.

"It followed the same principle as drop weight impact machine i.e. a mass of known quantity dropped from a known height till the specimen is fractured or cracked."

Impact number = drop height/ plate thickness.

The mixes were two as casted before and each had three specimens at 28 days. The impact test was performed at each mix and the results are shown below of the impact numbers and blows at 28 day strength of plates.

It was observed that when the mortar was reinforced with fibers, the plates did not crack like normal mortar. It means that the brittleness has decreased and hence the plates got fractured with some initial cracks and then they were broken but still they kept the cement matrix intact. It never split into pieces.

\

6.4.3 Test Results

For mix 1

Matrix composition	**Mix**	**28 day drop height at fracture**	**28 day impact number**
Mortar	1	21	42
		15	30
		18	36
Average		18	36
Poly propylene	1	69	138
		78	156
		72	144
Average		73	146
Carbon microfiber	1	66	132
		72	144
		60	120
Average		66	132
Glass fibers	1	46	92
		40	80
		36	72
Average		41	81

Table 6.15 Impact strength (number) of Mix 1

The table shows the average impact number of each fiber reinforced mortar of mix 1

The bar graph showing the impact numbers comparison with mortar of mix 1 at 28 day strength is shown below.

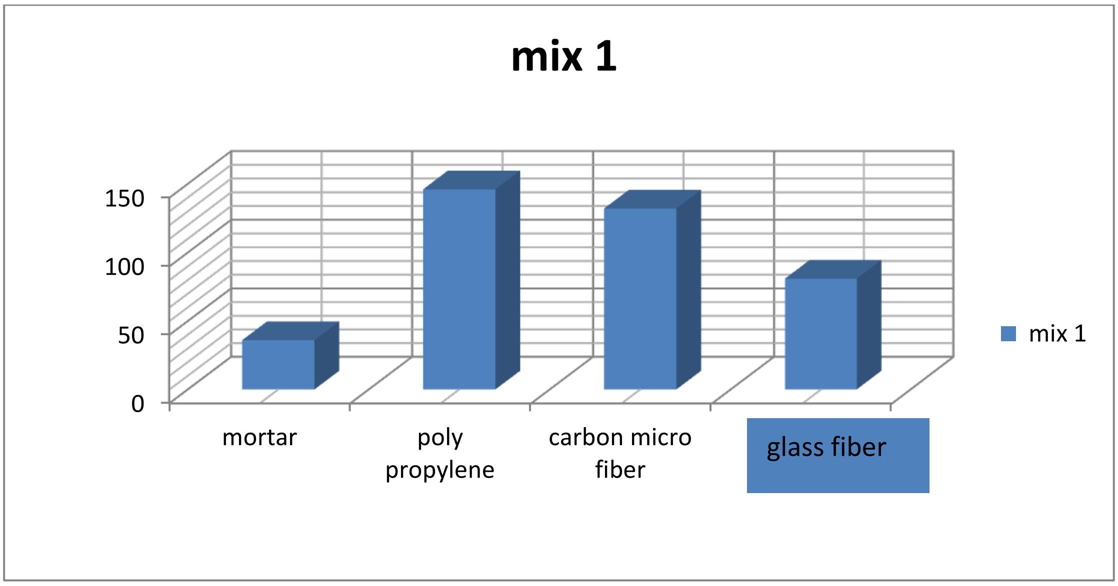

Figure 6.17 Impact strength of Mix 1 plotted on graph

The graph clearly shows that the poly propylene has reinforced the matrix to the best.

For mix 2

Matrix composition	Mix	28 day drop height at fracture	28 day impact number
Mortar	2	18	36
		21	42
		27	54
Average		22	44
Poly propylene	2	78	156

		72	144
		75	150
Average		75	150
Carbon microfiber	2	74	148
		66	132
		68	136
Average		69	139
Glass fibers	2	36	72
		42	84
		32	64
Average		37	73

Table 6.16 Impact strength (number) of Mix 2

The table shows the average impact number of each fiber reinforced mortar of **mix 2**

The bar graph showing the impact numbers comparison with mortar of mix 2 at 28 day strength are shown below.

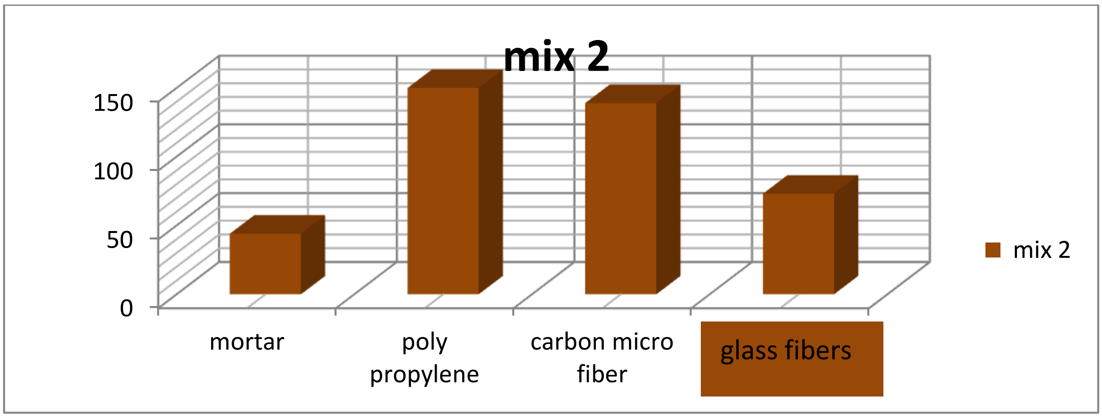

Figure 6.18 Impact strength of Mix 2 plotted on graph

The graph clearly shows that the poly propylene has reinforced the matrix to the best.

6.4.4 Cumulative result of both the mixes showing percentage increase of impact strength of normal cementitious matrix

The cumulative result of mix 1 and mix 2 is shown below. The table also shows the percentage increase in the impact number which is the response fibers have imparted to the cementitious matrix by reinforcing the matrix at the fiber –matrix level.

	AVG 28 day impact number		**Percent increase**	
Matrix composition	Mix 1	Mix 2	Mix 1	Mix 2
Mortar	36	44	0	0
Poly propylene	146	150	306	241
Carbon micro fiber	132	139	267	216
Glass fibers	81	73	56	66

Table 6.17 Cumulative Impact strength of Mix 1 & 2

In order to know how much per cent increase in impact has been observed as compared to cementitious matrix, the following bar charts have been drawn to ascertain that relation between mix 1 and mix 2 at 28 day strength for different fiber reinforcing matrices.

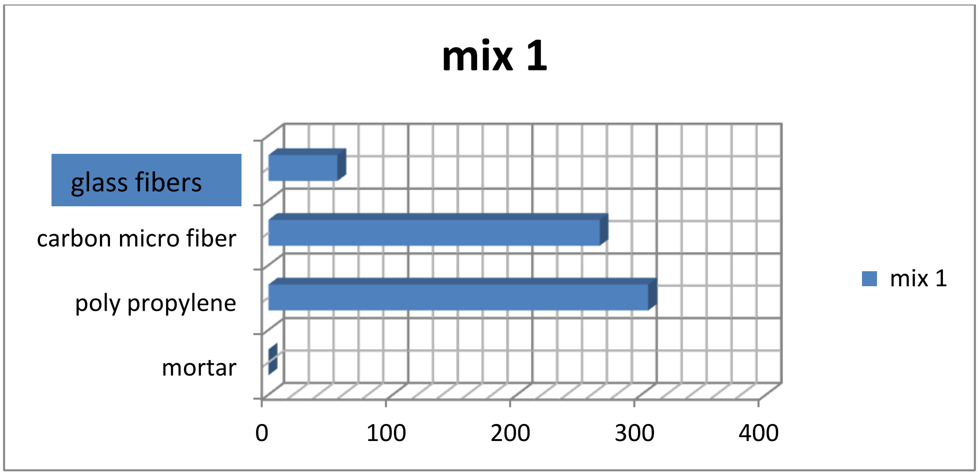

Figure 6.19 Impact strength of Mix 1 plotted on graph

Poly propylene fibers have shown the maximum increase of 306 %.

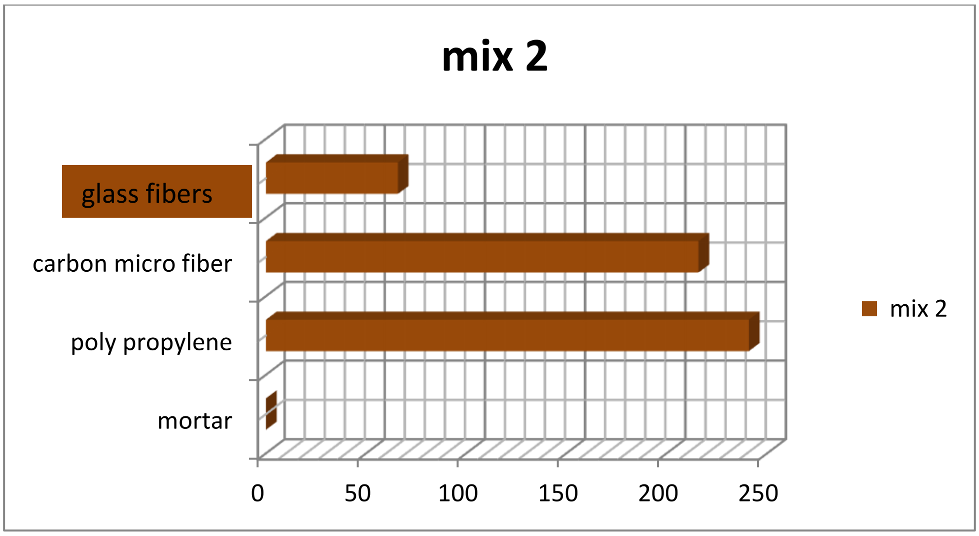

Figure 6.20 Impact strength of Mix 2 plotted on graph

Poly propylene fibers have shown the maximum increase of 241 %.

Result of both the mixes is shown below

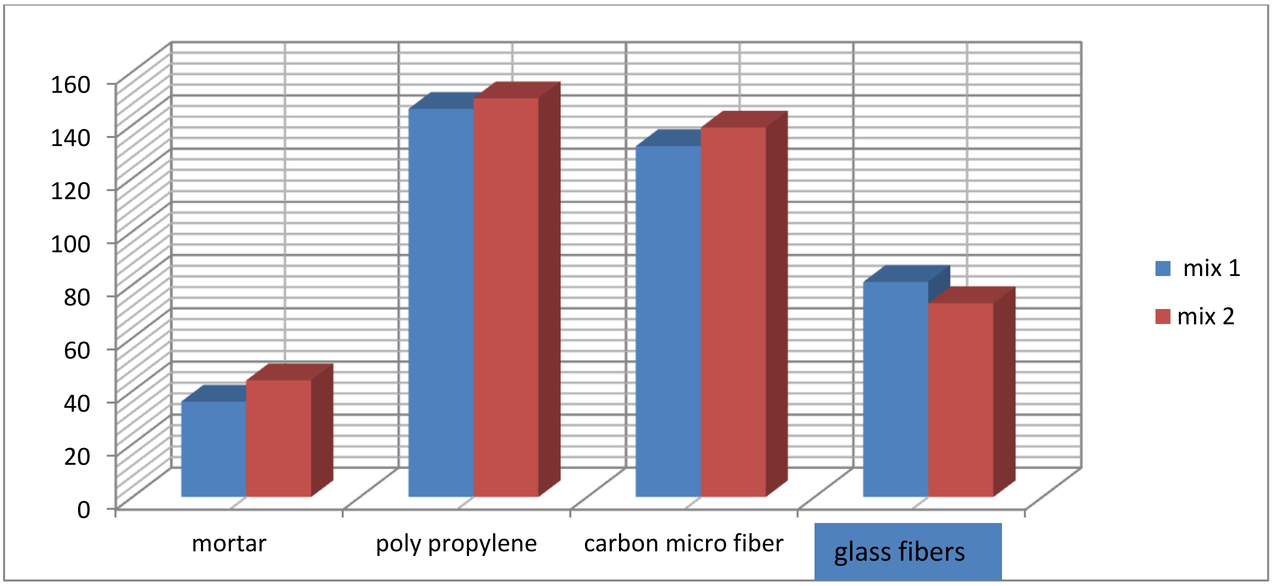

Figure 6.21 Impact strength of Mix1 & 2 plotted on bar graph

It's a comparison of both the mixes with each other at 28 days strength. The bar length show the required impact number.

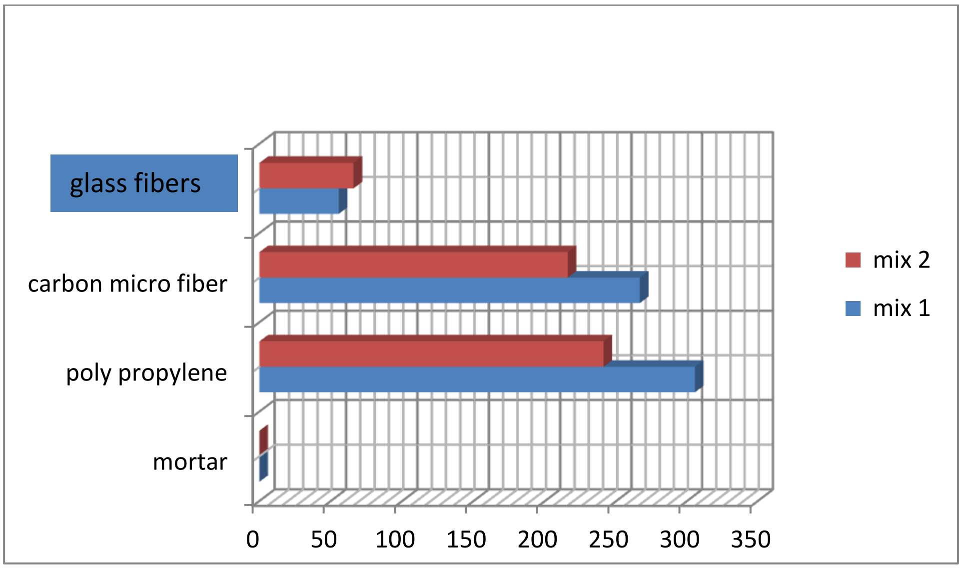

Figure 6.22 Comparison of Impact strength of Mix 1 & 2 plotted on bar graph

The cumulative result of the per cent increase of the impact number and in turn impact strength is shown below. It follows the same pattern in both the mixes in which poly propylene fibers have contributed more to the increase in the impact strength of cementitious matrix at 28 days strength of plates.

6.5 Summary

This chapter is basically the crux of the project. It includes the results of the experimental work which has been done according to the methodology and has been completed accordingly by using materials described in chapter 4 and by methods and experimentation techniques of chapter 5. The experimental work consists of trends which have been obtained and by them we have come to conclusion that poly propylene fibres are best suited for increasing ductility and imparting best impact resistant properties.

Chapter 7

SHIFTING TOWARDS ECC

7.1 Introduction

ECC stands for engineered cementitious composites.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 demands of a particular structure. ECC represents a unique group of short fiber reinforced cementitious composite materials with ultra-high ductility. ECC strain-hardens intension, accompanied by sequential development of multiple cracking after first cracking. The concept of ECC was given by Prof Victor Li of Michigan University. According to him tensile strain capacity exceeding 5% has been demonstrated on ECC materials reinforced with polyethylene (PE) and polyvinyl alcohol (PVA) fibers (Li1998; Li et al. 2002.)

The ECC is a type of high performance fiber reinforced Cementitious composite (HPFRCC) in which the coarse aggregate is not used hence it's a fiber based mortar and this has influenced our project and in producing this novel material. We have not included the coarse aggregate. It demands addition of small fibers at a specific percentage, which was taken as 2% by volume of the base materials added in production of it. These fibers are of the length of mm and 30-50- micron in diameter. Victor Li has produced this matrix by using PVA fibers. These fibers have known to cause strain hardening of the mix when loaded and hence result in increasing the strain capacity of concrete to 4-5%.

This extra-ordinary capability has led to the use of ECC in seismic resistant structural elements and repair and retrofit.

Unlike many common fiber/matrix composite systems, the bonding between fiber and a Cementitious matrix is too high and needs to be lowered. The oiling agent is demonstrated to be effective in counteracting the excessive chemical bond and slip-hardening effect for fibers in cementitious composites. Tensile strain-hardening with strain-capacity in excess of 4% can be achieved with fiber reinforced ECC composites provided that the interface is properly oiled up to content of 1.2% by weight of base material.

In the preparation of novel material ECC, the fibers should be selected and the trial mix be made so that they may be used handy in the preparation of mixes. Due to the prevailing security situation and the military involvement in the war against terrorism, we do need structures with adequate ductility to reduce the effect of impacts from blast and concerned damages. Hence it synergizes with our approach in obtaining more resistant structures for the collective safety approach.

7.2 Matrix materials' parameters evaluation

7.2.1 Cement sand ratio adjustment

Cement sand ratio which we had used in the IMDUC Cementitious matrix was 1:2. But as according to the literature of Prof Victor Li (2001) and (2003), the cement sand ratio used was 2:1. Hence he has used double the amount of cement as compared to sand. As we had in mind that we will focus our research approach from IMDUC to producing ECC using the fibers which had been used in preparing IMDUC and tailoring it to meet specific needs and producing a locally made ECC.

Thus the cement sand ratio was revaluated as 2:1 and the castings were done which are shown in appendix A. These castings were done to see what can be the steps in leading to produce ECC or bendable cementitious matrix.

7.2.2 Other materials' parameters evaluation

After adjusting the cement sand ratios according to the literature, rest of the parameters were kept same.

- water cement ratio was kept as 0.28

- Dosage of super plasticizer was kept same as 660 ml/ bag as mentioned on the SICA guidelines.
- Sand used was of same size, as we had selected in producing IMDUC. That was specially kept in mind when the fine aggregate was selected for producing IMDUC.
- Water used was same as the one used for producing IMDUC.
- The fiber selected was the same which had been selected out of carbon micro fibers, glass fibers and poly propylene fibers for producing IMDUC. As it had resulted in increase in ductility and impact resisting strength of mortar, **poly propylene** fibers were used for making this novel material.

7.3 Oiling agent

As mentioned before that the oiling agent was necessary to cause the crack to slip, and when the crack will slip only then the stresses inside it will be redistributed and those cracks will not get major and hence will not cause cracking. Strain hardening of the ECC is a result of oiling of the fibers with a specific amount and using it. In literature Prof Victor Li states that oiling agent is of the order of (0.8-1.2%) of the base material. Hence, selecting a viable percentage of oil that is 1.0% of base material, for producing ECC. The oiling agents are to be selected depending upon the fact that they should be abundantly available in Pakistan because the ECC is locally made matrix. The three different oiling agents tried for the purpose are

- Machine oil.
- Kerosene oil
- Mustard oil.

In the literature, only the oiling agent is mentioned, not the specific oiling agent or its formula. Prof Victor Li has not mentioned in any of his literature. The oiling agent is to be selected, as it helps in the strain hardening of the mix. Thus suitable testing is to be done to ascertain the best mix. The oiling agent calculations and subsequent addition in the cementitious matrix are shown in APPENDIX B.

7.3.1 Castings of specimen and selecting the suitable oiling agent

Castings were done with all oiling agents and then selecting the oiling agent which gives us the best results of ductility. As ductility is related to bending, hence the specific oil was then selected and castings were done with it to see how it effects the Cementitious matrix.

Specimens were casted using the same moulds used for IMDUC and the two point loading tests were performed on it at 28 days strength. The deflections were measured with the help of dial gauges whose least count is 0.01 mm. It is multiplied with the dial gauge reading to get the deflections at a specific load. These values are then used to calculate toughness by plotting load and deflection curves and observing the area under the curves.

7.3.2 Experimental results

The specimens were casted with poly propylene fibers and the oiling agents which are kerosene oil, machine oil and mustard oil is put on fibers. The result of the load and deflection curves and the increase in flexural strength is as shown below

Machine oil			Kerosene oil		Mustard oil	
	LOAD	**Deflection**	**LOAD**	**Deflection**	**LOAD**	**Deflection**
1	0.02	0.06	0.02	0.06	0.02	0.06
2	0.04	0.08	0.04	0.06666667	0.04	0.08
3	0.06	0.1	0.06	0.1	0.06	0.1
4	0.08	0.11	0.08	0.11	0.08	0.11
5	0.1	0.13	0.1	0.13	0.1	0.13
6	0.12	0.15	0.12	0.15	0.12	0.15

7	0.14	0.16	0.14	0.18	0.14	0.16
8	0.16	0.17666667	0.16	0.19666667	0.16	0.17666667
9	0.18	0.2	0.18	0.21	0.18	0.2
10	0.2	0.22333333	0.2	0.23	0.2	0.22333333
11	0.22	0.24	0.22	0.24	0.22	0.24
12	0.24	0.27333333	0.24	0.29333333	0.24	0.27333333
13	0.26	0.30666667	0.26	0.32333333	0.26	0.30666667
14	0.28	0.37666667	0.28	0.37666667	0.28	0.37666667
15	0.3	0.42666667	0.3	0.42666667	0.3	0.42666667
16	0.32	0.45333333	0.32	0.45333333	0.32	0.45333333
17	0.34	0.48333333	0.34	0.48333333	0.34	0.48333333
18	0.36	0.53666667	0.36	0.52666667	0.36	0.53666667
19	0.38	0.57	0.38	0.57	0.38	0.57
20	0.4	0.58	0.4	0.63	0.4	0.63
21	0.42	0.62333333	0.42	0.64666667	0.42	0.65
22	0.44	0.69666667			0.44	0.70333333
23	0.46	0.73333333			0.46	0.75666667
24					0.48	0.83
25					0.5	0.90333333
Flexural strength	**1221**		**1115**		**1327**	

Table 7.1 Load and deflection readings of 3 oils

This graph shows the average deflections of three specimens of each matrix at 28 days strength loaded with fibers oiled with different oiling agents which is mentioned at top in the table.

The table clearly shows that mustard oil results in more increase in flexural strength of the mix as compared to other oiling agents

The following graph shows the load deflection curves of all the specimens shown in the table at 28 days strength, reinforced with different oiling agents.

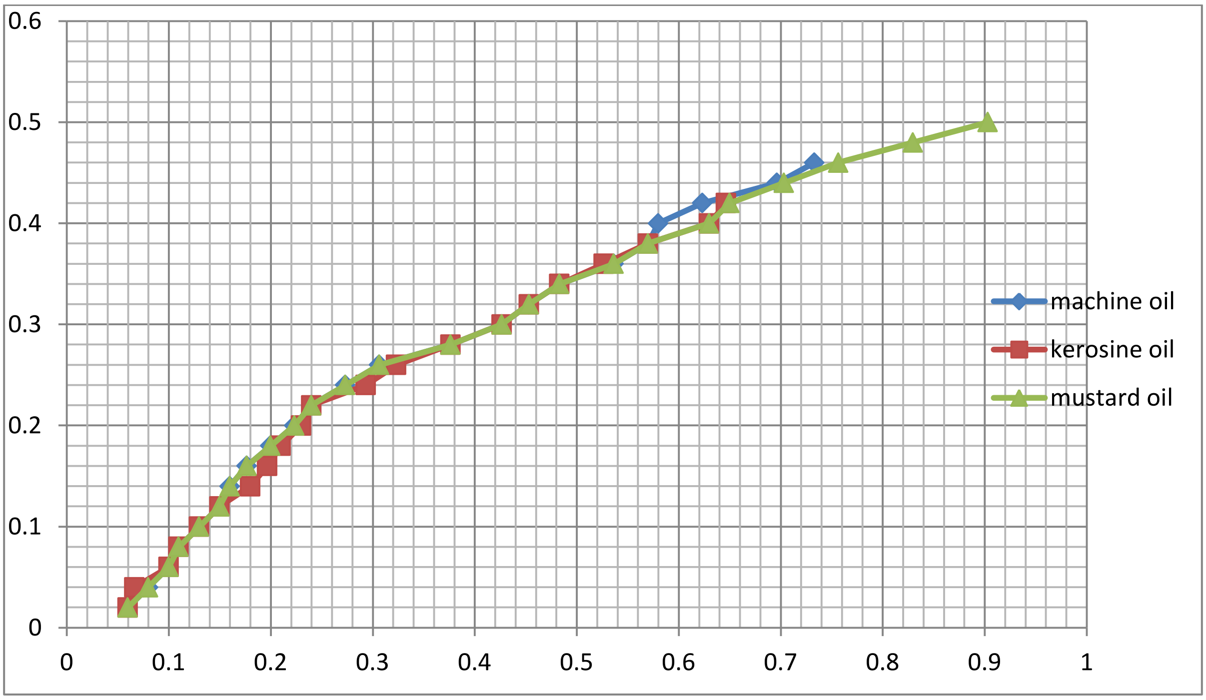

Figure 7.1 Load and deflection curve of 3 oils

The graph clearly shows that the mortar reinforced with poly propylene fibers with mustard oil coating had shown the best results where the matrix was more ductile then the other matrices. Hence it shows that the mustard oil can be used as the choice of oiling agent on the fibers for producing ECC.

7.3.3 Revising the oil and fibers

After selecting the suitable oiling agent which is available abundantly, we led to another test to increase ductility by differing the amount of fibers and oil each time to see which gives us the best result. The test sequence follows the general pattern:-

- Keeping the fibers same and doubling the quantity of oil.(Said as mix 1).
- Keeping the oil same and making the fibers half.(Said as mix 2).

Using first testing method i.e. keeping the fibers same and doubling the quantity of oil (said as mix 1). After that keeping the oil same and making the fibers half (said as mix 2). The following table shows the load deflection curve of the specimen with the mix 1 and mix 2.

Mix 1		**Mix 2**	
Load(tonnes)	**Deflection**	**Load(tonnes)**	**Deflection**
0.02	0.06	0.02	0.06
0.04	0.08	0.04	0.06666667
0.06	0.1	0.06	0.1
0.08	0.11	0.08	0.11
0.1	0.13	0.1	0.13
0.12	0.15	0.12	0.15
0.14	0.16	0.14	0.18
0.16	0.17666667	0.16	0.19666667
0.18	0.2	0.18	0.21
0.2	0.22333333	0.2	0.23
0.22	0.24	0.22	0.24
0.24	0.27333333	0.24	0.29333333
0.26	0.30666667	0.26	0.32333333
0.28	0.37666667	0.28	0.37666667
0.3	0.42666667	0.3	0.42666667
0.32	0.45333333	0.32	0.45333333
0.34	0.48333333	0.34	0.48333333
0.36	0.53666667	0.36	0.52666667
0.38	0.57		

0.4	0.63	
0.42	0.65	
0.44	0.70333333	
0.46	0.75666667	
0.48	0.83	
0.5	0.90333333	
0.52	0.99333333	
Flexural strength	**1380**	**956**

Table 7.2 Load and deflection values of Mix 1 & 2

The following graph shows the load deflection curves of all the averages of specimens shown in the table at 28 days strength, of mix 1 and mix 2. The mix 1 and mix 2 are specified above.

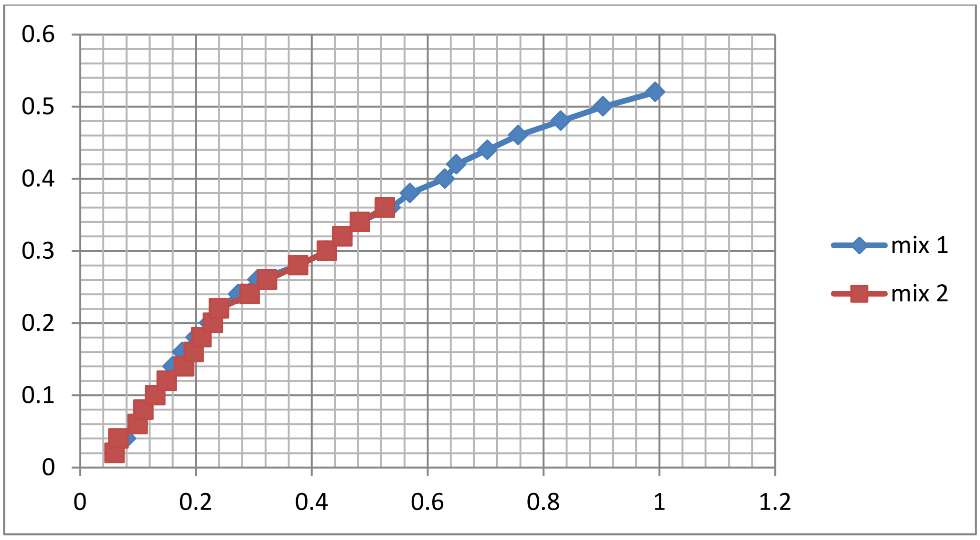

Figure 7.2 Load and deflection curve of Mix 1 & 2

The graph clearly shows that the mix 1 shows more ductility and toughness. **So keeping the fibers same and doubling the quantity of oil actually makes us closer in achieving ductility and hence making us a step closer in achieving bendable concrete or ECC.**

7.4 Conclusions from the oiling tests

But still when the two point loading test was performed on the mix the cracking pattern observed was a V shaped cracking pattern. It did not bend like the traditional ECC designed by Prof Victor Li. So we came to the conclusion that the fibers are not slipping the crack so it's converting into major cracks and hence causing the V-shaped failure. The reason for not slipping is that the fibers are not adequately oiled.

As Prof Victor Li has mentioned that the oiling is of Nano meter thickness on each fiber, and in our case we are not able to segregate the fibers and hence oiling of each fiber is almost impossible. Even oiling of more than 70% of fibers is impossible. So we ended our project with this conclusion that due to inadequate oiling technique we felt short of producing a locally made ECC.

Chapter 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Summary

In our project we had selected a cementitious matrix and selected fibers in each category of low medium and high modulus fibers which were poly propylene, glass and carbon micro fibers. We tested the fibers by reinforcing the cementitious matrix and testing the matrix for basic engineering properties and in doing so we prepared the cementitious matrix known as IMDUC. The IMDUC was more resistant to impact loadings and was more ductile and hence the selection of fiber leading to IMDUC shifted our focus towards ECC. The ECC is a very novel material as developed by prof Victor Li and it is simply a bendable Cementitious matrix capable of taking very high loads. The process of making ECC involves selecting a suitable oiling agent so that the micro cracks developed slip and don't crack the matrix and matrix bends like a ductile material. The tests performed on oil led to the selection of a suitable oiling agent and then tests were made to select oiling quantities to produce an ECC. The problem encountered in the process was the inadequate oiling of the fibers and that led to the cracking of matrix and repeated trials resulted in increase in ductility but not in pure ECC.

8.2 Conclusions

- IMDUC Cementitious matrix is basically designed with an idea of producing ECC. According to the study of Prof Victor Li, the coarse aggregate was excluded from the matrix in preparing the novel material ECC. Hence it is a mortar based matrix. The aggregate was excluded from the matrix to reduce the number of intangibles which can affect the ductility of the matrix and observe the pure response of matrix when different oiled fibers are added. He has excluded it as well because the effect of coarse aggregate is more pronounced as compared to fine aggregate as it takes up around 70% of concrete volume and any difference will cause significant difference in concrete properties. So in order to establish a general behavior of the matrix the coarse aggregate was excluded.
- In the testing of the basic engineering properties, the compressive strength was found to be more for the cementitious matrix reinforced with high modulus carbon poly acrylonitrile (PAN) fibers. The increase in compressive strength was found to be in the range of **41%- 51%** when compared with the normal matrix. The subsequent increase in compressive strength due to poly propylene fibers which are low modulus fibers is **15%-38%.** The increase in the compressive strength of the matrix due to glass woven medium modulus fibers is approximately **11%** in both the mixes.

- In the test of flexural strength, the matrix reinforced with poly propylene fibers showed maximum increase in the strength as compared to normal mortar, it was **23%** approximately. The subsequent increase in the flexural strength due to glass woven fibers is **17%** and due to high modulus fibers carbon microfibers is very minimal. K-12s (PAN) does not improve its flexural strength considerably

- In the measuring of the toughness of the material (area under the load and deflection curve), the poly propylene fibers had shown the maximum area as per the graphs. Hence it was concluded that they contribute the maximum in the improvement of toughness parameter of the matrix.
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- In comparing the impact strength parameters using the impact numbers calculated form the number of drops of a known mass from a known height using the MCE impact machine, the poly propylene fibers are found to impart the maximum strength in impact scenarios. By using poly propylene fibers the impact load resistance increased by **250%-300%** of the normal mortar matrix. The high modulus carbon microfibers have contributed an increase of **210%-260%** in the impact strength scenarios whereas medium modulus glass woven fibers have contributed only about **50%-60%** increase in the impact strength scenarios.

- Due to its excellent reinforcing properties in impact strength, flexural strength and toughness, poly propylene fibers were selected to produce IMDUC Cementitious matrix. It caused the maximum ductility when the load and deflection curves were made and hence it was selected as the choice of fiber for the IMDUC cementitious matrix.

- In shifting our focus from IMDUC to ECC (Engineering Cementitious Composites) for the development of novel material. The fiber selected was poly propylene due to its excellent enhancement of ductility as compared to other fibers and it led to pronounced increase in flexural strength.

- The next step was the selection of oiling agent to slip the cracks. For this three different oils tested in the process were kerosene oil, machine oil and mustard oil. Out of three oiling agents the mustard oil has shown the best and conforming results as it resulted in the increase in the load and deflection curve and subsequently in the flexural strength. So the oiling agent selected was mustard oil and then different trials were made to ascertain its rightful quantity.

- The next test included the two step process; reducing the fibers to half and keeping the oiling agent same and second step keeping the fibers same and doubling the oiling quantity. Keeping the fibers same and doubling the oiling quantity resulted in a more enhanced load and deflection curve. So form it we concluded that in preparing ECC the main hurdle was in oiling the fibers adequately. Our fibers had been clustered together and due to this it was not possible to oil them adequately (approximately only three fourth of the fibers were oiled up). Hence if adequate oiling techniques were available then the more enhancements in load deflection curve would have led to the production of novel material ECC using local available materials.

8.3 Recommendations

- The fibers selected for producing IMDUC and in turn producing ECC should be selected based upon the approach that how they behave in a matrix at micro level. Hence micro-mechanics properties should be studied so that a better understanding of the interaction of fibers with the cementitious matrix is observed.
- A more reliable and heavy duty impact test apparatus be developed or purchased as per the ASTM or British standards by the College for future Research.
- There is no two point loading mechanism for flexural strength calculation. Hence proper mechanism is made and the concerned apparatus be purchased for the purpose.
- The load and deflection curves be made using LVDTs. They help in plotting curves at various points of the specimen by noting the deflections at various points and hence better variability in the matrix due to application of load is observed
- The oiling agents selected should be adequate so that the matrix bends. For this all the fibers are needed to be oiled up adequately. For this a mechanism should be developed which lets the fibers to disperse to a considerable extent and then oiling agent be sprayed to achieve better results.
- In the preparation of novel material ECC, the fibers should be selected and the trial mix be made so that they may be used handy in the preparation of mixes. Due to the prevailing security situation and the military involvement in the war against terrorism, we do need structures with adequate ductility to reduce the effect of impacts from blast and concerned damages. Hence it synergizes with our approach in obtaining more resistant structures for the required purpose.

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