CHAPTER 1

INTRODUCTION

1.1 GENERAL

Modern Structural Engineering tends to progress towards more economical structures through gradually improved methods of design and use of higher strength materials, such developments are particularly important in the field of reinforced concrete. The limiting features of ordinary reinforced concrete have been largely overcome by the development of Ferrocement. Ferrocement is a type of thin reinforced concrete section commonly constructed with hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size weld mesh. In its role as a thin reinforced concrete product and as a laminated cement-based composite, the ferrocement has found its place in numerous applications both in new structures and in repair and rehabilitation of existing structures.

Compared with the conventional reinforced concrete, ferrocement is reinforced in two directions; therefore, it has homogenous-isotropic properties in two directions. Benefiting from its usual high reinforcement ratio, ferrocement generally has a high tensile strength and a high modulus of rupture. In addition, since the specific surface of reinforcement in ferrocement is one to two orders of magnitude higher than that of reinforced concrete, larger bond forces develop with the matrix resulting in average crack spacing and width more than one order of magnitude smaller than in conventional reinforced concrete (Shah and Naaman 1997, Guerra et al 1978). Other
appealing features of ferrocement include ease of prefabrication and low cost in maintenance and repair. Based on the abovementioned advantages, the typical applications of ferrocement are water tanks, boats, housing wall panel, roof, formwork and sunscreen (Nimityongskul et al 1980 and Kadir 1997). The renaissance of ferrocement in recent two decades has led to the ACI design guideline “Guide for the Design, Construction, and Repair of Ferrocement” (ACI Committee 549-1R-88 1993) and publications such as “Ferro-cement Design, Techniques, and Application” (Bingham 1974) and “Ferrocement and Laminated Cementitious Composites” (Naaman 2000), which provide comprehensive understanding and detailed design method of contemporary ferrocement.

However, the rapid development in reinforcing meshes and matrix design requires continuous research to characterize the new material and improve the overall performance of ferrocement. Instead of cement mortar, self compacting micro concrete is used in this study in order to eliminate the external vibration and to overcome the difficulties and problems in the construction process.

As a laminated composite, ferrocement often suffers from severe spalling of matrix cover and delamination of extreme tensile layer even at high reinforcement ratio, resulting in premature failure. Therefore, consideration of serviceability rather than strength limit would dominate composite design. Thus far, steel meshes have been the primary mesh reinforcement for ferrocement, but recently adding discontinuous short fiber to cementitious matrix has become in use (Sivakumar and Manu Santhanam 2007), which could bring significant improvement in ductility and shear capacity as well as moderate increase in tensile strength turns to be a logical and reasonable solution to solve serviceability problems. When concrete cracks, the randomly oriented fibers arrest the micro cracking, thus improving the
strength, ductility and convert its brittle characteristics to a ductile one. In this study, the addition of polypropylene fibers also enhances the flexural strength and Impact resistance of HF slabs.

Fiber Reinforced Polymer (FRP) composite materials have been successfully used in the construction of new structures and in rehabilitation of existing structures (Tarek Almussallam and Yousef Al-Salloum 2001). FRP plating is a versatile technique which can be applied equally well for existing and for new structures. Plating of FRP laminates results in increase of composite moment of inertia of the section, thus making it behave with more stiffness after plating. FRP is a composite material generally consisting of carbon, glass fibers in a polymeric resin matrix. FRP composites are, as the name suggests, a composition of two or more materials which, when properly combined, form a different material with properties not available from the ingredients alone. Depending on the ingredients chosen and the method of combining them, properties of FRP can be controlled. The major constituents of FRP are the fiber and the resin. The mechanical properties of FRP are controlled by the type of fiber and resin. The commonly used types of FRP are: i) Carbon Fiber Reinforced Polymer (CFRP), ii) Glass Fiber Reinforced Polymer (GFRP), iii) Aramid Fiber Reinforced Polymer (AFRP).

1.2 FERROCEMENT

Ferrocement is a form of reinforced concrete that differs from conventional reinforced or prestressed concrete primarily by the manner in which the reinforcing elements are dispersed and arranged. It consists of closely spaced, multiple layers of mesh or fine rods completely embedded in cement mortar. A composite material is formed that behaves differently from conventional reinforced concrete in strength, deformation, and potential applications, and thus it is classified as a separate and distinct material. It can be formed into thin panels or sections with only a thin mortar cover over the
outermost layers of reinforcement. Unlike conventional concrete, ferrocement reinforcement can be assembled into its final desired shape and the mortar can be plastered directly in place without the use of a formwork. Ferrocement has found itself in numerous applications both in new structures and repair and rehabilitation of existing structures. The renaissance of ferrocement in recent two decades has led to the ACI Committee 549-1R-88, design guideline "Guide for the Design, Construction, and Repair of Ferrocement" (1993), and publications such as "Ferro-cement Design, Techniques, and Application" (Bingham 1974) and "Ferrocement and Laminated Cementitious Composites" (Naaman 2000) which provide comprehensive understanding and detailed design method of contemporary ferrocement. However, the rapid development in reinforcing meshes and matrix design requires continuous research to characterize the new material and improve the overall performance of ferrocement.

1.2.1 Characteristics of Ferrocement

A working definition of ferrocement slab is “a thin shell of highly reinforced Portland cement mortar”. Generally, Ferrocement slabs range from 10 to 25 mm in thickness and the reinforcement consists of layers of steel mesh, usually with steel reinforcing bars sandwiched midway between. The resulting slab or panel of mesh is impregnated with a very rich (high ratio of cement to sand) portland cement mortar.

Various research works on ferrocement carried out throughout the world so far reveal that ferrocement possesses the following characteristics:

- The High Ductility nature of the mesh provides an added degree of protection against sudden collapse.
Because of the distribution of small diameter wire mesh reinforcement over the entire surface and sometimes over the entire volume of matrix, very high resistance against cracking is obtained.

Improvement in toughness, fatigue resistance, Impermeability. Stiffness increases with an increase in the reinforcement.

This can be fabricated into very slender sections, as small as one cm. Thus Ferrocement is ideal for thin shell construction.

Ferrocement has substantial potential for supporting vibratory loads.

Light weight as compared with similar structures made of reinforced or prestressed concrete.

Ferrocement is more economical than the materials that it replaces.

1.2.2 Advantages

The construction of ferrocement slabs has been found attractive in many developing countries because:

Ferrocement is made of materials that are readily available in most countries.

Ferrocement is suitable for a wide range of construction techniques, ranging from self-help construction for housing and agricultural structures to highly prefabricated industrial processes.
• At the low end, ferrocement requires a low level of technology and common labor skill, because of its light weight, it does not require heavy construction equipment or plants.

• Ferrocement can be fabricated in any desired shape, it is particularly suitable for shells and free form shapes.

• Ferrocement is durable and resistant to the environment like concrete and masonry, it is non-flammable, it is less prone to corrosion than steel, it is not sensitive to humidity and unlike wood, does not rot, and has longer life than fiber reinforced plastics.

• Ferrocement can be easily maintained and repaired after damage.

• Ferrocement is cost effective.

• The skills for ferrocement construction can be easily acquired.

• Ferrocement construction is less capital-intensive but more labour intensive.

• Ferrocement qualifies in terms of using fewer resources and less energy, in being less polluting, and in generating less waste.

1.2.3 Applications

In its role as a thin reinforced concrete product and as laminated cement-based composite, ferrocement can be used in numerous applications, including new structures and the repair and rehabilitation of existing structures.
• Marine applications of ferrocement include boats, fishing vessels, ferries, barges, docks, cargo tugs, floatation buoys and water or fuel tanks.

• Terrestrial applications of ferrocement include agricultural applications, applications in water supply and sanitation, housing and rural energy.

• Repair and Rehabilitation – Because of its ease and low cost of application, ferrocement is ideal for patching and other small repair work, examples are confinement jackets for reinforced concrete columns to improve their seismic resistance, skin reinforcement for unreinforced brick or masonry walls, also to improve their seismic response, lining for existing swimming pools and lining for corroded steel water tanks.

1.3 SELF COMPACTING CONCRETE

Self-Compacting Concrete (SCC) was developed in the middle of the 1980’s in Japan. Now-a-days, self compacting concrete has been widely used in the construction of all structures. Self compacting concrete gets compacted due to its own weight without any external vibration; this concept is used in place of conventional cement mortar, in the construction of Hybrid Ferrocement slabs in order to overcome the problems and difficulties in the construction process. The use of SCC in the construction of Ferro cement slabs which can be used as walls and floors facilitate the easy placing of mortar without the requirement of skilled labours, vibrators and improving the quality and speed of manufacturing ferrocement products.

The common practice to obtain self-compatibility in SCC is to limit the maximum size of coarse aggregate content and to use lower water-powder
ratios together with Hyperplasticizers (HP). During the transportation and placement of SCC the increased flow ability may cause segregation and bleeding which can be overcome by providing necessary viscosity, which is usually supplied by increasing the fine aggregate content, by limiting aggregate size, by increasing the powder content or by utilizing Viscosity Modifying Agents (VMA). One of the disadvantages of SCC is its cost, associated with the use of chemical admixtures and use of high volumes of Portland cement, one alternative to reduce the cost of SCC is the use of mineral additives such as stone powder and natural pozzolonas.

### 1.3.1 Properties of Self Compacting Concrete

The SCC flows alone under its dead weight up to leveling, airs out and consolidates itself thereby without any entry of additional compaction energy and without a nameable segregation. The SCC owns over three key characteristics which are listed below. These characteristics were made possible by the development of highly effective water reducing agents (superplasticizers), those usually based on polycarboxylate ethers. The mixture composition of SCC deviates from conventional concrete. The powder contents of SCC are normally lying (in some cases even considerably) above those of conventional concrete.

1. **Filling Ability**: Ability of to fill a formwork completely under its own weight.

2. **Passing Ability**: Ability to overcome obstacles under its own weight without hindrance. Obstacles are e.g. reinforcement and small openings etc.

3. **Segregation resistance**: Homogeneous composition of concrete during and after the process of transport and placing.
An idea of SCC, is a material that flows into formwork and compacted under the influence of its own self-weight without vibration and additional processing. Realisation of self-compacting as the key feature of fresh concrete enabled at the same time application of technologically higher quality material with improvement of economic building conditions.

### 1.3.2 Uses and Advantages of Self Compacting Concrete

The main advantages of application of self-compacting concrete on site are as follows:

- No vibration of fresh concrete is necessary during placement into forms.
- Placement of concrete is easier.
- Faster and more efficient placement of fresh concrete is achieved. Total concreting time is reduced.
- Noise level on construction site is reduced. Thus the number of working hours on the construction site can be increased and the night shift in urban zones is enabled.
- Energy consumption is reduced.
- Required number of workers on construction site is reduced.
- Safer and healthier working environment is obtained.

Upon self-compacting concrete hardening in structures:

- High quality of placed concrete is achieved, regardless of the skill of the workers.
• Good bond between concrete and reinforcement is obtained, even in congested reinforcement.

• High quality of concrete surface finish is obtained with no need for any subsequent repair.

• With a better final appearance of concrete surface, smooth wall surfaces and flat floor surfaces that need no further finishing are obtained.

• Improved durability of structures is achieved.

• Maintenance costs are reduced.

1.4 HYBRID FERROCEMENT SLAB

Research efforts to improve materials and production processes used in ferrocement follow a number of parallel paths that deal with increasing strength, improving toughness, improving durability, increasing mechanical efficiency and decreasing material usage and production cost. Ferrocement could be seen as a scaled down system of reinforced concrete construction with reinforcement distributed throughout the depth of the member. Improved elasticity, cracking, extensibility and impact characteristics are achieved by proper control of reinforcement parameters. While ferrocement can benefit from being considered an extreme boundary of reinforced concrete, it has and is still taking advantage from the rapid development in the field of composite materials including advanced laminated and hybrid composites and thus it must also continue to establish its own identity.

By concrete standards, ferrocement can be thought of a thin reinforced concrete construction with very high performance characteristic such as high tensile strength to weight ratio, ductility and impact resistance,
these characteristics are required for earthquake prone area applications. For instance, a factory produced ferrocement element using self compacting concrete and square weld mesh instead of woven wire mesh cost two to three times less than conventional ferrocement elements of equivalent performance. The increasing availability of fiber reinforced polymer is likely to lead further cost reduction.

Applications of ferrocement in small size structures and structural elements have mushroomed in developing countries. In a way, Ferrocement is becoming an all purpose material and its potential combinations with other materials is a testimony to its versatility. This may take the form of mechanized production of small size elements such as cement sheets and pipes to replace asbestos cement products.

The investigations by Naaman and Gurrero (1996) shows the addition of discontinuous fibers to the matrix of ferrocement can effectively increase its moment of resistance and significantly reduce the average crack spacing and width at ultimate loading and it also prevent the spalling of concrete. To improve the structural performance and reduce total cost of construction, a new ferrocement system performance is enhanced with polypropylene fibers, FRP laminates and which is termed as Hybrid Ferrocement system. Most of the past research work has focused on the potential use of ferrocement in structural applications as permanent formwork (Kadir 1997) secondary roofing elements, etc.

Very little research has been done on altering the inherent character and material properties of the ferrocement. This research work aims at to study the flexural response, deformation characteristics, ductile performance and energy absorption capacity under impact load of ferrocement slabs made up of self compacting concrete and wrapped with GFRP sheets at the bottom face.
1.5 NEED FOR INVESTIGATION

Research efforts to improve materials and production processes used in structural concrete in Ferrocement that deal in particular with increasing strength or strength-to-weight ratio, improving toughness or energy absorption capacity, improving durability, increasing mechanical efficiency and decreasing materials and production cost.

1.6 OBJECTIVES AND SCOPE

In this investigation, the association of continuous and discontinuous reinforcements for thin reinforced concrete products is explored following a design philosophy different from that of previous studies. The objectives of the thesis are as follows:

1. To extend the principles of reinforced concrete design by using continuous steel reinforcement as the main reinforcement to satisfy ultimate stress limit state and fibers as a secondary reinforcement to control cracking and satisfy the crack width limit state in service.

2. To use polypropylene fibers (Matthias Zeiml 2005) instead of steel fibers, differently from most prior investigations were used. Improvement in shrinkage cracking is also expected.

3. To study the influence of SCC mixture used instead of conventionally vibrated concrete.

4. To study the experimental tests on simply supported HF slabs, in order to determine the ultimate flexural capacity under the two point loading.

5. To analyze the nonlinear behaviour of HF slabs by determining the moment curvature response and corresponding load deflection response for the slabs tested.
6. To investigate the ductile performance and energy absorption capacity of slabs under impact loading.

7. To identify the critical parameters affecting the performance of HF slabs.

8. To arrive at the analytical equations for moment of resistance, load deflection profile up to serviceability limit. Curvature ductility factor of HF slabs from the experimental investigations carried out.

9. To develop the numerical model for HF slabs using commercially available software SPSS for predicting the initial and final energy absorption capacity under impact loading.

1.7 THESIS ORGANISATION

Chapter 2 surveys the literatures related to historical development and studies on Ferrocement, SCC, Fiber reinforced concrete, FRP wrapping, Analytical modeling of SCC and flexural analysis of RC elements.

Chapter 3 presents the mechanical properties of the constituents of hybrid ferrocement slab with the fresh property tests of self compacting concrete and include the detailed description of the experimental procedure of Hybrid Ferrocement slab under flexure. Behaviour of slab during loading is discussed and the results of the testing programme are used to develop analytical models.

Chapter 4 includes the drop weight impact test on Hybrid Ferrocement square slabs. A detailed study on impact strength, ductility index and energy absorption at initial and final stages of the HF slabs are presented.

Chapter 5 provides theoretical models for flexural strength, load-deflection response and ductility of HF slabs. These models are based
upon the fundamental stress-strain laws, equilibrium equations strain compatibility behaviour observed in bending tests. It also includes the equations for Initial and final energy absorption capacity under impact load of HF slabs by regression analysis.

Chapter 6 gives the discussion of results of experimental investigations and theoretical models of the current research. The behavioural response of the HF slabs is also summarized.

Chapter 7 concludes the key findings of the research work along with recommendations for future research work on various aspects of the development of HF slabs.