CHAPTER 1

INTRODUCTION

1.1 GENERAL

Natural disasters such as earthquakes, cyclones, tornadoes and tsunamis often threaten the integrity of civil infrastructures and safety of their uses. A large number of existing reinforced concrete buildings and other structures do not have sufficient capacity to resist the forces during such catastrophes considering present codal requirements. In order to guarantee the safety of the people, the older and existing structures needed to be repaired and strengthened to prevent their distress. Efficient methods are to be developed for structural repair and strengthening. The ageing of the nation’s infrastructure in a tight economic environment has necessitated the search for innovative and cost effective solutions. Several studies have been focused on the use of externally bonded ferrocement laminates to reinforce existing structures which are in need of strengthening.

The construction industry consumes a large quantity of natural resources such as water, sand and gravel as raw materials. Certain waste materials produced in manufacturing industries like steel slag, copper slag etc. have similar properties as that of sand and gravel. Interestingly, the utilisation of such materials as raw materials in construction will reduce the environmental impact due to mining of sand and gravel. This thesis evaluates the effectiveness of utilising steel slag as a replacement material for fine aggregate in ferrocement laminate which is used for strengthening of reinforced concrete beams.
1.2 FERROCEMENT

In general, ferrocement is considered as a highly versatile form of composite material made of cement mortar and layers of wire mesh or similar small diameter steel mesh closely bound together to create a stiff structural form. This material, which is a special form of reinforced concrete, exhibits a behaviour so different from conventional reinforced concrete in performance, strength and potential application that it must be classed as a separate material (Khanzadi & Ramesht 1996). In rationally designed ferrocement structures, the reinforcement consists of a small diameter wire mesh in which the proportion and distribution of the reinforcement are made uniform by spreading out the wire meshes throughout the thickness of the element. The uniform distribution and high surface area to volume ratio of its reinforcement result in better crack arrest mechanism. Its ultimate strength depends almost entirely upon the volume fraction of mesh reinforcement. The mechanical behaviour of ferrocement is highly dependent upon the type, quantity, orientation and strength properties of mesh and reinforcing rods (Sheela & Ganesan 2005). Ferrocement construction, unlike other sophisticated construction, requires minimum number of skilled labourers and utilises readily available materials. The most important advantage of this is that it can be fabricated into almost any desired shape to meet the needs of the user. These potential advantages and novelty of the concept have stimulated what is now considered a worldwide interest in the use of ferrocement.

1.2.1 Advantages of Ferrocement

- 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, including precast panels for housing, pipes, channels, façade and curtain walls.
• At the low end, ferrocement requires a low level of technology and common labour skills; because it is relatively lightweight, it does not require heavy construction equipment or plants.

• At the high end, ferrocement is suited for industrialised construction and high levels of prefabrication, where its relative lightweight compared to conventional reinforced concrete is also a benefit.

• Ferrocement can be fabricated in any desired shape; it is particularly suitable for curved elements like shells and free from shapes. It has been used for domes, boats, housing structures, and sculptures.

• Ferrocement can be easily maintained and repaired after damage.

• Ferrocement is cost effective.

1.3 NEED FOR PARTIAL REPLACEMENT OF SAND

For decades, sand and gravel have been used in the construction of roads and buildings. Today the demand for sand and gravel continues to increase. Excessive instream sand and gravel mining cause the degradation of rivercourse. Instream mining lowers the stream bottom, which may lead to bank erosion. Sand mining is a threat to bridges, river banks and nearby structures. The impact
- Water quality: Mining and dredging activities poorly planned stockpiling and uncontrolled dumping of overburden and fuel spills will cause reduced water quality for downstream users, increased cost for downstream water treatment plants and poisoning of aquatic life.

- Ecological: Mining which leads to the removal of channel substrate, resuspension of stream bed sediments clearance of vegetation and stockpiling on the streambed, will have ecological impacts.

This situation has warranted the need for exploring alternatives for granular sandy material. This problem is now being solved to some extent by substituting river sand with industrial by-products like steel slag. Hence, an effort is made to study the behaviour of ferrocement laminate with partial replacement of fine aggregate by steel slag.

1.4 **NEED FOR UTILISATION OF STEEL SLAG**

1.4.1 Steel Slag and its Production

India’s steel production grew constantly in the last five years from 57.8MT in 2008 to 76.7MT in 2013. Currently India is the fourth largest steel sector in the world. It is set to become the second largest producer of steel (Corporate catalyst India, 2013) in the world by 2014. The waste generated in
aluminum, manganese, calcium and magnesium that are developed simultaneously with steel in basic oxygen, electric arc, or open hearth furnaces. The chemical composition and cooling of molten steel slag have a great effect on the physical and chemical properties of solidified steel slag.

1.4.2 Consumption of Steel Slag

The steel slag in India is used mainly in cement manufacturing and in other unorganised work such as landfills, and railway ballast. A small quantity is also used by the glass industry for making slag wool fibres. Cement plants utilise steel slag for the production of slag cement. Only about 15% to 20% of the steel slag is consumed by the Indian Cement Industry (Nadeem & Pofale 2012). Some of the current uses of steel slag according to the National Slag Association (2003) are as follows:

- Steel slag is used as an ideal aggregate in Hot Mix Asphalt (HMA) surface mixture application due to its high frictional resistance and skid resistance characteristics. The cubical nature of steel slag and its rough texture provides more resistance than round, smooth and elongated aggregates.

- It is also used in making Stone Matrix Asphalt (SMA) because the particle-to-particle contact of the aggregate does not break down during the manufacturing, laying down or compaction process.

- It is used in base application, construction of unpaved parking lots, as a shoulder material, and in the construction of embankment.

- It is also used in agriculture because it has minerals like iron, manganese, magnesium, zinc and molybdenum which are valuable plant nutrients.
• It is environment friendly. During the production of cement, the CO₂ emissions are reduced as slag has previously undergone the calcination process.

• Steel slag aggregates are used for soil stabilisation or soil improvement of material and for remediation of industrial waste water run-off.

1.4.3 Effect on the Environment and Health

Steel Slag Coalition (SSC) was formed in 1995 (National Slag Association, 2003) to provide a comprehensive study of steel slag. This coalition consisted of iron and steel manufacturers, slag processors, chemical laboratories and risk assessment teams, environmental scientists and toxicologists to conduct an industry-wide Human Health and Ecological Risk Assessment (HERA) on iron and steel slag. The result of this study confirmed that the iron and steel slag have no threats to human health or the environment when used in residential, agricultural, industrial and construction applications. Slag has also been effectively used to treat acid mine drainage discharge and it is also useful in the removal of excess phosphorous from waste water discharges, thus rendering the waste water more ecologically beneficial if it is properly utilised. However, the dumping of a large quantity of waste steel slag becomes a crucial problem.

1.5 CURRENT RESEARCH TRENDS

The techniques of recycling waste slag from blast, BOF and other metallurgical units have been applied widely due to the increasingly strict environmental demand. In addition to utilising the waste slag to produce common cement and bricks, a new trend has occurred. The waste slag has been used to prepare high performance cementitious materials, glass ceramic, as well as replacement material for fine aggregate and coarse aggregate in the
construction industry. The waste slag has also been utilised in waste water treatment in the paper-making industry. Some investigations on the addition of steel slags in contaminated soils have been carried out. The stabilisation technique (Branca & Colla 2012) is based on the incorporation of amendments, in order to minimize metals and metalloids, such as As, Cr, Cu, Pb, Cd and Zn that can be found in contaminated soils at wood treatment plants.

1.6 PROBLEM STATEMENT

In its role as thin reinforced concrete product and strengthening material, ferrocement has found wide spread application in different fields like marine, terrestrial structures and in the repair and upgrading of existing structures. A large number of RC structures constructed in the past using the older design codes in different parts of the world are structurally unsafe according to the new design codes. Since replacement of such deficient elements of the structures incurs a huge amount of public money and time, strengthening by ferrocement laminates has become the acceptable way of improving their load carrying capacity and extending their service lives.

In ferrocement, mortar matrix usually comprises more than 95% of the ferrocement volume, hence great care should be taken in choosing constituent material. Today the demand for sand and gravel continues to increase. This situation has warranted the need for exploring alternatives for granular sandy material. This problem is now being solved to some extent by substituting river sand with industrial by-products like steel slag. Thus ferrocement laminates with steel slag modified mortar can be used as strengthening materials for RC beams.
1.7 AIM AND OBJECTIVES OF THE STUDY

The main aim of this research investigation is to study the effect of steel slag replacement as fine aggregate in ferrocement laminates for flexural strengthening as RC beams. Towards achieving the above mentioned aim, the related objectives associated were identified as follows:

- To find an eco-friendly material for replacing fine aggregate in ferrocement laminates.
- To study flexural behaviour and impact behaviour of ferrocement laminates with steel slag as a replacement material for fine aggregate.
- To propose an analytical model to calculate the ultimate moment capacity in ferrocement laminate due to flexure.
- The investigation shall be further extended experimentally to study flexural behaviour of reinforced concrete beams and to propose an analytical model to calculate the ultimate moment capacity in reinforced concrete beams, strengthened with ferrocement laminates with partial replacement of fine aggregate by steel slag.

1.8 SCOPE OF STUDY

- To find optimum percentage replacement of steel slag in cement mortar.
- To study the flexural and impact behaviour of ferrocement laminates with optimised cement mortar.
To investigate the flexural behaviour of RC beams strengthened with ferrocement laminates.

1.9 METHODOLOGY

The first step in this study was optimisation of mortar matrix containing cement, sand and steel slag. The ferrocement laminates were cast using optimised mortar to study the flexural and impact behaviour. For flexural investigation on ferrocement laminates totally 144 specimen were cast of size 150 mm × 25 mm × 500 mm and for studying the impact behaviour of ferrocement laminates 144 specimens were cast of size 300 mm × 300 mm × 25 mm. An analytical investigation was carried out as a confirmation study for experimental results obtained from flexural investigation on ferrocement laminates. Based on the experimental investigation, an appropriate ferrocement laminate was chosen for flexural strengthening of RC beams.

For experimental investigation on strengthening of RC beams, totally ten RC beams of size 100mm × 150mm × 1220 mm and eight ferrocement laminates of size 100mm × 25mm × 1220 mm were cast. Of these, four beams were strengthened with three and four layers of galvanised square weld mesh with volume fraction 1.76% and 2.35% respectively and mortar mix of cement sand ratio 1:2 with 0% replacement of steel slag for fine aggregate and the other four beams were strengthened with three and four layers of galvanised square weld mesh with volume fraction 1.76% and 2.35% with mortar mix of 1:2 and 30% replacement fine aggregate by steel slag.

After 28 days of curing both laminates and beams were allowed to dry in air for 24 hours. Then the surface of beam was prepared to attach ferrocement laminates. Of the ten beams, eight beams were strengthened at tension face by ferrocement laminates with epoxy resin. The remaining two
beam were left unstrengthened which acted as control specimens. The strengthened beams were subjected to third point loading. The experimental moment values are further compared with the analytical values. Figure 1.1 represents the methodology of the thesis.

**Figure 1.1 Methodology of the thesis**
1.10 ORGANISATION OF THE THESIS

The thesis consists of nine chapters.

The Chapter 1 provides a brief introduction to the ferrocement and its advantages, the need for replacement for sand, need for utilisation of steel slag as replacement materials for fine aggregate. Towards the end of this chapter, the objectives and methodology are discussed.

The Chapter 2 discusses the definition of ferrocement given by various researchers and it also deals with the history of ferrocement, the constituent materials of ferrocement and its applications. The chapter furnishes the details of strengthening methods for RC beams. The studies carried out by various researchers in the field of flexural behaviour and the impact behaviour of ferrocement laminates, steel slag usage as replacement material for fine aggregate and the application of ferrocement in the field of strengthening have been briefly reviewed. At the end, the scope of the investigation is underscored.

Chapter 3, delineates the properties of materials, optimisation of mortar matrix for ferrocement laminates, experimental investigation on flexural and impact behaviour of ferrocement laminates with different volume fraction and percentage replacement of fine aggregate by steel slag. An analytical model for determining the ultimate moment of ferrocement laminates has been proposed on plastic moment approach in chapter 4.

Chapter 5 deals with the study of properties of materials used for casting RC beams and bonding agent used for flexural strengthening of RC beams, experimental investigation on flexural strengthening of RC beams with ferrocement laminates. An analytical model has been proposed for
determining the ultimate moment capacity of strengthened RC beam in Chapter 6.

Chapter 7 is devoted to the results and discussion of the test results of flexural behaviour and comparison of experimental ultimate moment with predicted analytical moment values of ferrocement laminates. The impact behaviour of ferrocement laminates is highlighted in terms of energy absorption. Test results of strengthening of RC beams using ferrocement laminates are presented in terms of first crack load, ultimate load, energy absorption, ductility ratio and effectiveness factor. At the end of the chapter, experimental ultimate moment values of strengthened RC beams are compared with the predicted analytical ultimate moment values. Chapter 8 deals with conclusions arrived at from the research findings and points out the frontiers of future work in this field.