CHAPTER 1

INTRODUCTION

1.1 GENERAL

Today concrete has become an unavoidable construction material in the construction industry. Cement is the main ingredient in concrete and its production increases global warming by releasing huge amount of carbon dioxide into the atmosphere which is one of the main threats to the environment. To address this problem, Supplementary Cementitious Materials (SCMs) are used in concrete to reduce the use of high amount of cement content. SCMs such as Fly Ash, Rice Husk Ash, Ground Granulated Blast Furnace Slag, Silica Fume and Metakaolin play a vital role in concrete industry. It has not only economical and environmental benefits but also enhanced concrete properties. Since most of the SCMs are by-product materials of industrial and agricultural sectors, their utilization in concrete has become an efficient alternative to disposal of the same.

During the hydration of Portland cement, Calcium Silicate Hydrate (C-S-H) and Calcium Hydroxide (Ca (OH)₂) are produced. The C-S-H gives strength to concrete whereas Ca (OH)₂ in hydrated cement paste gives a negative effect to concrete quality. It is an undesirable material which reduces the strength of concrete. When SCMs are added to the Portland cement concrete, the amorphous silica present in SCMs reacts with more of Ca (OH)₂ and converts them into C-S-H. This gives strength and reduces the permeability of concrete as well as improves the durability of the concrete. The addition of SCMs enhances the concrete properties due to pozzolanic effect and filler effect. Blending of SCMs in Portland cement concrete enhances the resultant concrete by making it
stronger and more durable. Mineral admixtures have been incorporated into binary, ternary and quaternary concrete mixes (Shi et al. 2012). Many researchers prove that these materials improve the properties of blended cement concrete.

1.2 FIBER REINFORCED CONCRETE

Despite the benefit of concrete made by SCMs in the concrete structures, it is not promising due to its poor tensile strength and a low strain capacity at fracture. In addition to static loads, many concrete structures are often subjected to short duration dynamic loads such as impact from missiles and projectiles, wind gusts, earthquakes and machine vibrations. Addition of fibers in concrete is not a new concept as it had been used in construction materials since ancient times. Straw and horsehair were used as fibers to reinforce sun-baked bricks and masonry mortar and plaster in ancient periods.

The major drawback of unreinforced cement concrete with SCMs is that it is weak in tension and fails in a brittle manner when subjected to loads. Cracks develop in concrete when subjected to tensile stress. To overcome this weakness, fibers are added in concrete to improve its static flexural strength, impact strength, tensile strength, ductility and flexural toughness. The strengthening mechanism of fibers involves the transfer of stresses from the matrix to the fiber by an interlock between the fiber and the matrix. The stress is shared by the fiber and the matrix in tension until the matrix cracks and then the total stress is progressively transferred to the fibers. The addition of fibers increases the structural integrity of the concrete structures. Thus, in Fiber Reinforced Concrete (FRC), the weaker matrix is reinforced with strong fibers to produce a composite of superior properties. Steel, glass, carbon and polypropylene fibers are generally used in concrete. The combined use of fibers and pozzolan significantly improves the properties of the concrete. Earlier studies (Khaledmarar et al. 2001; Mohammadi et al. 2008; Yao et al. 2003 and
Nili & Afroughsabet (2010a) & (2010b) prove that addition of fibers improved the engineering performance and better mechanical properties of concrete.

Incorporation of fibers in cementitious materials can improve the durability of the materials. The inclusion of silica fume in glass, sisal and steel fiber reinforced materials made the greatest capillary reduction (De Gutiérrez et al. 2005). Hence, the combinations of fibers with pozzolan in concrete are highly recommended by researchers.

1.3 HYBRID FIBER REINFORCED CONCRETE

There has been much enthusiasm recently in the field of FRC for the development of hybrid fiber systems where two or more types of fibers are combined. Adding one type of fiber to concrete can improve the composite properties to some degrees. When the fibers are added as a hybrid having two or more combinations, the hybrid composites exhibit more attractive engineering properties than the addition of a single type of fiber in the composites (Yao et al. 2003). When only steel fibers (macro fibers) are used in concrete, the fiber spacing will be higher. However, when polypropylene or carbon fibers (micro fibers) are mixed with steel fibers, the resulting hybrid composite plays a better role in the strength improvement by reducing the spacing between the fibers.

The hybrid fibers enhance the strength beyond what was achievable with steel macro fibers alone. Thus, when the fibers are added in hybrid form, the overall performance of the composite is improved. Research findings in the past clearly demonstrate that the incorporation of different kinds of hybrid fibers in concrete, improves the engineering performance of concrete and better mechanical properties than mono fiber reinforced concrete (Yao et al. 2003; Sivakumar & Santhanam 2007; Qian & Stroeven 2000; Banthia & Sappakittipakorn 2007 and Chen & Liu 2005). The inclusion of hybrid micro and macro fibers can be effective in retaining the cementitious matrix integrity.
and controlling disruptive pressures resulting from voluminous reaction products (Bassuoni & Nehdi 2007).

1.4 NEED FOR THE PRESENT STUDY

Most of the earlier experimental investigations have focused the effect of incorporation of SCMs in concrete properties, mechanical properties of mono FRC and hybrid FRC separately. Limited research works have been carried out to investigate the influence of fiber addition either in mono form or in hybrid form with incorporation of SCMs. However, further study is needed to investigate the influence of multiple blending of SCMs with hybrid fibers. Addition of steel, carbon and fibrillated polypropylene fiber either in mono form or in hybrid form with incorporation of Fly Ash (FA), Rice Husk Ash (RHA) and Lime stone Powder (LP) as a multiple blending in cement concrete has not been investigated so far. At present, fiber hybridization in multiple blending Portland cement concrete is becoming important due to environmental and structural considerations. Therefore, there is a vital need to study the mechanical properties, impact resistance, durability properties and flexural behaviour of multi blended hybrid FRC. These specialized multi blended hybrid FRC can also be used extensively to meet the demand of concrete structures when subjected to short duration dynamic loads in addition with static loads.

1.5 OBJECTIVES OF THE INVESTIGATION

This research work aims at investigating the mechanical and durability properties of hybrid fiber reinforced concrete produced by partial replacement of cement with FA, RHA and LP. The limestone filler addition to Ordinary Portland Cement (OPC) increases the hydration at early ages which contributes a high early strength, but it can reduce the later strength due to the dilution effect (Ghrici et al. 2007). However, pozzolanic materials enhance the strength at later ages. RHA is a highly reactive pozzolanic material. Addition of
RHA to OPC not only improves the strength of concrete, but also forms a highly dense and less porous C-S-H gel around the cement particles. The utilization of RHA in cement and concrete enhances the strength and durability properties (Saraswathy & Song 2007). The use of ternary blend of OPC, RHA and FA significantly improves the mortar in terms of strength at the low replacement level and at the later age. Both FA and RHA are very effective in improving the corrosion resistance of mortars. RHA is slightly more effective than FA (Chindaprasirt & Rukzon 2008).

Steel, carbon, and polypropylene fibres are used in this investigation. The addition of steel fibres and polypropylene fibres improved the mechanical properties and energy absorption of concrete (Nili & Afroughsabet (2010a) & (2010b)). The addition of carbon fibers improves the cracking resistance and fatigue life of concrete (Deng 2005). Carbon fibers are characterized by superior mechanical and thermal properties, and chemical stability (Park et al. 1991). The combined use of fibers and pozzolan significantly improved the properties of the concrete at later ages (Nili & Afroughsabet (2010a). Fibers are more effective in the presence of pozzolans (Kayali 2004). Considering the advantages of adding fibers in concrete, an attempt has been made by using steel, carbon and polypropylene fibers in hybrid form in the present investigation.

The quaternary mix is proposed as the control mix in which OPC is partially replaced with 20% FA, 10% RHA and 10% LP by weight of cement based on the earlier investigation done by Kathirvel et al. (2013). The objectives of the present experimental investigation are summarized as follows.

1. To evaluate the effect of steel, carbon and fibrillated polypropylene fiber (PP) in mono form and hybrid form on quaternary blended control concrete with respect to compressive strength, splitting tensile strength, flexural strength and impact resistance
2. To assess the effect of SCMs on the mechanical properties of mono fiber and hybrid fibers incorporated quaternary blended concrete with respect to extended curing periods. Based on the investigation, the optimum combination will be identified.

3. To evaluate the durability properties such as water absorption, sorptivity, acid resistance, sulphate resistance and chloride permeability of quaternary blended concrete with optimum mono and hybrid fibers.

4. To evaluate the flexural behaviour of the quaternary blended concrete beams with optimum mono and hybrid fibers.

1.6 METHODOLOGY

The PP and carbon fibers will be added individually at 0.25% and 0.5% in weight fractions of cementitious materials. When carbon fibers are added in hybrid form with polypropylene fibers, the total weight fraction will be maintained as 0.25% and 0.5% weight of cementitious materials. The steel fibers will be added at 0.5%, 1% and 1.5 % volume fractions individually and combined with mono PP fiber, mono carbon fiber and carbon- PP hybrid fiber systems. The concrete specimens will be subjected to curing periods of 28, 56 and 90 days respectively. Then the relevant tests with respect to strength and durability characteristics as well as flexural behavior will be conducted.

1.7 ORGANIZATION OF THE THESIS

This thesis has been arranged in five chapters. A brief description of each chapter is given below.

**Chapter 1** provides an introduction about the advantage and behaviour of the SCMs in concrete, FRC, hybrid FRC, need for the present study, objectives, and methodology of this research work.
Chapter 2 deals with the review of literature for this research work.

Chapter 3 describes the material properties, mix proportion, casting and testing methodology, the experimental program on the fresh, hardened properties and flexural behaviour of reinforced concrete beams.

Chapter 4 discusses in detail about the experimental results obtained in this investigation. The experimental results of the workability, compressive strength, splitting tensile strength, flexural strength and impact resistance of mono fiber and hybrid fibers incorporated quaternary blended concrete with respect to 28, 56 and 90 days are discussed. Multi regression analysis mathematical models developed and compared with the experimental results. The results of the durability properties such as water absorption, sorptivity, acid resistance, sulphate resistance and chloride permeability of quaternary blended concrete with optimum mono and hybrid fibers are discussed. The flexural behaviour of the reinforced concrete beams with mono and hybrid fibers are discussed.

Chapter 5 deals with the conclusions drawn from this investigation and suggestions for further research are presented.