UNIVERSITI PUTRA MALAYSIA

FLEXURAL BEHAVIOUR OF RUBBERISED SELF-COMPACTING FERRO CEMENT

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By

SHAHAD DAWOOD SALMAN

Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

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DEDICATION

To my dear country, great Iraq

To the souls of the martyrs of my country

To whom her satisfaction is my goal and ambition, so she gives me a lot and does not wait for thanks (My beloved mother)

To the person who taught me how patience is a path to success and has always been a support and role model (My beloved father)

To those among whom I grew up and walk the path with them
(My brothers and my sister)

To those who did not and will never forget me in their prayers
(My Grandmother and aunt)

To my friends and everyone who helped in my study journey.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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January 2022

Chairman : Professor Dato' Ir. Mohd Saleh bin Jaafar, PhD
Faculty : Engineering

Ferro cement can be referred to as a thin wall reinforced concrete element usually having a relatively small size diameter wire mesh layers of reinforcement made from metallic or other suitable materials which are closely spaced and cast with hydraulic cement. The mesh may be made of metallic or other suitable materials. Although it has many advantages such as lightweight, easy to shape and has lower carbon footprint compared to reinforced concrete, there is a difficultly for mortar to fill and pass-through wire mesh during casting due to high volume of mesh reinforcement. Therefore, there is a need to find acceptable mix which has high degree of workability such as self-compacting mortar (SCM). The SCM can self-compact under its own weight without vibration and egregation, as well as offering much improved flow ability, filling rate, self-levelling in comparison with conventional mortar. One of the SCM technology drawbacks is its brittleness, which is greater than that of conventional mortar due to the higher cementation content and cost. This study focuses on the development of a rubberised self-compacting ferro cement mortar for use as a structural lightweight beam for low-cost construction. The study was conducted in two phases. The first phase involves the development of a suitable mix and obtain an optimum rubberised self-compacting ferro cement matrix. The developed matrix was aimed at substituting the traditional manual method of rendering of wire mesh mechanically (motorised). The suitable and optimal mortar performance was investigated in terms of its workability and strength properties. Similarly, curing by wet covering and the partial replacement of fine aggregate with crumb rubber (CR) by volume at 5% incremental level up to 20% were done. A mix ratio of 1:2, 0.38w/c, 30% pulverised fuel ash (PFA) partial cement replacement and 2.5% super plasticiser (SP) addition were determined through trial mixes until a good flow without segregation was achieved in conformity with the self-compaction requirements as per EFNARC to produce a rubberised self-compacting Ferro cement mortar (RSFM). The second phase of the study dwell on the development and investigation of the structural behaviour of the RSFM U-shape beam containing either 2 or 4 layers (2L, 4L) of rectangular or square welded wire mesh respectively. To achieve this objective, a 100 mm x 200 mm x 2000 mm U-shape beam having a constant flange of 25 mm were cast

and tested. The parameters investigated includes compressive strength, flexural strength, failure mode, load-deflection behaviour, load-strain behaviour, and role of type and layers of the wire meshes. The results reveal that the incorporation of rubber crumbs decreases the workability/flow ability and strength without using pulverized fuel ash (PFA) as replacement of cement, but with 30% (PFA) of cement replacement can improve the strength with 25.61%. load and Ultimate and higher first crack loads were achieved in the beam containing Square welded wire mesh compared with rectangle welded wire mesh for the same mix. Using four layers of welded metal mesh for both type (square and rectangle) is possible due to the high workability property of the mortar, and it will obviously result in greater load carrying capacity, compared with the use of two-layer mesh. The ductility ratio percentage reduction depends on the layers, number and type of wire mesh used. In conclusion, it was found that the RSFM mix with 10% CR and reinforced with 4 layers of rectangular and square welded mesh have potential for application in channel beams which can serve as permanent forms or structural elements within a structure.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

KELAKUAN LENTURAN SIMEN FERRO BERCAMPUR GETAH MAMPAT SENDIRI

Oleh

SHAHAD DAWOOD SALMAN

Januari 2022

Pengerusi : Profesor Dato' Ir. Mohd Saleh bin Jaafar, PhD
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Simen Ferro boleh dirujuk sebagai elemen konkrit bertetulang dinding nipis biasanya mempunyai lapisan dawai garis pusat yang agak kecil tetulang yang diperbuat daripada logam atau bahan-bahan lain yang sesuai yang dijarakkan dengan rapat dan dibuang dengan simen hidraulik. Jejaring boleh dibuat daripada bahan logam atau lain-lain yang sesuai. Walaupun ia mempunyai banyak kelebihan seperti ringan, mudah dibentuk dan mempunyai jejak karbon yang lebih rendah berbanding dengan konkrit bertetulang, terdapat sukar untuk adukan kapur semen mortar untuk mengisi dan melepasi dawai semasa pemutus kerana jumlah tetulang jejaring yang tinggi. Oleh itu, terdapat keperluan untuk mencari campuran yang boleh diterima yang mempunyai tahap kebolehkerjaan yang tinggi seperti mortar pemadatan diri (SCM). SCM boleh kompak sendiri di bawah beratnya sendiri tanpa getaran dan pengasingan, serta menawarkan keupayaan aliran yang lebih baik, kadar pengisian, meratakan diri berbanding dengan mortar konvensional. Salah satu kelemahan teknologi SCM adalah kerapuhannya, yang lebih besar daripada mortar konvensional kerana kandungan dan kos simenasi yang lebih tinggi. Kajian ini memberi tumpuan kepada pembangunan mortar simen ferro yang dipadatkan sendiri getah untuk digunakan sebagai rasuk ringan struktur untuk pembinaan kos rendah. Kajian ini dijalankan dalam dua fasa. Fasa pertama melibatkan pembangunan campuran yang sesuai dan mendapatkan matriks simen ferro yang bersalut sendiri getah yang jumlah maksimum. Matriks yang dibangunkan bertujuan untuk menggantikan kaedah manual tradisional untuk membuat dawai secara mekanikal (bermotor). Prestasi mortar yang sesuai dan jumlah maksimum telah disiasat dari segi kebolehkerjaan dan sifat kekuatannya. Begitu juga, pengawetan dengan penutup basah dan penggantian separa agregat halus dengan getah serbuk (CR) mengikut jumlah pada tahap tambahan 5% sehingga 20% telah dilakukan. Nisbah campuran 1:2, 0.38 w / c, 30% penggantian abu bahan api pulverised (PFA) separa dan penambahan 2.5% super plasticiser (SP) ditentukan melalui campuran percubaan sehingga aliran yang baik tanpa pengasingan dicapai selaras dengan keperluan pemampatan diri seperti EFNARC untuk menghasilkan mortar simen Ferro bersalut sendiri bergetah (RSFM). Fasa kedua kajian ini bergantung kepada pembangunan dan penyiasatan tingkahlaku struktur rasuk bentuk U, RSFM yang mengandungi sama ada

2 atau 4 lapisan (2L, 4L) mesh dawai dikimpal segiempat tepat atau persegi masing-masing. Untuk mencapai matlamat ini, rasuk bentuk U 100 mm x 200 mm x 2000 mm yang mempunyai bebibir berterusan 25 mm telah dibuang dan diuji. Keliling yang disiasat termasuk kekuatan mampatan, kekuatan lenturan, mod kegagalan, tingkahlaku pesongan beban, tingkahlaku beban-strain, dan peranan jenis dan lapisan mesh wayar. Hasilnya menunjukkan bahawa penggabungan serbuk getah mengurangkan keupayaan dan kekuatan kebolehkerjaan / aliran tanpa menggunakan abu bahan bakar pulverized (PFA) sebagai pengganti simen, tetapi dengan 30% (PFA) penggantian simen dapat meningkatkan kekuatan dengan 25.61%. beban dan Ultimate dan beban retak pertama yang lebih tinggi dicapai dalam rasuk yang mengandungi Square dikimpal dawai mesh berbanding dengan segiempat tepat dikimpal dawai mesh untuk campuran yang sama. Menggunakan empat lapisan mesh logam dikimpal untuk kedua-dua jenis (persegi dan segiempat tepat) adalah mungkin kerana sifat kebolehkerjaan mortar yang tinggi, dan ia jelas akan menghasilkan kapasiti penyimpanan beban yang lebih besar, berbanding dengan penggunaan mesh dua lapisan. Pengurangan peratusan nisbah kemuluran bergantung pada lapisan, bilangan dan jenis dawai yang digunakan. Kesimpulannya, didapati bahawa campuran RSFM dengan 10% CR dan diperkuat dengan 4 lapisan mesh dikimpal segiempat tepat dan persegi mempunyai potensi untuk aplikasi dalam rasuk saluran yang boleh berfungsi sebagai bentuk kekal atau elemen struktur dalam struktur.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- The research conducted and the writing of this thesis was under our supervision;
- Supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CRA	Coarse Rubber Aggregate
CRT	Concrete with Recycled Waste Tyre
EFB	Empty Fruit Bunch
FA	Fine Aggregate
FCRA	Fine and Coarse Rubber Aggregates
FRA	Fine Rubber Aggregate
FRC	Fibre Reinforced Concrete
CR	Crumb Rubber
RSFM	Rubberised Self-compacting Ferro cement Mortar
SP	Super Plasticiser
PFA	Pulverised Fuel Ash
EFNARC	European Federation of National Association Representing for Concrete
SCM	Self Compacting Mortar
SCRC	Self Compacting Rubberised Concrete
TCR	Tire Crumb Rubber

CHAPTER 1

INTRODUCTION

1.1 Research Background

The most widely used construction material for civil engineering applications is concrete as stated by Neville (1995) of which its constituents consist of cement, water, aggregate for traditional concreting while incorporating chemical and mineral admixtures for modern concrete. In 1995, Abang stated that industrialization concept had emerged in construction technology; it is also an acceptable and preferred option in building construction. This had maximally help in the reduction of in situ construction. This is achievable by employing some strategies including the usage of newly developed cement-based composites for structural applications. Cement based composites were found to perform better than conventional plain concrete. There would be some pressure relieve on conventional and existing building materials supply to some extent due to the development of new and innovative construction materials and technology which would assist in arresting the continuous increase in material cost and reduction of in-situ construction activities. The quest for an appropriate alternative strengthening component for reinforced concrete element by the construction industry positively encouraged Ferro cement use (Bong and Ahmed, 2010). Ferro cement had been used for decades and is a composite thin-walled concrete that is reinforced by continuous close layers of wire mesh, it is light-weight, easily shaped and having a low carbon footprint as compared with concrete (ACI 549R, 1997; ACI 5492R, 2004, 2006).

Ferro cement is a hydraulic cement mortar with closely spaced wire mesh reinforcement that could be made of a wide spectrum of materials including steel, polymer, synthetic woven fibres (Naaman, 2000). The closely spaced reinforcement confines the cementitious matrix and enhances uniformity (ACI549- R97, 1997). Similarly, Ferro cement is a construction material that proved to have superior qualities of crack control, impact resistance, and toughness, (Fahmy et al., 2014) largely due to the close spacing and uniform dispersion of reinforcement within the material. Ferro cement has received attention as a potential building material, especially for roofing of housing construction (National Academy of Sciences 1973) and several civil engineering applications (Naaman 2000). Many investigators have reported the physical and mechanical properties of this material, and numerous test data are available to define its performance (Naaman 1979; Yogendran et al. 1987; Korany 1996). Ferro cement with multi-wire reinforcement provides larger surface contact energy when compared with conventional isolated-bar reinforced concretes. This, in turn, causes the matrix to gain a higher degree of energy absorption and, equally important, a higher modulus of rupture and elasticity (Behnia et al., 2017).

It further exhibits homogeneous isotropic mechanical and physical characteristics when reinforced multi directionally. The high modulus of rupture of ferro cement composites combined with the excellent bonding between embedded internal mesh reinforcements

and the surrounding cement mortar matrix contribute to their superb high tensile strength (Naaman, 1979; Kubaisy and Jumaat, 2005). It has been shown that the minimization of crack-width and subsequent performance enhancement in the ferro cement structures can be achieved by reducing the thickness of concrete or mortar cover of the elements (Kubaisy and Jumaat, 2005).

However, thin ferro cement elements often suffer from difficulties during concrete vibration due to the congestion of reinforcement that could eventually lead to honeycombing and/or non uniformity. Owing to its high flowability, self-compacting concrete (SCM) can, thus, be a suitable alternative to ordinary concrete in ferro cement production (Svec et al., 2014). Full and partial replacement of fine aggregates by high energy-absorbent materials, such as rubber, could enhance toughness of the cementitious matrix as well as the mode of structural failure (Aitcin, 2000). The use of appropriate waste and by-product as a filler in ordinary or special concretes also enables production of durable, affordable and environmentally friendly concrete (Su et al., 2015). The global lavish and often reckless tire disposal poses an imminent environmental threat as rubber is a non-degradable menace occupying significant surface and underground volumes in dumping yards (Oikonomou and Mavridou, 2009; Onuaguluchi and Panesar, 2014). Incorporation of waste tires in concretes enables high tolerance to plastic deformation and superb fracture energy (Grinys et al., 2012). Benazzouk et al. (2007) reported that the use of rubber admixtures in concrete beams could reduce their brittleness whilst allowing greater plastic deformations. In addition, improvement in fatigue and impact resistance of tire rubber concretes and composites has been reported in numerous studies (e.g. Ganesan et al., 2013; Liu et al., 2012; Abdullah and Khatab 2014).

In view of this, ferro cement applications require maintaining a good balance between improving material ductility without compromising its strength. To this end, the induced plastic deformation capacity (strain rate) by introducing tire rubber into plain concrete is quite instrumental. Thus, replacing fine aggregate with rubber inclusions in normal and self compacting concretes is believed to have a great potential. Notably, in 2017, Behnia et al. carried out an investigation on rubberized multi-layered ferro cement slabs because literature on that is lacking. This signifies the usefulness of rubberized ferro cement in the construction industry.

Recently Tawab et al. (2012) has presented the results of an experimental investigation to examine the feasibility and effectiveness of using precast U-shaped ferro cement laminates as permanent forms for construction of reinforced concrete beams. The precast permanent ferro cement forms were proposed as a viable alternative to the commonly used wooden and/or steel temporary forms. The authors used woven wire mesh, X8 expanded wire mesh, and EX156 expanded wire mesh for reinforcing the precast ferro cement forms. The precast ferro cement forms were filled with conventional concrete reinforced with two steel bars. Neither bonding agent nor mechanical shear connection was used in that research to provide shear connection between the forms and the core. The reported results showed that high serviceability and ultimate loads, crack resistance control, and good energy absorption properties could be achieved by using the proposed ferro cement forms. In a similar development, Fahmy et al. (2013) continues the investigation reported by Tawab et al. (2012) where

they used single and double layers of welded wire and X8 expanded steel meshes to reinforce the U-shaped forms in their investigation.

Amongst the numerous differences and similarities that exist between convenetional reinforced concrete and Ferro cement as earlier stated, the main difference is that the former is reinforced with large diameter iron rods and contains large size aggregates as constituents while the latter is a composite and reinforced with small diameter wires that are spaced closer and the member cross-section ranges between 25 mm to 50 mm. Durability is a fundamental item in construction most significantly when in aggressive and tropical environments. Adequate cover to reinforcing steel plays a vital role in maintaining and sustaining durability, although ferro cement sections are usually thin and adequate compaction is required which can be achieved under the supervision of skilled personnel and they are relatively scarce. To curtail over dependence on skilled personnel, self-compacting Technology was introduced in Japan more in the late 1980s (Neville, 1995; Najim and Hall, 2010) and early 1990s (Najim and Hall, 2012). This technology self-compacts without vibration nor segregation under its own weight (Khatib and Bayomy, 1999). Similarly, its flow ability, filling rate, self-levelling improved including reduction in blockage in a stocky reinforced areas within a concrete section compared with conventional concrete (Tahaet al., 2008). Global concrete production was between 21 and 31 Gt/year in 2006 as estimated by The European Concrete Platform ASBL (Tung-Chai, 2011), resulting in approximate aggregate consumption to be between 15–22 Gt/year and recalling in concrete, volume of aggregate is about 70%. The global aggregate demand has worsen the environmental impact of mineral extraction methods (e.g. marine dredging, quarrying); hence, alternative aggregate resources should be explored.

Crumb rubber is is an alternative aggregate resource to be used partially or wholly in replacing fine aggregate. Its use encourages avoidance of extraction/waste landfill levies because of scrap tire stockpiling (Figure 1.1a), thereafter it is burnt (Figure 1.1b) (Ouchi and Okamura, 2003) as commonly practiced in many countries. Similarly, crumb rubber has notable advantageous properties such as low water absorption (negligible) and unit weight that can be used to produce special civil engineering composites material as shown in Figure 1.2, (Ouchi and Okamura, 1999).

Figure 1.1: (a) Stockpiling and (b) burning scrap tires
(Ouchi and Okamura, 2003)

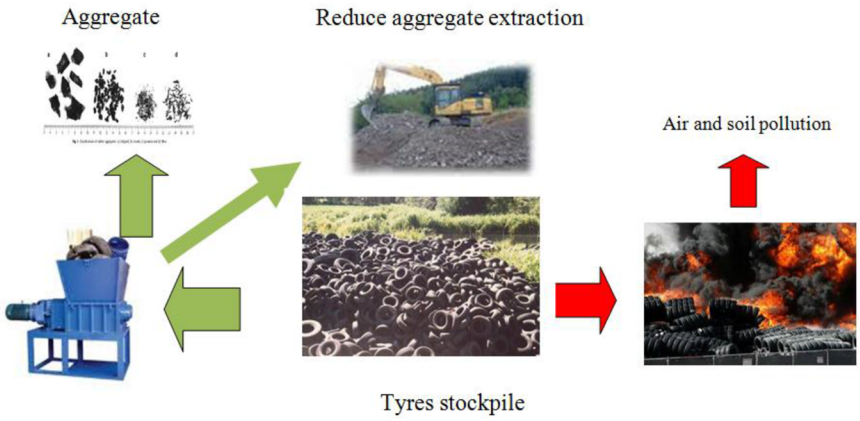

Figure 1.2: Tire life cycle
(Ouchi and Okamura, 1999)

Su et al. (2001) states that there is an exceptional importance in sustainable development with respect to re-use of end-of-life tires in the construction industry because of the enormous existing stockpiles and the high demand and global rise in car production. For instance, in 2007 at UK, about 46 million tires were used and the production with the corresponding usage is increasing continuously (Domone, 2007), but only 4.5% of this quantity is currently recycled in civil engineering applications (Felekoglu, Türkel and Baradan, 2007). Annually, about three million tons are generated by the EU states (Nanthagopalan, and Santhanam, 2009) and the quantity stockpiled is about 600 hundred metric tons (Kou and Poon, 2009), whilst the global

tyre production as estimated in 2011 was put at one billion annually (Nagataki and Fujiwara, 1995). The humongous quantity of scrap tyre accumulation poses an urgent threat in waste management, increasingly resulting in environmental problems which breads and houses vermin and infestation when stockpiled because of their non-biodegrading nature (Gesoglu, and Güneyisi, 2011). Stockpiling of scrap tyre had been banned by many governments globally, e.g. since 2006, EU-European Concrete Platform, ASBL (2009), had implemented the banning of stockpile but encouraged its consumption as alternative aggregates there by reducing unhealthy natural aggregate extraction resulting in increased economic value and enhancing sustainability accordingly by:

(i) Scrap tires re-use that could have posed a threat to the environment, and

(ii) Reduction in the unhealthy extraction of naturally occurring aggregate resource (Bida, 2014 and Mukaddas, 2015). The construction industry consumes There is an annual consumption of between 2.8 and 4.1 billion tonnes of cement the construction industry (Sukontasukkul, 2009 and Waste and resource action programe, 2007), which is significantly increasing because of population growth globally. There is deterioration of ozone layer as a result of cement Production due to virgin material consumption from the environment (about 1.5 metric tons of raw materials are required for each metric ton of cement) (Cairns, Kew, and Kenny, 2004), resulting in increased CO_2 emissions: with every one metric ton cement produced, about 0.8 tonnes of CO_2 is released, constituting 5–8% CO_2 emission globally (ETRA, 2006). Furthermore, SO_3 and NO_2 are released into the atmosphere during cement production adding to the greenhouse effect and acid rain (Aiello, and Leuzzi, 2010). The global represents the second largest greenhouse gases producer globally is the cement industry (Ozbay, Lachemi, and Sevim, 2011). Hence, reduction in cement manufacturing while continuing to provide sufficient cementitious material imperative. To actualise this, encouraging wider use of self-compacting fibrocement with crumb rubber particles with incorporation is a better way because of the wide range of natural/by-product cement replacement materials that can be utilised such as Pulverized Fuel Ash (PFA).

1.2 Problem Statement

Strength and serviceability are unique properties associated with ferro cement which is why it is referred to as a versatile construction material. Similarly, properties such as lightness, durability, fire resistance, and environmental stability cannot be matched by any other thin construction material (Naaman, 2000). For pre-fabrication and industrialization of the building industry, Ferro cement has proven to be a promising composite material (Suresh, 2004; Austriaco, 2006). However, Ferro cement mortar production requires skilled and experienced workmen whom are not easily and readily available always. There is always a challenge of mortar flow to pass through high volume of wire mesh reinforcement in Ferro cement element/structures. Therefore, this necessitated the adoption of self-compacting technology but it has some shortcomings.

Some of the shortcomings include brittleness, (which is greater than conventional concrete owing to high cementations material content), low water/cement ratio and use of super plasticizer (SP). Using crumb rubber as partial aggregates replacement for mineral aggregates is an innovative way to reduce natural aggregate consumption whilst utilising the by-product solid waste materials in a more environmentally friendly manner and introducing performance advantages to the materials themselves. However, this approach characterised by reduction in mechanical strength. Hence the introduction of different steel wire mesh so that strength characteristics of the self – compacting rubberised Ferro cement beam can be improved.

1.3 Research Objectives

The aim of this research is to determine the flexural behaviour of Rubberised Self – compacting Ferro cement U-beam reinforced with wire mesh layers of different types and number, thus the following specific objectives are outlined:

i. To identify a suitable mix using self-compaction method for the rubberised Ferro cement matrix.

ii. To identify the optimum crumb rubber percentage required in producing Ferro cement rubberized self-compacting mortar.

iii. To study the flexural behaviour of rubberized self-compacting ferro cement specimen (U-shape beam) reinforced with 2 layers and 4 layers each of rectangular wire mesh and square wire mesh in terms of flexural strength, crack pattern, deflection and strain of the rubberized ferro cement matrix respectively.

1.4 Scope and Limitation of Study

The material properties and flexural behaviour of rubberised Ferro cement U-shaped beam samples were produced in accordance with the standard method of civil engineering laboratory practice and its characterisation was limited to the laboratory investigation only. The research was divided into two phases. In phase I, was for the development of self-compacting Ferro cement mortar by partially replacing fine aggregate from 0% to 20% at 5% incremental levels by volume of fine aggregate respectively with crumb rubber and ascertaining the optimum percentage required for the crumb rubber matrix. Tests conducted include workability and compressive strength.

Production and characterisation of the U- shaped beam (100 x 200 x 2000) mm produced from the optimum mix ratio obtained from first phase was carried out in phase II. Both mix and water cement ratios of 1:2 and 0.38 respectively were kept constant. Chemical treatment was not performed on the crumb rubber to for sustainability by producing green mortar matrix. U-shaped beam was produced for both

the control mix with 0% crumb rubber and rubberised ferro cement self-compacting mortar with 10% crumb rubber replacement of fine aggregate. The effect of using wire mesh (square and rectangular) and different layers of the wire mesh (2 and 4 layers) on the structural behaviour of U-shaped beam was investigated.

The test set-up has the following limitations and or shortcomings:

- Two Swivelling rollers were used at the supports and another set of two at the loading point below the spreader beam to accommodate any probable specimen deformations prior testing.

- The LVDT needles were set with magnet footing on a metal clamped to the set-up frame to freely touch the bottom surface of the beam to measure the vertical deflections. The readings of these LVDTs might be affected while the specific beam is under loading (the clamped metal might shift during testing).

- Cyclic loading was not considered as it is beyond the scope of the study.

- Demec guage and crack mouth opening device were not used.

1.5 Thesis Outline

There are five chapters within the thesis within which chapter one presents the development of self-compacting Ferro cement matrix by replacing sand with crumb rubber by volume, subsequently produced U-shaped beam and characterising its structural behaviour experimentally. The introduction, background and objectives of the work are explained as well. The discussion of previous research work follows in Chapter 2, the methodology and experimental works were made, and the details of research methodology explained in Chapter 3. Chapter 4 discusses the experimental results and lastly the conclusions and recommendations for further investigation were presented in Chapter 5.

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