THE EFFECT OF CRUMB RUBBER FINE AGGREGATE REPLACEMENTS ON THE FLEXURAL PERFORMANCE OF FIBRE REINFORCED CONCRETE BEAMS

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by

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DEDICATION

To my loving mother and father who have supported me all my life; to my lovely wife Fatimah for her unlimited love and encouragement; to my sons and daughter whose innocent energy was and still is a source of inspiration; to all my sisters and my brother; and to all of my friends who believe in me and support me, I dedicate this work with all my love

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LIST OF ABBREVIATIONS

PC	Plain concrete
RC	Reinforced concrete
Cr	Crumb rubber
HSFs	Hooked-end bundled steel fibre
MSFs	Micro copper coated steel fibre
RCB	Rubberized concrete beam
HRCB	Hybrid rubberized concrete (layered)
CFCB	Cooper fibrous concrete beam
CFRCB	Cooper fibrous rubberized concrete beam
HCFRCB	Hybrid cooper fibrous rubberized concrete beam (layered)
EFCB	End fibrous concrete beam
EFRCB	End fibrous rubberized concrete beam
HEFRCB	Hybrid end fibrous rubberized concrete beam (layered)
OPC	Ordinary Portland Cement
LVDT	Linear variable differential transducers
Sp.#	Specimen number

LIST OF SYMBOLS

L	length of beam
b	Width of the beam
A	Area of cross section
F_c	Concrete compression strength
P	Applied force
E	Elastic modulus
R	Modulus of rupture
L	Span length
d	Depth of the spacemen
h	Height of the spacemen
μ	Ductility Index
d_u	Experimental deflection at ultimate load
d_y	Experimental deflection at yielding load
P_{cr}	Cracking Load
Δ_{cr}	Cracking Deflection
P_{yield}	Yield Load
Δ_{yield}	Yield Deflection
P_{ult}	Ultimate Load
Δ_{ult}	Ultimate Deflection
E_{total}	Total energy (Toughness)
K	Stiffness
σ_{cr}	Stress at First crack load
σ_{υ}	Stress at Ultimate load

ε_{cr}	Strain at First crack load
ε_{υ}	Strain at Ultimate load
$\varepsilon_{s\upsilon}$	Steel strain at Ultimate load
$\varepsilon_{c\upsilon}$	Concrete strain at Ultimate load
F_f	Flexural strength
Cr_{width}	Mix width of cracks
m_a	The cube mass in air
m_w	The cube mass in water
v	The cube volume
ρ	The density
D	Cylinder diameter
W_c	The cube density
σ_t	Tensile strength
P_t	Tensile load
a	is the distance to point load
I	The moment of inertia

KESAN PENGGANTIAN AGREGAT HALUS GETAH REMAH TERHADAP PRESTASI LENTURAN RASUK KONKRIT BERTETULANG GENTIAN

ABSTRAK

Diketahui umum bahawa getah remah apabila dicampurkan lu a dalam konkrit menunjukkan peningkatan dalam sifat elastik bergetah yang meningkatkan penyerapan tenaga. Walau bagaimanapun, tindakbalas statik gentian berbeza pada nisbah bidang gentian yang berbeza dicampurkan dengan agregat getah remah pada dua lapisan belum lagi disiasat. Kajian ini menyiasat kesan agregat getah remah dengan dan tanpa gentian keluli terhadap kelakuan lenturan rasuk bertetulang berlapis dan tidak berlapis pada skala penuh. Spesimen konkrit getah berlapis dan tidak berlapis disediakan dengan penggantian separa pasir sebanyak 10%, 12.5% dan 15%. Konkrit bergentian disediakan daripada gentian keluli dengan nisbah bidang yang berbeza. (80 dan 60) dengan panjang yang berbeza untuk hujung bercangkuk dan bersalut tembaga dengan nisbah isipadu 0.5%. Spesimen berlapis dibina dengan menggantikan konkrit bergetah pada lapisan atas dan kedua-dua lapisan, sementara lapisan bawah dikhaskan untuk konkrit bergentian. Spesimen tidak berlapis disediakan dengan kombinasi konkrit bergetah dan bergentian bergantung kepada nisbah bidang. Tindakbalas statik dinilai berdasarkan sifat segar dan sifat kelakuan rasuk. Dapatan kajian ini mendedahkan bahawa lapisan meningkatkan prestasi sifat mekanikal dibandingkan dengan tanpa lapisan. Peningkatan nisbah bidang gentian keluli dengan memasukkan agregat getah remah menyebabkan peningkatan kekuatan lenturan dan kekukuhan rasuk sementara nisbah bidang yang lebih rendah meningkatkan keliatan, pesongan muktamad, indeks kemuluran dan terikan. Tambahan lagi,rasuk berlapis yang baru

dibangunkan pada skala penuh membantu rasuk untuk kawalan retak seterusnya dan meningkatkan corak kegagalan. Secara keseluruhannya, keputusan menunjukkan prestasi yang memberangsangkan untuk rasuk berlapis dan spesimen piawai.

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ABSTRACT

It is well known that crumb rubber when incorporated in concrete has shown an improvement in elastic properties which actually enhance the energy absorption. However, the static responses of fibre at different aspect ratios incorporated with crumb rubber aggregate in a double layer are yet to be investigated. This study investigates the effect of crumb rubber aggregates with and without steel fibres on the flexural behaviour of layered and non-layered reinforcement concrete beams on a full scale. Rubberized concrete of layered and non-layered specimens were prepared by partial replacement of 10%, 12.5%, and 15% of sand aggregate volumes. Fibrous concrete were prepared from different types of aspect ratios of steel fibres (80 and 60) with different lengths for hooked-end and micro copper coated steel fibres at a 0.5% of the volume fractions. The layered specimens were constructed by placing rubberized concrete at the top and both layers, whilst the bottoms were dedicated to fibrous concrete. The non-layered specimens were prepared using a combination of rubberized and fibrous concrete subjected to their aspect ratios. The static responses were evaluated in terms of their fresh properties and beam characteristics' behaviour. The findings revealed that the layering enhanced the mechanical properties' performances compared to the non-layered samples. Increasing the aspect ratios of the steel fibres with inclusion of the crumb rubber aggregate led to increase in flexural strength and stiffness of the beams, whilst the lower aspect increases the toughness, ultimate deflection, ductility index and strain. Furthermore, the newly developed layered beams helped for further cracking control and enhanced the failure patterns.

Overall, the results have shown promising performance in the layered form whether in beams or standard specimens.

CHAPTER ONE
INTRODUCTION

1.1 Background

The economy, in general, and the construction industry, in particular, has grown rapidly for the last two decades. This noticeably increasing growth has led to the use of new materials in construction. Some of these materials have originated from solid wastes, which are produced by industries' processes like plastic, cartons, paper, rubber, and glass. Rubber, for instance, can expire and, therefore, it can be no longer be useful for things like tires. As environmental awareness has been growing worldwide and, therefore, many environmental agents have been striving for environmentally sustainable solutions to important issues like using rubber from scrap tires due to its way of disposal.

Scrap rubber tires constitute a world environmental issue because these tires are preferably discarded in landfills, which unfortunately provides a good ground for mosquito proliferation. This would cause diseases, as well as other serious issues being brought about when the tires are burnt, which can be a major threat to the environment. People's health can also be affected caused by the health hazards because of the air contamination which is generated from the burning of these scrap tires. Around the globe, huge quantities of waste tires are off the road from automobiles and trucks. It is estimated that around 1000 million tyres were out of service, and this figure is likely to reach up to 1200 million annually by 2030 (Blessen et al., 2016). Consequently, many countries in the world suffer from huge excesses of annually generated scrap tires as shown in Table 1.1.

Table 1.1 Statistical figures of scrap tires in several countries in the world

Source	Country	Scrap Tire Estimation
Williams et al. (1995)	Turkey	4.5 million tonnes of tires produced annually
Martin et al. (2001)	UK	37 million tires used annually
Rafat et al. (2004)	France	Over 10 million tires used annually
Sukontasukkul et al. (2006)	Thailand	250,000 metric tonnes of rubber produced annually
Batayneh et al. (2008)	US	290 million tires generated per year
Sook-Fun et al. (2009)	Singapore	25,100 tires generated per year
National Solid Waste Management (2011)	Malaysia	300 thousand tonnes produced in 2015
Yung et al. (2013)	Taiwan	Over 100,000 tonnes of tires generated yearly
Daniel et al. (2013)	Europe (EU)	1.43 billion tonnes per year
Mohammadi et al. (2014)	Australia	20 million tires used annually

It is, therefore, a big challenge for scientists to find ways recycling the large number of tires in the high consumption rate by reusing the scrap tires in different aspects of our life. An estimated over 50% of scrap tires were disposed of without receiving proper treatment, and only a small percentage of these tires underwent recycling (Blessen et al., 2016). For instance, a management programme or agents have been established in the developed countries to tackle this problem through many programmes, which help eliminate the disposal of waste tires by recycling them in different aspects of industries including engineering applications, energy recovery, and export. In this regard, data were collected and presented by Farhad et al. (2015) as to the value of recycling tires for the Organization of Economic Cooperation and Development countries (OECD) as shown in Table 1.2.

Researchers have exerted concerted efforts on investigating the possibility of reusing scrap tires in our life as illustrated in Table 1.2. Tires can be recycled in various civil engineering applications such as embankments, backfills, highway construction, soil improvement, asphalt, asphalt concrete pavement, and improving concrete properties (Peter & Tuncer, 1994; Moo-Young et al. 2003; Youwai & Bergado, 2003; Gunjian et al., 2009; and Shu &Huang, 2014).

Table 1.2 Statistical figures of scrap tire of several developed countries in civil engineering applications (Farhad et al., 2015)

Country	Recycling (%)	Civil Engineering (%)	Energy Recovery (%)	Export (%)	Total Recovery (%)	Disposal (%)
USA	17	15	55	2	89	11
Europe	43	-----	47	5	94	6
Japan	9	-----	64	17	91	9
Mexico	90	90	-----	-----	90	10
South Korea	16	16	77	-----	-----	----
Canada	75	75	20	-----	95	5
New Zealand	15	15	---	-----	15	85
Australia	17	8	1	29	55	45

Figure 1.1 Different applications of civil engineering have used the recycling of waste tire

However, most scrap tires are used in energy recovery due to the low price and the cheaper fuel resources than oil, coal, and gas. The rest of the tires' recycling proportion is exported to various countries in the world to be used in different industry sectors.

1.2 Classification of recycled rubber production

The waste rubber tires being manufactured can release as many types products after exposing them to a dual cycle of magnetic separation, then screening them based on shape and various sizes, such as ground rubber, crumb rubber, and a shredded or chopped tire products as shown in Figure 1.2. These rubber particles can be employed in concrete through partial replacement of one or more of the main ingredients of the concrete mixture (Shaheen et al., 2010).

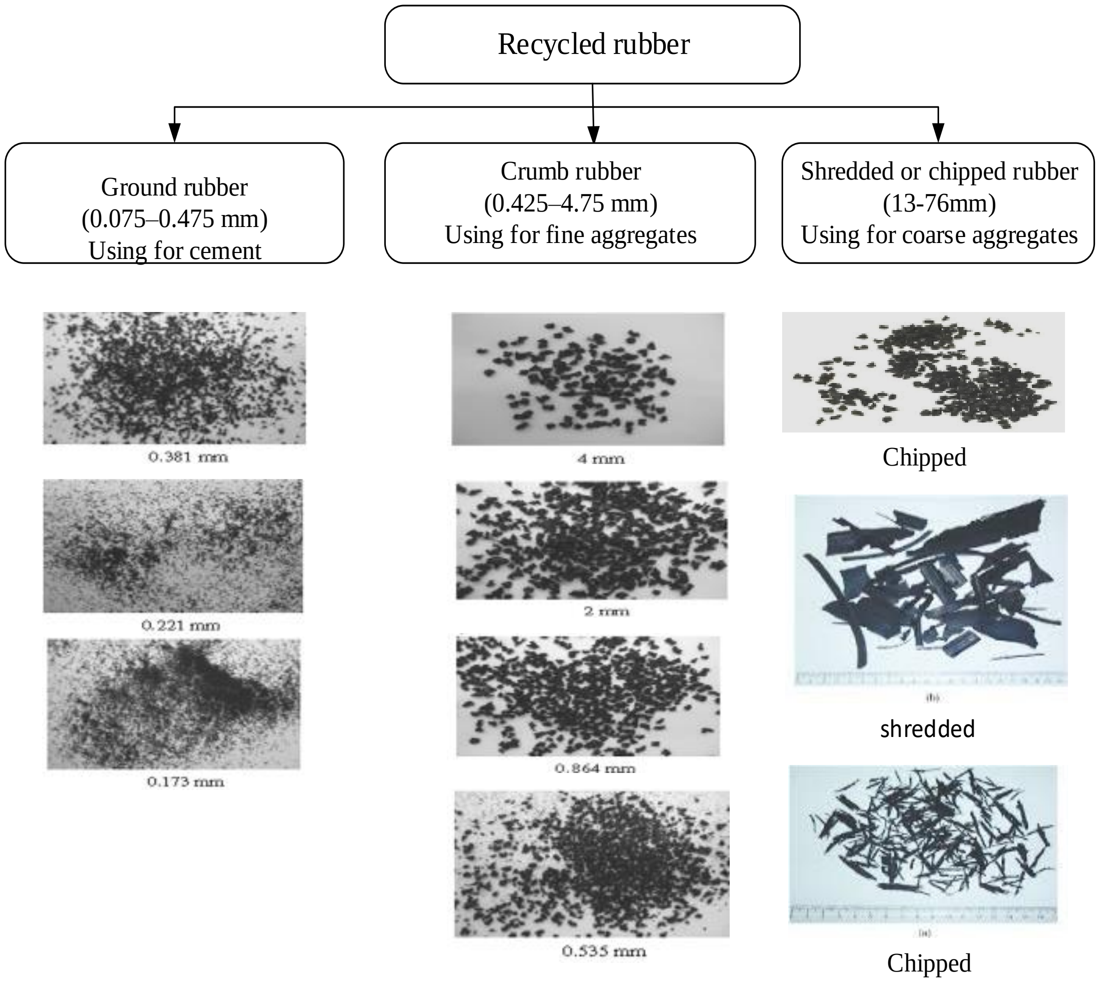

Figure 1.2 Different forms and sizes of recycled rubber (Li et al., 2014)

1.3 Steel fibre properties

Steel fibre has been well known as a finer reinforcement over the last two decades through helping reduce the concrete's brittleness and by increasing the load capacity (Tarannum et al., 2014). Using a small amount of fibre in the traditional reinforced concrete allows it to achieve better performance than the normal concrete reinforced beams. Which means improving the concrete's ability to resist extreme loadings through its mechanism that reinforces the concrete in short term (Vikrant et al., 2012). Thus, the hardened concrete properties will be improved. As a result, more energy absorption and crack control will follow (Wang et al., 2010).

Steel fibres' efficiency is based in many criteria, such as shape geometry, the volume fractions, and the aspects of ratios and distributions (Bentur et al., 2010). So, the measurement of the improvement of concrete depends on those factors. There are several types of steel fibres with different lengths. The length of the steel fibres ranges from 1.5 to 75 mm (1/4 to 3 inches). Therefore, the short or long steel fibres length have various effects on the characteristics of the concrete.

According to Carroll et al. (2016), the highest compressive strength has been found in a mix containing straight fibres and rubber particles with reasonable workability. According to Thomas and Ramaswamy (2007), steel fibres significantly affect the splitting tensile strength up to nearly 40% with the incorporation of 1.5% steel fibres into the normal concrete; as a consequence, the fibres bridge the concrete and provide crack resistance as shown in Figure 1.2. As a result, it improves the ductility and toughness of the material.

There are several aspect ratios of steel fibres and they ranged from 20 to 100. The term of the aspect ratio is defined as the length to diameter of the steel fibres (l/d ratio). Wang et al. (2010) conducted an experimental study on different aspect ratios of steel fibres incorporated in concrete and revealed the fibre's significant influence on the mechanical properties of concrete. The higher aspect ratio led to lower compressive strength, elastic modulus, and toughness, contrary to those reduced properties, it had better crack control (Wang et al., 2010).

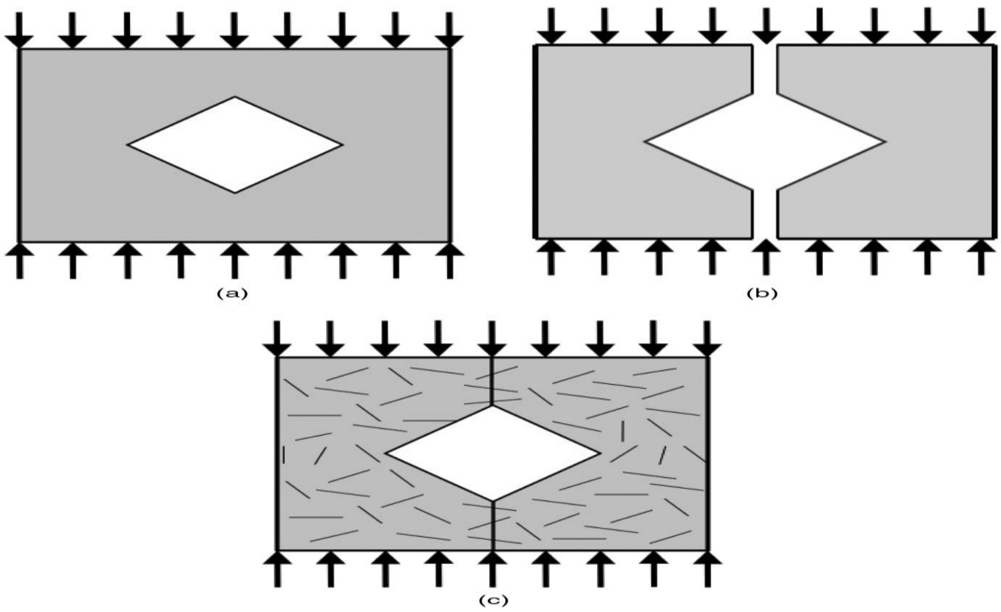

Figure 1.3 Concrete influenced by steel fibres: (a) Applied load on concrete, (b) tensile cracks perpendicular to the applied load, and (c) fibre-bridging of tensile cracks (Carroll et al., 2016)

The amount of fibres in the concrete are determined by the percentage of the total volume of the mixtures and range from 0.1 to 3% (Vairagade et al., 2015). Increasing the percentage of the steel volume in the concrete has been found to be inconsistent, which means increasing the viscosity of the cement matrix, leading to poor workability (Wang et al., 2010). Chao et al. (2006) suggested that the volume fractions of steel fibres range from 1 and 2% with some limitations, such as the proper matrix constituents and fibre type.

1.4 Fibrous rubberized concrete, layered and non-layered beams under static load

Static responses under a four-point bending loading are a common approach used to evaluate the flexural performance of full-scale beams, which represent structural elements in various construction projects. However, only a limited number of studies were conducted on such scales to test the structural members made of rubberized concrete with the inclusion of steel fibres (non-layer) at different lengths. Promising results were obtained for the fibrous rubberized concrete. For instance, Mohamed et al. (2017 a) studied the effect of crumb rubber with two types of steel fibres in two different lengths with the same aspect ratio on flexural behaviour. They pointed out that, increasing the amount of crumb rubber will reduce the crack widths and increasing the number will reduce the concrete self-weight and decrease toughness at 15% of the crumb rubber. In addition, the results exhibited an improvement in most characteristics, especially with the small length of the fibre.

Other studies by Mohamed et al. (2017 b) investigated toughness, shear capacity, cracking resistance of the rubberized and fibrous rubberized reinforcement concrete beams on a full scale with no shear reinforcement and they were tested under a four-point bending loading. In the study, the fine aggregates were replaced by a volume of 5%, 15 %, 25, and 35% of crumb rubber. Two types of steel fibre were added at different percentages, i.e., 0.35% and 1%; both had the same aspect ratio of 65 with different lengths (35 mm and 60 mm). It was concluded that the crumb rubber and steel fibre affected, directly, the bearing capacity of the beams and delayed their deformation. As a result, the ultimate energy absorption of the beams was improved by increasing the steel fibre amount when adding rubber from 5 to 15 % replacement.

However, there was a 23.6% reduction in the beam toughness by adding crumb rubber from 15% to 25%, and more than 25 % of the crumb rubber ratio caused a higher reduction in the amount of energy absorption compared to a lower ratio. Ismail et al. (2015, 2016) investigated the flexural behaviour of reinforced self-consolidating rubberized concrete (SCRC) and vibrated rubberized concrete (VRC) beams. They showed a reduction in the first crack load, ultimate failure load, and stiffness by using crumb rubber up to 20% of the fine aggregate replacement, the deformation capacity, ductility, toughness, and the concrete's strain increased. Sandeep et al. (2018) investigated the behaviour of reinforced deep beams containing fibrous rubberized concrete. It was found that the combination of the new materials reduced undesirable rubber effectiveness by balancing and reducing the loss of mechanical properties

Abqari (2016) carried out a comparative study including the rubberized concrete and layered rubberized concrete beam (hybrid) with two layers. The top was given for normal concrete, whilst the bottom was given for rubberized concrete at 20% of the volume for the fine aggregate replacement. Their height of being filled was based upon the neutral axis. The results revealed that the performance was the same for the rubberized reinforced concrete beam and the layered reinforced concrete beam during the first crack loading. However, the stiffness of the layered beams exhibited better performance than the rubberized concrete. This can be attributed to the layered reinforced concrete beam deflection, which is slightly lower than the rubberized reinforced concrete beam.

Based on the review of previous studies in this section, it can be concluded that there is a gap in the conducted previous studies. The limitations are related to the flexural behaviour of layered and non-layered fibrous rubberized reinforced concrete beams on a full scale with a different aspect ratio of fibre.

1.5 Problem statement

Steel Fibre has benefits in concrete, especially for improving the flexural strength and cracks resistance whilst, the crumb rubber improved toughness and ductility as mentioned in several studies. Most studies utilising waste rubber incorporated with steel fibres are on small-scale structures. Norman et al., (2017) investigated the mechanical properties of fibrous rubberized concrete and found that steel fibre provides a balance of losing strength that causes rubber aggregate. Another study was undertaken by Basem et al. (2018) on fresh properties with several types of fibres incorporated with rubber in concrete. The results confirmed the negative effect of crumb rubber when using steel fibre, which has led to further enhancement in mechanical properties. Aabqari (2016) investigated the effect of the layered structure (hybrid) on the flexural strength (modulus of rupture) with rubberized concrete at a 20% ratio on the bottom of the layer. The compressive strength of the cube for the layered structure (hybrid) showed a 9% better performance than rubberized concrete.

Accordingly, no previous research has so far investigated the mechanical properties of a layered structure including rubberized concrete in one or both layers with the bottom layer for the fibrous rubber at different aspect ratios

On a small scale, Al-Tayeb et al. (2012) investigated the flexural behaviour of the layered beam structures (hybrid) using a prism (100 x 100 x 400 mm) that consisted of two layers: the rubberized concrete on the top layer and the normal concrete on the bottom layer. The results showed that the energy absorption was significantly improved compared with the control sample. Ahmed (2017) investigated small beams (sized 100 x 100 x 400 mm) of layered fibrous rubberized concrete under static and dynamic loads. The results showed that the layered structures with a rubberized top layer absorbed higher flexural energy in the impact load than the static load. On the full scale, Abqari (2016) improved Al-Tayeb's proposal by investigating the characteristics of the reinforcement beam at a fixed rate of rubber (20% of volume) on the bottom layer and obtained positive results.

Based on an extensive literature review, there were some tests carried out on fibrous rubberized concrete on full scale specimens. However, there has been no research investigating the characteristics on a full scale layered beam at different aspect ratios. There were two layers; one for the rubberized concrete with different replacement ratios and the other layer was for steel fibres (straight and hook-end) at different aspect ratios. Therefore, this study aimed to investigate the effects of those combinations (crumb rubber and two different aspect ratios of steel fibres) on a full scale. In addition, this study has identified the crack patterns between several models of the layered and non-layered concrete beams.

1.6 Research objectives

This study mainly aims to enhance the characteristics of fibrous rubberized concrete for layered and non-layered structural reinforced beams by achieving the following objectives.

1. To characterize the mechanical properties of layered rubberized concrete at different ratios, including selected aspect ratios of different steel fibres.
2. To investigate the characteristics' behaviours of rubberized concrete beams with different aspect ratios of steel fibres subjected to flexural loads.
3. To identify the characteristics' performances of layered rubberized concrete beams with different aspect ratios of steel fibres subjected to flexural loads.
4. To observe and investigate the crack patterns of layered and non-layered structural beams.

1.7 Scope of the study

The scope of this study included the determination of the mechanical properties of two hundred and seventy layered and non-layered structures for fibrous rubberized concrete at 10%, 12.5%, and 15% of rubber as a partial replacement for the fine aggregate to produce rubberized concrete with long or short steel fibres at 0.5% of the volume fractions that were evaluated by using the splitting tensile and compressive strengths and density of standard specimens (cube and cylinder). However, in the current study, there were limitations and a lack of prior research studies on the mechanical properties of double-layered fibrous rubberized concrete. Twenty-four fibrous rubberized reinforced beams with control specimens of 150 x 200x 1000 mm were cast using three different ratios of rubber (10, 12.5, and 15%) and two types of steel fibres (micro copper and hooked end) at a fixed volume of 0.5%. These specimens were divided into three groups, including group (A) which represented the rubberized concrete with control, group (B) which represented the fibrous rubberized concrete with micro copper fibres, and finally, group (C) which represented the fibrous rubberized concrete with hookedend fibres. All the testing of the beams was performed under the ASTM C78/C78M (2015) standard to study the characteristics and failure behaviour.

Eighteen of the 150 X 200 X 1000 mm layered fibrous rubberized reinforced beams with equal double layers were cast using three different ratios of rubber (10, 12.5, and 15%) located on the top layer for all the groups (A, B, and C), whereas the bottom layers were cast for the normal concrete in group (A), fibrous concrete with micro copper fibres at 0.5% in group (B), and hooked end fibres at 0.5% in group (C). Then, they were tested under the flexural test to study the behaviours of the beams' characteristics and failure modes . However, there were limitations to the current study in that the contents at each layer had to include the right material as designed because mistakes may have impacted of the results.

Also, a similar set of the layered fibrous rubberized beams with additional rubberized concrete in both layers for eighteen of the 150 x 200 x 1000 mm beam specimens was studied. Then, four of the layered fibrous rubberized reinforced beams were subjected to testing for behaviour evaluation. Linear variable displacement transducers (LVDTs) were placed under the middle span of the beams to measure the deflection in the vertical directions during the flexural test. Strain gauges were attached at the middle of the concrete's top surface and steel bars in the tension zones to record the stain during the experimental process.

1.8 Structure of the thesis

This thesis has been organised into six chapters. Chapter one introduced the topic of the study, which involved rubber, fibres, and layered and non-layered structures under static load. The problem of the study, the research objectives, and the scope of the study were also presented in this chapter. Chapter two critically reviews the relevant literature, as well as the previously conducted studies on the mechanical properties and flexural behaviours of fibrous rubberized concrete of layered and non-layered structures based on the failure patterns, total energy (toughness) and stiffness, and the ultimate deflection, modulus of rupture, strain capacity, and ductility index. The methodology, the programme, and the materials, which were used in the study, are presented and discussed in chapter three. Chapter four presents, in detail, the experimental results of the fresh properties and beam characteristics of the layered and non-layered structures with failure resistance. Chapter five focuses on the layered structure through comparative studies. Chapter six is allocated for the conclusions and recommendations for future research in this area.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Concrete is one of the most popular materials used in the construction industry due to its availability, low price, and easy formation into different shapes and sizes. However, there exists a shortcoming in the bearing capacity of normal concrete and its brittleness when subjected to a bending load. This issue is because of two significant and conflicting properties at the same time, the strength and ductility of concrete, when lower ductility, subsequently, leads to higher concrete strength (Ramli & Dawood, 2011). This level of conflict needs to be improved by balancing those criteria until they reach the optimum value through adding waste materials for brittleness and ductility improvement and, at the same time, other materials for strength enhancement. An example of the waste material is scrap tires (out-road tires), which can be recycled and reused in the construction industry in different applications.

Crumb rubber, which is the commercial name, emerges from waste tires and is used by many researchers in their experiments through partial replacement of the ingredient materials of concrete, such as the fine aggregate. Thus, crumb rubber helps reduce the consumption of the raw sources used in concrete and eliminates the disposal land that is dedicated to scrap tire. Moreover, this approach can be considered as green technology and environmentally friendly and, therefore, it is recommended by many agents nowadays for recycling of the scrap tire in all possible aspects of our life (Senthamaria et al., 2011). These primary goals have encouraged many researchers to explore an appropriate way of recycling scrap tires in various and multiple aspects of our life. However, there exists some drawbacks of using rubber directly in concrete, especially in regard to the strength of the concrete, but by using some enhancement materials, such as steel fibres, the obstacle will be tackled by improving its characteristic properties.

2.2. Historical background of rubber in concrete mixtures

The growth of the construction industry has led to the use of new materials in construction, including the use of rubber from scrap tires. Prior to this, scrap rubber tires were a major environmental issue due to the way of discarding these tires in landfills where they were either buried or burnt. The potential applications of this material have needed to be investigated. Many studies have been conducted since the 1990s to determine the most appropriate rate of adding scrap tires to the concrete mixture or combining them with other materials. In the early stages of this field of research, many researchers followed the basic procedure of trial mix when adding rubber into a concrete composite by replacing a specific percentage for one or more of the main composites of the concrete, such as coarse or fine aggregates, or cement powder. This might be because there was very limited knowledge in the use of rubber. However, with time, researchers have started to understand the behaviour of rubber and its responses under static and dynamic loads.

Such a development is a green technology due to the positive effect on the environment as this method recycles rubber. Also, early studies encouraged using rubber concrete due to its improved properties in terms of toughness and ductility, which are needed in many civil engineering applications, such as jersey barriers, bunkers, and railway buffers (Shaheen et al., 2010). The manufactured rubber concrete and its amount in the concrete composite during the mixing process is crucial and must be considered in the early stages of preparation to match the design and reduce the rubbery affect. According to Najim and Hall (2010), there is a major problem of using the crumb rubber in the mixtures, which tends to segregate because the rubber absorbs the water. Therefore, to prevent this, the replacement proportion and size of the crumb rubber must be as optimum as possible for an acceptable result. Youssf et al. (2014) reported that the adhesion of the mixture to the cement was increased when mixing crumb rubber with the dry raw materials by partial replacement of the sand aggregate. However, the concrete strength was affected and became lower.

In the casting process, the time for producing the mixture, sequence of the steps, and the admixture play an essential role in the final and acceptable product of rubberized concrete. As a result, many researchers used several techniques for the mixture process' incorporation with rubber. As an example of the admixture, time, and sequences for the rubberized concrete process, the superplasticizer (SP) had been used in the ingredients of the cement mixture, with rubber and a fine aggregate in two steps, one with water containing 75% of the superplasticizer (SP); whilst the rest was added in the second step in three minutes within the mixing duration to control the workability and the slump test design (Ganjian et al., 2009). In another procedure, which concentrated on time and sequences, two minutes for dry materials mixing with rubber was suggested by Najim and Hall (2013), then water is added gradually and mixed for three minutes to ensure that the concrete is workable. The sequence of the steps and the mixture time were the focus of Su's (2014) experiments, which were divided into two mains steps. The first step was five minutes for a dry mixture, including coarse and fine aggregates, cement, and particles of rubber. The second step involved adding water, which was be done by using half of the water in the mixture for five minutes, then the remaining water was added for the next five minutes to ensure that the mixture was more consistent. There is a limitation of using rubber in the concrete composite as emphasised by many researchers to avoid any potential problems. For instance, Naito et al. (2013) suggested that less than 20% of the fine aggregate replacement with crumb rubber achieved an acceptable reduction in some specific properties, such as compressive and flexural strengths. However, according to Khaloo et al. (2008), not more than 25% of the rubber contents were acceptable in the concrete composite. Furthermore, Al-Tayeb et al. (2012a) and Ahmed (2017) recommended that the rubber concentration should not exceed 20% of the replacement because it leads to a considerable reduction in some mechanical properties. Tests were also carried out by several researchers by using different sizes of rubber and the proportion of fine aggregate replacement to explore the optimum value of using rubber in concrete mixtures. Most studies used crumb rubber between 10% - 15% in fine aggregate replacement to achieve a homogenous interaction with the rest of the concrete composite and to obtain the best results (Rashad, 2015).

2.3 Effect of fibre on normal concrete

Over the last few decades, fibres have become a common material which is recognised in the construction sector. Fibre is a modern material which is used in a variety of applications in the construction industry. Many researchers have, therefore, explored its benefits in concrete, especially for hardening. For example, Fitzgerald (2000); Mahrez et al. (2003); and Norambuena et al., (2015) reported that strength, fatigue resistance, ductility and crack pattern , tensile strength, and fracture resistance can be improved. Under an optimum load, the occurrence of cracks can be delayed in fibreized concrete compared to in normal concrete, which is a good indication of its use.

Furthermore, Gielen et al. (2008) emphasised that using fibre in a concrete mixture helps reduce the environmental impact of the structure and, as a result, the maintenance life of the structure will be extended. Li (1992) also pointed out that compressive, tensile, and bending strengths, which are critical to mechanical concrete performance, can be improved with fibre added in the concrete due to good control of resistance for both pre-existing micro-cracks and the growth rate of wing-cracks. However, the fibre addition rate, according to Shao and Shah (1997), must not be more than 1% of volume to avoid any potential workability problems. Also, Mahadik et al. (2014) concluded that the most effective approach to enhance the hardness of concrete representatives through the flexural and compressive strengths of concrete is by using steel fibres. They added that the highest benefit through getting optimum values can be obtained by using the steel fibres of 0.75% and 0.5% by fraction volumes of concrete. When this percentage of steel fibres exceeds that, the concrete will face some obstacles, such as the workability problem and air cavities, which causes a void in the concrete ingredients. On the other hand, Ramakrishna et al. (1981) reported that the elastic properties of concrete do not undergo any significant changes when lowering the fibre content. The efforts that were exerted by researchers have led to increasing the use of fibre in different sectors due to a greater exploration of its potential applications by examining its behaviour and integration with other materials.

There are several commercial types of fibre available in the market. These types are made of steel, carbon, glass, synthetics, and polymers. They are common in concrete applications. These involve all types of steel (hooked-end steel fibres, twisted steel fibres, straight steel needle fibres, and crimped steel fibres) and all types of polymers (ultra-high molecular weight polyethylene (Spectra) fibres, low-density polyethylene fibres, polypropylene fibres, and polyvinyl alcohol (PVA) fibres) (Chris et al., 2016). Figure 1.2 shows the common steel fibres used in reinforced concrete with their names and shapes (Dinh et al., 2011).

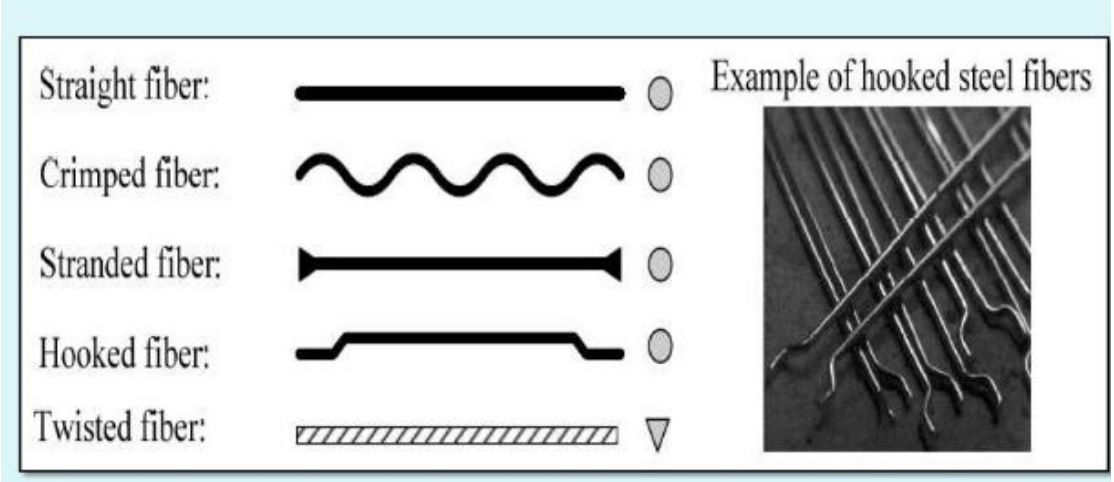

Figure 2.1 Types of steel fibres (Dinh, et al., 2011)

2.4 Properties of rubberized and fibrous rubberized concrete

2.4.1 Workability and density of concrete

Using rubber as a component of concrete is helpful in achieving a safe environment, which is free from serious hazards due to the traditional method of disposing of it. Many experts and scientists have highlighted the effects of using rubber in their experiments (the side-effects), whether they are positive or negative in concrete properties. To clarify this point, over the past 20 years, much information has become available and published on using rubber as part of a concrete mixture. Researchers have confirmed that one of the main side effects of rubberized concrete, with crumb rubber particles as the partial replacement of the fine aggregate volume, was the workability of the concrete, which can be shown by using a slump test like Ozbay, et al. (2011) who observed the workability problem due to the partial replacement of the fine aggregate in plain concrete with crumb rubber at 5%, 15%, and 25% volume percentage and used superplactizer at a fixed dosage ratio to solve the problem. They concluded that there was a reduction in the slump value (workability) at 2.27%, 9.1%, and 15.91%, respectively, with the inclusion of 5%, 15%, and 25% crumb rubber contents. In a similar work by Topcu and Demir (2007), it was reported that the workability decreased with an additional rubber content of 10%, 20%, and 30% in the concrete mixture, which was demonstrated by the reduction of the slump test at 3.1%, 6.2%, and 8.53% values, respectively. On the other hand, some researchers found an increase in workability at a specific percentage of replacement (> 10%) or a smaller size of crumb rubber.

The effect on the density of concrete with the inclusion of crumb rubber was emphasised by many researchers as being one of the side effects on concrete due to the higher porosity and lower specific gravity compared with fine aggregate particles (Albano et al., 2005; Raj et al., 2011). A lower density was reported by Albano et al., (2005), in their study, by adding crumb rubber at 5% and 10 % as partial replacements of the fine aggregate weight. They found a reduction in the concrete density at 20.33% and 29.58%, respectively. Taha et al. (2008) reported a lower density of concrete with the inclusion of crumb rubber at a high level of fine aggregate replacement from 25 up to 100%. The reduction increased at 11.57%, 14.35%, 17.13%, and 21.48% by increasing the rubber content at 25%, 50%, 75%, and 100%. Table 2.1 summarises several types of research on the effects of rubberised concrete on density and workability.

Table 2.1 Selected studies on rubber's influence (Rashad, 2015)

Study	Rubber content (%)	Rubber sizes (mm)	Effects	
			Positive	Negative
Gesoglu & Guneyisi (2007)	5%, 15%, 25%	0.15–4.75	-------	Lowered workability
Guneyisi et al. (2010)	5%, 15%, 25%	0.15–4.75	-------	Lowered workability
Ozbay et al. (2011)	5%, 15%, 25%	0-3	-------	Lowered density
Topcu & Demir (2007)	10%, 20%, 30%	(4–1)	-------	Lowered workability
Karahan et al. (2012)	10%, 20%, 30%	0.15–4.75	-------	Lowered workability
Sukontasukkul & Tiamlom (2012)	10%, 20%, 30%	3.35	-------	Lowered workability
Grdic´ et al. (2014)	10%, 20%, 30%	0.15–4.75	-------	Lowered workability, Lowered density
Balaha et al. (2007)	5%, 10%, 15%, 20%	<4	higher workability	-------
Raj et al. (2011)	5%, 10%, 15%, 20%	4.75	higher workability	-------
Parveen et al. (2013)	5%, 10%, 15%, 20%	0.075–4.75	higher workability at 5% and 10%	15% & 20% reduced workability
Antil et al. (2014)	5%, 10%, 15%, 20%	0.075–4.75	higher workability at 5% and 10%	15% & 20% reduced workability
Bravo & de Brito (2012)	5%, 10%, 15%	0.15–4.75	higher workability at 10%	Lowered workability at more than 10%
Onuaguluchi et al. (2014)	5%, 10%, 15%	<2.3	Increased workability due to smaller size	-------
Youssf et al. (2014)	5%, 10%, 20%	2.36 and 1.18	-------	Lowered workability
Pelisser et al. (2011)	10%	4–1	higher workability	-------
Guo et al. (2014)	4%, 8%, 12%, 16%	1.4–0.85		Lowered workability
Taha et al. (2008)	25%–100%	5–1		Lowered workability & Lowered density
Albano, et al. (2005)	5% - 10%	0.59		Lowered density
Turgut & Yesilata (2008)	10–70%	0.075–4.75	10- 40% higher workability	> 50%, Lowered workability
Khaloo et al. (2008)	25, 50, 75,100%	4.75	Higher workability at (25, 50, 75%)	Lowered workability & Lowered density at 100%
Azmi et al. (2008)	10, 15, 20, 30%	2–2.36	Higher workability	-------
Topcu and Sarıdemir (2008)	15, 30, 45%	0-1	Higher workability	Lowered density at 45%

In fibrous -rubberized concrete, Ahmed et al. (2017) investigated the influence of rubberized and fibrous rubberized concrete at 17.5%, 20%, 22.5%, and 25% with a fixed ratio of hook-end fibres at 0.5% of the volume fractions. It was found that the density of the rubberized concrete was lower than the fibrous-rubberized with the same replacement of sand by crumb rubber. The results confirmed that steel fibre has struck a balance between crumb rubber contents and its volumetric ratio. Mohamed et al. (2017) conducted experiments on the mechanical properties of the fibrous-rubberized concrete at 5%, 15%, and 35% of crumb rubber with two different lengths of steel fibre (35 and 60 mm) at the same aspect ratio. It was found that the density of both fibrous-rubberized was the same due to the same aspect ratio of steel fibre. However, there was a reduction of density with an increase of rubber contents, whereas the fibrous-rubberized concrete was found to be more workable with the small size of steel fibre in the same study.

Basem et al., (2018) confirmed those results in their experiments on fibrous-rubberized concrete with same materials confirming that when there was an increase in the fibre length, this has led to the risk of segregation by finding the height of slumping for short and longer fibre at 160 and 110 mm, respectively.

2.4.2 Compressive strength, modulus of elasticity and splitting tensile strength

Several studies revealed that incorporating crumb rubber in concrete caused a reduction in compressive strength based upon the replacement ratio for the fine aggregate and the reduction potential increased with increasing the content because of different materials (rubber) and its stiffness lower than particles of fine aggregate (Fattuhi & Clark,1996). Najim and Hall (2010) reported other causes that modulus of elasticity is the variance between the cement paste and rubber in the interfacial transition zone, which led to the weakness between them.

Batayan (2008), investigated the effects of crumb rubber for sizes between 0.15-4.75mm on the compressive strength of concrete by replacement of fine aggregate volume started from 20% ,40%,60%,80% and 100%. The results showed that there was a reduction in the compressive strength when increasing crumb rubber percentage at 37.8%, 47.9%, 66.7%, 81%, and 92.2%, respectively. These experiments revealed that there was a limitation percentage of fine aggregate replacement by rubber in plain concrete.

In the same phenomenon, Liu et al., (2012) experimentally investigated the compressive strength of concrete with two incorporating materials, i.e., crumb and steel fibre at a fixed ratio of 0.5% of the volume fractions and the results showed 4%, 13%, 19%, and 28% reductions in the compressive strength at 5%, 10%, 15%, and 20% of the crumb rubber content as a partial replacement for the fine aggregate.

Also, Mustafa et al. (2012) had experimentally investigated the compressive strength, modulus of elasticity, and splitting tensile strength of rubberized concrete containing 5% and 20% of the waste powder rubber with particle sizes of 0.15-0.6 mm for the cement replacement volume. The results showed a decline in the compressive strength and tensile stresses of the concrete with values of about 19%-51% and 13%-40%, respectively, compared with the control specimens. However, the elastic modulus with the same mixture composite was reduced to 10%-31%, respectively, compared with the control specimens as shown in Table 2.2.

Table 2.2 Compressive strength, splitting tensile strength, and modulus of elasticity (Mustafa et al., 2012)

Concrete type	Average compressive stress (MPa)	Average splitting tensile stress (MPa)	Average elastic modulus (KN/mm^2)
Plain	37	3.36	28.83
Pr 5%	30	2.91	26.02
P20%	18	2.03	19.81

Similarly, Su et al. (2014) had experimentally investigated the splitting tensile strength of plain concrete with the main variables containing 20% of crumb rubber for sizes between 0.3-3 mm for sand replacement. The results showed a decline in the splitting tensile strength at about 7.7% of the value.

Onuaguluchi and Panesar (2014) had experimentally studied the modulus of elasticity of concrete containing crumb rubber at different ratio replacements (5%, 10%, and 15%) by volume of the fine aggregate. The results showed a reduction of the modulus of elasticity at 14.5%, 20.1 %, and 29.8%, respectively. Based on the experiments in the compression test, both the modulus of elasticity and the compressive strength became lower when using crumb rubber.

A test was conducted by Lv et al. (2015) to investigate the effects of crumb rubber with sizes between 0.15-4.75 mm by a partial replacement ratio (10%, 20%, 30%) by volume of the fine aggregate. It was observed that there were decreases in the modulus of elasticity values of the concrete at 6.6%, 15.3%, and 23.2%, respectively, depending on the replacement ratio.