FLEXURAL BEHAVIOUR OF RUBBERIZED CONCRETE COMPARED TO NORMAL REINFORCED CONCRETE RECTANGULAR BEAM

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By

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ABSTRAK

Penyelidikan berkenaan penggantian sebahagian agregat dalam konkrit dengan elemen getah tayar yang tamat hayat perkhidmatan telah diusahakan untuk menyelesaikan masalah kesihatan dan alam sekitar yang berkaitan dengan isu pelupusan tayar sekaligus menyelesaikan masalah kekurangan sumber asli. Kebanyakan penyelidik mengerjakan kesan jumlah kandungan getah tayar dan saiz getah tayar pada sifat konkrit di peringkat bahan tetepi kajian pada ciri-ciri konkrit pada tahap struktur adalah amat terhad. Dalam kajian ini, dua jenis getah tayar, getah remah (CR) (1.15-2.36mm) dan getah serbuk (GR) (0.177mm) dan gabungan kedua-duanya telah digunakan untuk menggantikan 20% agregat halus dalam konkrit. Empat spesimen rasuk (termasuk spesimen rujukan) yang mempunyai konfigurasi tetulang yang sama telah dikaji dengan ujian empat titik lenturan untuk membandingkan kekuatan lentur muktamad, pesongan pada puncak beban dan corak retaknya. Sifat mekanik konkrit termasuk kekuatan mampatan, kekuatan tegangan juga telah diperiksa. Keputusan ujian kekuatan mampatan dan kekuatan tegangan mempunyai trend yang sama di mana saiz zarah getah berkadar songsang dengan kadar pengurangan kekuatan. Hal ini bermakna konkrit yang bercampur dengan getah bersaiz kecil (GR) mengalami kehilangan kekuatan yang lebih besar berbanding dengan getah yang bersaiz besar (CR). Hasil kajian juga menunjukkan bahawa walaupun kapasiti lentur muktamad rasuk menurun akibat campuran getah tayar, capaian pesongan rasuk pada puncak beban telah meningkat. Pada penggantian isi padu pasir yang tetep, rasuk mengandungi getah bersaiz kecil mempamerkan keupayaan lenturan muktamad yang lebih tinggi dan mencapai pesongan maksima di tengah rasuk dengan nilai yang lebih tinggi. Rasuk-rasuk ini menunjukkan keupayaan lentur muktamad yang hampir serupa

kerana ciri-ciri ini ditadbir oleh kekuatan tetulang besi pengukuhan padahal kurang dipengaruhi oleh kekuatan mampatan.

ABSTRACT

Due to the health and environmental issue associated with the waste tyre disposal and problem of the natural resources depletion, the effort of incorporating waste tyre rubber particles bring twofold benefits. Most of the researchers investigated the effect of rubber content and the rubber sizes on concrete properties at material level but limited studies carried out to determine the rubberized concrete behaviours at structural level. In this study, two types of tyre rubber, crumb rubber (CR) (1.15-2.36mm) and ground rubber (GR) (0.177mm) and a combination of both are used to replace 20% fine aggregate by volume in concrete. Four reinforced beam specimens including controlled specimens were prepared with the same reinforcement configuration and tested under four point bending test to compare their ultimate flexural strength, deflection at peak load and their cracking pattern. The mechanical properties of the rubberized concrete such as compressive strength and splitting tensile strength were also examined. For the compressive strength and splitting tensile strength test results, both possessed similar trend at which the rubber particle size is inversely proportional to their reduction rate. This means that the concrete mix with small rubber particles experienced a greater loss in strength compare to those with larger rubber particles. The results also indicated that although the ultimate flexural capacity of the beams decreased with the incorporation of rubber particles, the deflection of the beam improved with the inclusion of tyre rubber aggregate. At constant sand volume replacement, reinforced beam contained smaller rubber particles exhibited higher ultimate flexural capacity and achieved a higher maximum deflection at midspan of beam before failure. The beams exhibited almost similar ultimate flexural capacity since this property is governed by the yielding of tensile reinforcement and less influence by the compressive strength.

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CHAPTER 1

INTRODUCTION

1.1 Background information

Vehicles have been the major transportation mode for Malaysian undoubtedly. Ranking as the 3rd largest in Southeast Asia and the 23rd largest in the world, Malaysia's automotive industry has an output of 500,000 vehicles annually. The automotive industry has contributed 4% or RM40 billion to Malaysia's Gross Domestic Product (GDP) (Malaysia Automotive Institute, 2016). The blooming of the automotive industry has promoting the tyre production tremendously at the same time. When the service life of a tyre has come to the end, it turns to be a scrap tyre or waste tyre. Referring to a report prepared by Chemsain Consultant Sdn Bhd (2011), the estimated annual tonnage of scrap tyres generation has reached a total amount of 245,087 in Malaysia at 2010.

Tyre waste disposal becomes a major solid waste disposal problem which could result in a significant impact to the health and environment. Scrap tyres are non-biodegradable, durable, inflammable and their chemical composition causing air, soil and water pollution when burning. Their ability to contain water made them a suitable ground for breeding of mosquitoes which causing spreading of disease. The increasing rate of end-of-life tire generated has raise the urge to treat or recycle the scrap tire in order to minimize the amount of rubber tire discarded to legal landfill or dumped illegally. Hence, the use of recycled tire rubber in Portland cement concrete is a possible alternative to reduce the amount of tire rubber to be disposed.

Concrete, which is made up of water, aggregate and Portland cement, is the most commonly used material in civil works. The scarcity of the valuable natural aggregates used in concrete prompt the researchers to look for other waste materials to partially replace the aggregate in concrete such as waste glass, fiber and rubber. Replacement of aggregates with the waste materials can help to conserve the limited natural resources while reduces the burden of landfill at the same time. Therefore, the effort of incorporating waste tyre rubber particles into normal concrete has twofold environmental benefits as they can help to relief the waste tyre management problem and natural resources deficiency (Mendis et al., 2017).

The effort of incorporating rubber into concrete is not a new development in civil engineering field. Many researches had been done to evaluate the performance of rubberized concrete to search for possible applications on the interested field. From the studies, rubberized concrete is suitable for non-structural purpose such as lightweight concrete walls, building façades, architectural units and cement aggregate base under flexible pavements (Khatib and Bayomy, 1999). However, the use of rubber in structural concrete applications is limited due to insufficient understanding of rubberized concrete structural behaviour and adverse effects of rubber on certain concrete properties (Raffoul et al., 2016).

Hence, this project is drawn up to investigate the flexural strength of rubberized concrete beam in order to take a closer step towards the understandings of structural behaviour of rubberized concrete element.

1.2 Problem statement

Substituting aggregate in concrete with tyre rubber bring both pros and cons to the properties and performance of concrete. From previous research, rubberized concrete has found to have improved ductility, impact resistance, toughness and energy dissipation. On the other hand, the compressive strength, tensile strength and modulus of elasticity of rubberized concrete have reduced compare to the normal concrete. Due to the reduction of compressive strength as proven by other researchers, it is believed that the inclusion of rubber into normal reinforced concrete will cause a reduction on its flexural strength as well. Therefore, more experimental investigations on the structural properties of the rubberized concrete are to be carried out in order to obtain a better understanding on the behaviour of the rubberized structural element. In this study, different rubber sizes to be used to replace a fixed volume of aggregate of the normal reinforced beam to investigate the behaviour of flexural strength of rubberized beam.

1.3 Objectives

The objectives of this project are stated as follow:

i. To characterize the mechanical properties of concrete with the inclusion of waste tyre.
ii. To investigate the flexural behaviour of concrete due to the inclusion of waste tyre.
iii. To determine the deflection of the concrete beam with partial waste tyre replacement.

1.4 Scope of work

In this study, percentage of the mineral aggregate replaced by tyre rubber is keep constant which is 20% by aggregate volume. The manipulated variable in this experiment is the rubber particle size. Two types of waste tyre rubber were used which are crumb rubber and ground rubber. Both rubber types are replacing the fine aggregate in concrete. Mechanical properties of rubberized concrete are tested and evaluated such as compressive strength and split tensile strength. The main focus of this experiment is to determine the flexural capacity and deflection of the rubberized reinforced concrete beam and observe their crack pattern. Minimum reinforcement is adopted for all the beam samples and is designed following the Eurocode 2 (2004).

1.5 Dissertation outline

For better reading and understanding of this study, the thesis is categorized into five chapters including introduction, literature review, experimental program, result and discussion and conclusion.

Chapter 1: Introduction – this chapter presents a background information of the study field which reveals the tyre waste disposal issue and its possibility to be incorporated into the concrete composite. It is then followed by the problem statement to identify the reasons to conduct this research. After that, the objectives of this research are defined in order to set the desired target of work and finally the job scopes are drawn to define the boundary of this investigation.

Chapter 2: Literature review- this chapter consists of the review on the previous works conducted by other researches who use similar material (tyre rubber) to replace the aggregate in conventional concrete with different concrete properties investigation.

Chapter 3: Experimental works and details- this chapter shows the flow of the process of the research, the preparation of the experimental specimens and the procedure of the laboratory tests carried out.

Chapter 4: Results and discussion- this chapter presents the results and observations acquired through a series of laboratory works, tables and graphs are drawn to present the results and explanation and discussion are made with the support of findings from other researches.

Chapter 5: Conclusion- this chapter summarize the significant findings with respective to the objectives of this study and provide recommendations for future research purpose.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Referring to a research done by Thiruvangodan (2006), the number of waste tyres generated annually in Malaysia was estimated to be 8.2 million or approximately 57391 tonnes. The increasing number of waste tyre generated has induced tyre waste disposal problems as a huge amount of tyre wastes are stockpiled or dumped illegally. This phenomenon occurred because tyre waste requires high cost for disposal as they require large landfill area and hardly to be discomposed as well (Chemsain Consultant Sdn Bhd, 2011). Hence, burning of waste tyre becomes one of the easiest method in handling the waste tyre, which resulting in serious fire hazards. Once the tyre is ignited, the ability of it to store lot of free oxygen made the fire hardly extinguish (Thomas and Gupta, 2016). The burning of used tyres generate tremendous amount of black smoke which pollutes the air while the residue powder and oil cause soil pollution (Chemsain Consultant Sdn Bhd, 2011).

Waste tyre rubber can be used in a variety of civil and non-civil engineering applications such as geotechnical works, road construction, feedstock for carbon black manufacturing, artificial reefs in marine environment and aggregate in cement based products (Thomas and Gupta, 2016). In Malaysia, there are several scrap tyre treatment facilities established to treat or process the end-of-life tyres such as recycling of scrap tyres, production of reclaimed rubber, pyrolysis treatment and as energy recovery in cement industry (Chemsain Consultant Sdn Bhd, 2011). As a support to the effort of reducing the amount of waste tyre rubber generated, waste tyre rubber has been introduced as a partial substitution in the conventional concrete.

Numerous studies have been conducted to study the performance of rubberized concrete on the material level. A comprehensive overview about recycling rubber as fine aggregate replacement in traditional cementitious materials is done by Rashad (2016). In is generally agreed that the incorporation of tyre rubber to replace mineral aggregate in concrete has reduced the compressive strength, split tensile strength and modulus of elasticity compared to normal concrete (Eldin and Senouci, 1993); (Khatib and Bayomy, 1999); (Khaloo et al., 2008); (Taha et al., 2008); (Topcu,1995); These adverse effects may be due to the following reasons. Firstly, the rubber particles are weaker and softer than the mineral aggregates which are the main strength contributor of the normal concrete. Secondly, the rubber particles which have low water absorption, poor hydraulic conductivity and smooth surface result in a lack of adhesion between the rubber particles and cement paste, causing uneven stress distribution occur (Ganjian et al., 2009); (Khatib and Bayomy, 1999); (Raffoul et al., 2016). Thirdly, a zinc stearate layer on the rubber surface, which is developed during the manufacturing process have reduced the friction between the rubber particles and cement paste (Youssf et al., 2014).

Despite the strength and stiffness reduction brought by the rubberized concrete, some other properties of concrete are improved with the addition of tyre rubber particles such as the toughness, impact resistance, ductility, energy dissipation, damping ratio, sustainability and durability. These findings have promoting the utilization of tyre rubber in concrete for non-structural applications such as road barriers (Toutanji, 1996); (Atahan and Yucel, 2012), road kerb (Gunasegar, 2017), thin overlays, concrete panels and paving blocks. Other applications of rubberized concrete such as thermal and acoustic insulation (Holmes et al., 2014); and vibration absorbency (Toutanji, 1996) are investigated as well. For example, the precast concrete panels with partial crumb rubber substitution were found to exhibit superior thermal and sound insulation properties as measured by the decrease in thermal conductivity coefficient (k) and the increase in sound absorption coefficient (α) and noise reduction coefficient (NRC) in an experiment conducted by Sukontasukkul (2009).

2.2 Classification of scrap tyre

The production of crumb rubber in a wide range of particle size and quality levels from scrap tyre through shredding and granulation process is described in (Chemsain Consultant Sdn Bhd, 2011). Scrap tyres can be obtained from passenger cars or trucks. The tyre will be first shredded into smaller pieces and the steel wires and fabrics will be removed before mechanical grinding can be performed. Granulation can be carried out at ambient temperature, at ambient temperature under wet condition, at high temperature and at cryogenic temperature (Thomas and Gupta, 2016).

Ganjian et al. (2009) have classified tyre rubber into three main categories which are chipped, crumb and ground rubber.

(1) Shredded or chipped rubber that replace coarse aggregate

The tyres are shredded in two stages to produce this kind of rubber. The rubber pieces with 300-430mm length and 100-230mm width are produced at the end of first stage. In the second stage, the length of the rubber pieces would be reduced to 100-150mm and then further to 13-76mm. At this point, the rubber particles are named as "shredded particles" which can be used to replace coarse aggregate constituent in concrete.

(2) Crumb rubber that replaces fine aggregates

Crumb rubber particles with high irregularity in the range of 0.425-4.75mm are produced by special mills. Different sizes of rubber particles can be produced depending on the types of mills and the process temperature.

(3) Ground rubber that may replace cement

The size of the rubber produced is dependent upon the equipment used. Rubber particles sizes in a range of 0.075-0.475mm are made in micro-milling process. The waste tyres are subjected to two stages of magnetic separation and screening and various rubber size fractions are recovered in more complex procedures.

2.3 Effect of rubber particle size on mechanical property of rubberized concrete

2.3.1 Higher strength achieved by fine rubber substitution

An experiment was carried out by Eldin and Senouci (1993) to investigate the strength and toughness properties of rubberized concrete. Two types of rubber (chipped rubber and crumb rubber) were used to replace different percentage of aggregate. When the coarse aggregate was fully replaced by the chipped rubber, there was a reduction of compressive strength and tensile strength of 85% and 50% respectively. For the sample which had a full replacement of sand by the crumb rubber, a smaller reduction in compressive strength (65%) was observed. Their result also showed that the concrete containing rubber did not exhibit brittle failure under compression or split tension.

Khatib and Bayomy (1999) conducted an experiment to study the effect of both crumb rubber and chipped rubber on the basic engineering properties of rubberized concrete. Three groups of rubberized mixes were developed where the rubber contents ranged from 5 to 100% of the aggregate volume. In group A, crumb rubber was used to replace the fine aggregate while chip rubber was used to replace the coarse aggregate in group B. For group C, both types of rubber were used and the rubber content was divided equally between crumb and the chip. From the strength data developed, as the rubber content increased, the compressive, flexural and split tensile strength decreased. The strength of the rubberized concrete was reduced to as low as 10% of the control mix strength for rubber contents of more than 60% by aggregate volume. For instance, the compressive strength of fully crumb rubber and rubber chips replacement were reduced from 38MPa to 3.6MPa and 3MPa respectively. This infers that the concrete with coarser rubber inclusion has a lower strength than the fine one.

In the study conducted by Taha et al. (2008), the mechanical, fracture and micro-structural properties of concrete mixes including chipped and crumb rubber replacing the coarse and fine aggregates of concrete were examined. The replacement levels were 25%, 50%, 75% and 100% by volume of the coarse and fine aggregates. The chipped rubber was made up of two sizes from 5 to 10mm and from 10 to 20mm which were mixed with a ratio of 1:1. The crumb rubber particles ranged from 1 to 5mm. Refer to Figure 2.1, it showed that the reduction in strength due to the use of chipped tyre rubber was more significant than that when crumb tyre rubber particles were used. This indicates that the larger the size of the tyre rubber particles, the lower the compressive strength of the rubberized concrete. In addition, the reduction in compressive strength is directly proportional to the tyre rubber content.

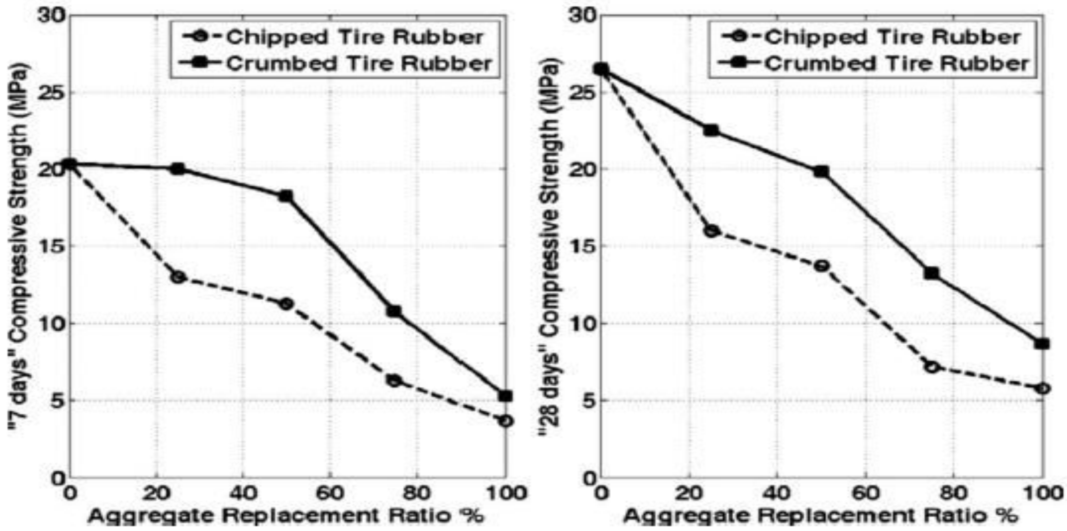
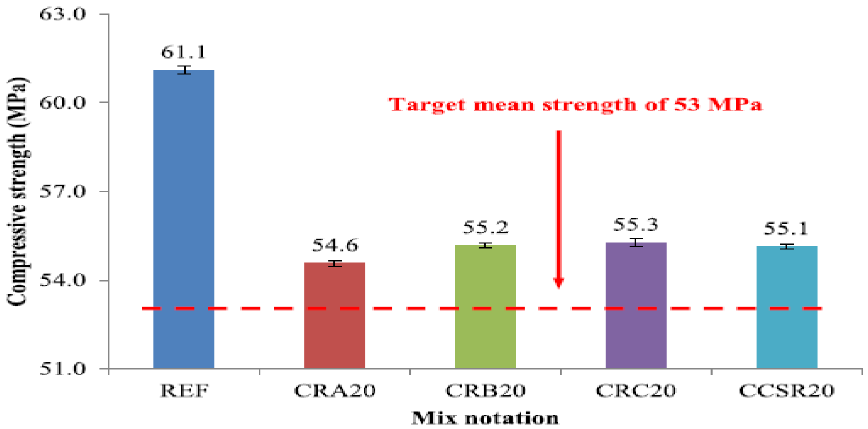


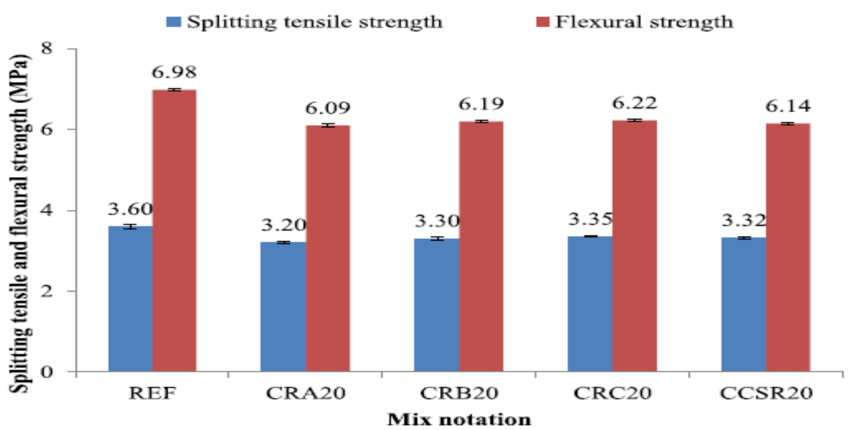
Figure 2.1: Compressive strength of rubber concrete at 7 days and 28 days of age.
(Taha et al., 2008)

Topcu (1995) investigated the changes of the properties of the rubberized concrete in terms of both size and amount of rubber chips. Physical and mechanical tests were conducted on cylindrical and cubic specimens by incorporating rubber at aggregate volume ratio of 15%, 30% and 45% into C20 quality concrete. Their results showed a reduction of 50% in the cylinder and cube compressive strength and of 64% in the tensile strength were observed in the rubberized concrete specimens containing fine rubber particles. For the rubberized concrete specimens with coarse rubber particles, they had a reduction in cylinder and cube compressive strength by 60% and 80% respectively while the tensile strength was decreased by nearly 74%. It was observed that the usage of coarse rubber particles had a more significant negative effect on the strength reduction than the fine rubber particles.

In the study conducted by Su et al. (2015), three groups of singly sized rubber particle samples labelled as CRA20 (3mm), CRB20 (0.5mm) and CRC20 (0.3mm) and one sample of continuous size grading (CCSR20) were used to replace 20% of the fine aggregate by volume. Their results showed that the mix with larger rubber particles exhibited better workability but lower strength than those with finer rubber particles. The varying sized rubber performed similar strength with the finer rubber particles but better workability than the singly sized rubber particles. As shown in Figure 2.2, the compressive strength, split tensile strength and the flexural strength increase when the rubber particles size decrease from CRA20 to CRC20.



(a) Compressive strength



(b) Splitting tensile and flexural strength

Figure 2.2: Compressive, splitting tensile and flexural strength of concrete mix with various rubber particle sizes.
(Su et al., 2015)

2.3.2 Higher strength achieved by coarse rubber substitution

Khaloo et al. (2008) studied the mechanical properties of rubberized concrete by using tyre chips, crumb rubber and a combination of both to replace mineral aggregates in concrete. The rubber particles were replaced 12.5%, 25%, 37.5% and 50% of the total mineral aggregate volume in concrete. A large reduction in compressive strength and the tangential modulus of elasticity resulted from the substitution of mineral aggregates with tyre rubber. Below 25% of rubber content, the strength for coarse aggregate replacement (C) specimen was slightly higher than the strength for the fine aggregate replacement (F) specimen while the strength of combined specimen was nearly between them. A maximum toughness index was occurred in the concrete with rubber content of 25%. Hence, rubber concentration exceeds 25% is not recommended due to the considerable decrease in strength. However, rubberized concrete has more ductile behavior under compressive force. The crack width in rubberized concrete was smaller and the propagation of failure symptom was more gradual and uniform.

Albano et al. (2005) has conducted destructive and non-destructive tests to find out the characteristic of concrete composite with partial rubber substitution. Referring to the results recorded, it was noticed that as the percentage of rubber content increase and the size of rubber particles decreased (0.59mm and 0.29mm), the flow and density of fresh concrete decreased, as well as the compressive strength and splitting tensile strength of hardened concrete.

In a research carried out by Li et al. (2014), the effect of rubber content and rubber particle size on the mechanical properties of rubberized concrete was investigated such as axial compressive strength, elastic modulus, peak strain, ultimate strain, appearance of visible cracks and failure pattern of specimens. The sizes of rubber particles used were 4mm, 2mm, 0.535mm, 0.221mm and 0.173mm. Their results showed that the axial compressive strength and the elastic modulus decreased as the rubber content increased and the rubber particle size decreased as shown in Figure 2.3. Besides, the ultimate strain of rubberized concrete was higher for smaller particles size, which indicating that the rubber particles aid in improving the deformation capability, reduce the brittle fracture of concrete and postpone the damage process of concrete. When the rubber content increased and their size deceased, the crack stress of the rubberized concrete decreased gradually but increased in crack strain, the width, length and number of cracks decreased as well.

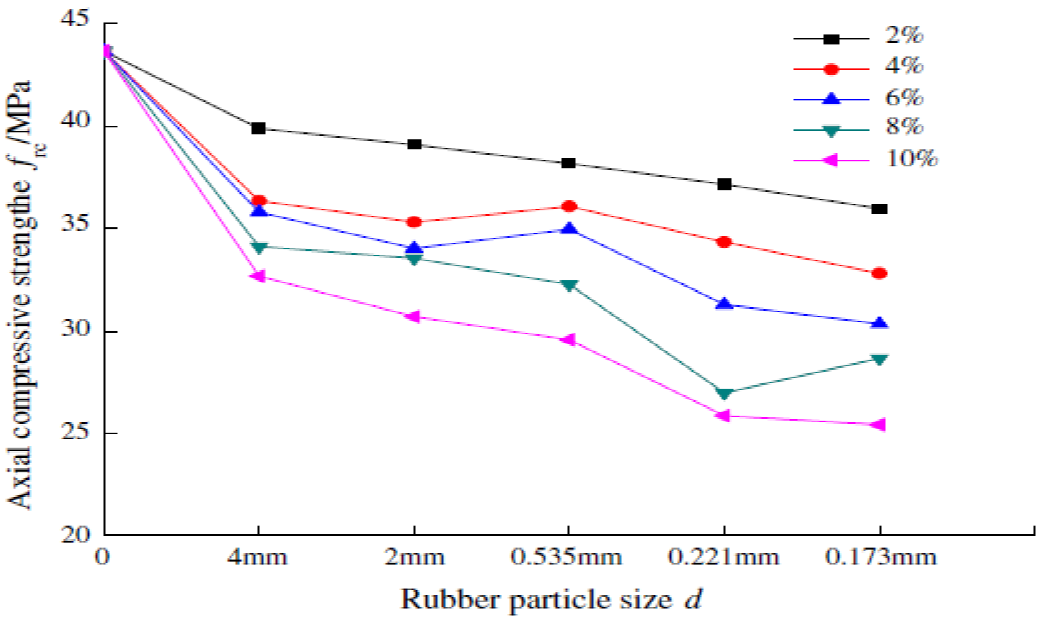


Figure 2.3: Compressive strength of concrete mix with different rubber particle size. (Li et al., 2014)

2.4 Structural properties of rubberized concrete with crumb rubber substitution

Bakar et al. (2017) carried out a research to investigate the toughness and flexural performance of beams and slabs with the inclusion of crumb rubber, steel fiber and a combination of both materials. The crumb rubber (0.15-2.36mm) was used to replace fine aggregate of plain concrete at volume ratio of 17.5%, 20% and 22.5%. Their experimental results showed that the compressive strength of all rubberized mixtures decreased with the increased in the amount of crumb rubber substitution. The loss of compressive strength was more than 20%. For the four points bending load test, reduced flexural strength at first crack and ultimate failure were observed on all the rubberized concrete beams. The optimum replacement ratio of sand aggregate by recycled crumb rubber was 20% as the maximum toughness of rubberized concrete was achieved at this ratio. At the same time, the ultimate deflection value of rubberized concrete slab increased as the rubber content increased. The post cracking behavior of the rubberized concrete slab indicated a more ductile behavior with the increased ratio of rubber content to 20%. Maximum energy absorption capacity of rubberized concrete slab was achieved at 20% rubber replacement which was 20% higher than the plain concrete slab.

Ismail and Hassan (2017) conducted a study to investigate the influence of crumb rubber (CR) with or without steel fibres on the shear behaviour and cracking of large scale self consolidating and vibrated concrete beams without shear reinforcement. The fine aggregate of concrete was replaced by crumb rubber at different volume level from 0 to 35%. In general, their results showed a negative impact on the fresh and mechanical properties, ultimate shear load, post-diagonal cracking resistance and toughness of the tested beam but improved deformability. Increase crumb rubber contents from 0 to 25% reduced the 28th day compressive strength, tensile splitting test and modulus of elasticity by 41.5%, 30.9% and 33.16% respectively. As the percentage of crumb rubber contents increased from 0 to 25%, the maximum crack width decreased from 8mm to 5mm but the number of cracks increased from 9 to 11. Similarly, varying the percentage of crumb rubber from 0 to 25% reduce the ultimate shear load and post diagonal cracking resistance of beam by 30.5% and 12.4% respectively.

Al-Tayeb et al. (2013) tested rubberized beam specimens with dimension of 100mm wide, 50mm deep and 400mm long under impact and static three point bending loadings. The rubberized concrete samples were prepared by partial substitution (5%, 10% and 20% volume replacements) of sand by waste crumb rubber. Their test results showed the impact bending load increased with the increased of sand replaced by crumb rubber, while the opposite trend was observed on the static bending load.

2.5 Flexural behaviour of large scale beam

In a research performed by Ismail and Hassan (2016), the curvature ductility, ultimate flexural capacity and cracking characteristics of different self-consolidating rubberized concrete and vibrated rubberized concrete mixtures were tested by using large scale reinforced concrete beams with square cross section of 250mm and length of 2440mm. Crumb rubber of different percentage (0-50%) were replacing the equivalent volume of sand. A reduction in fresh properties, compressive strength and tensile strength of the concrete mixtures were observed as the rubber content increased. However, the beams' curvature at service load increased as well which indicated an enhancement in deformation capacity. The optimum crumb rubber replacement percentage was 20% as highest curvature ductility is achieved at this point. Up to 20% rubber replacement, the rate of reduction of flexural capacity was lower. The crack width of beam was limited and the number of cracks increased as the rubber content increased due to increase of beam's deflection.

Four reinforced concrete beam specimens (130mm width, 225mm depth and 2800mm length) which having 0%, 6%, 12% and 18% of sand volume replaced by crumb rubber, were fabricated and tested by Hassanli et al. (2017) to examine the effect of rubber content on their structural properties. The beams were tested under incrementally cyclic loading and their behaviours including damage pattern, failure mode, force-displacement response and energy dissipation behavior were compared. Their studies showed a reduction on the compressive strength and ultimate capacity of the beam by 31% and 6% respectively when the rubber contents increased from 0% to 18%. No diagonal shear cracks were observed. As the rubber contents increased, the number of cracks increased but with reduced width and size noted. Rubberized concrete beam also exhibited more deflection capacity where an increment from 7.7% to 27.9% was observed.

Mendis et al. (2017) studied the flexural behavior of reinforced beams made up of crumb rubber concrete (CRC) mixes of similar compressive strength. The beams (100mm width, 200mm depth and 2200mm length) subjected to a two point bending load were made up of identical reinforcement arrangements and support conditions. Two groups of mixes were prepared with Group 40 and Group 30 referred to target strength of 40-45 MPa and 30-35 MPa respectively. Different CRC mixes has different rubber content (5-21%) despite having similar target strength. They found out that the CRC beams made from similar strength CRC mixes possessed similar ultimate flexural capacity in spite of having different rubber contents. These beams also showed very similar cracking moments, load-deflection behavior and peak deflection.

2.6 Summary

To the author’s best knowledge, all the researchers reported a reduction in compressive strength and splitting tensile strength when rubber particles are incorporated into the normal concrete mixture. Most of the researchers investigated the effect of rubber size on the mechanical properties of concrete by partial replacing the coarse and fine aggregate with large tire chips and small crumb rubber respectively. (Eldin and Senouci, 1993); (Khatib and Bayomy, 1999); (Taha et al., 2008); (Topcu et al., 1995); (Khaloo et al., 2008); Limited studies were carried out to inspect the fine aggregate replaced by crumb rubber with varying sizes. Among those studies, two distinct strength reduction trends were observed. Su et al. (2015) found out that the rubber particle size was inversely proportional to the strength of the rubberized concrete. However, their findings were disagree with Albano et al. (2015) and Li et al. (2014) where concrete mix with smaller rubber particles experienced a greater strength loss than the larger rubber particles.

At the structural level, most of the researches monitor the effect of percent rubber inclusion rather than the rubber particles size on the structural properties of rubberized concrete structural element (Hassanli et al., 2017); (Ismail and Hassan, 2016).

Hence, a research is drawn to investigate the effect of rubber size replacing fine aggregate of concrete on the flexural behaviour of large-scale rubberized beam.

CHAPTER 3

EXPERIMENTAL WORKS AND DETAILS

3.1 Overview

The methodology applied consists of

(i) established trial mix for the concrete mix design to perform compressive strength test;

(ii) formwork and steel reinforcement preparation; and

(iii) performed actual mix and carried out laboratory test to determine the mechanical properties and flexural behaviour of rubberized reinforced concrete beam;

The general flow of the studies is as shown in Figure 3.1.

One original Portland cement concrete as control set, two concrete mixes with crumb rubber and ground rubber each and another one concrete mix with the combination of both rubber sizes were prepared and casted. Compressive strength test was performed on cube and cylinder specimens at 7th day and 28th day of curing while splitting tensile strength test was performed on cylinder specimens at 28 days of curing. These two tests were conducted to verify the reduction in strength when rubber particle replace the aggregate of normal concrete which is also the first objective in the current studies.

Second and third objectives can be achieved when four point bending test was conducted on the large-scale reinforced concrete beam. In this test, the flexural capacity of the beams with different rubber particle size can be measured and compared. Observation was made on the cracking pattern upon flexural loading and the deflections of the beams at midspan were recorded as well.

3.2 Flowchart of study methodology

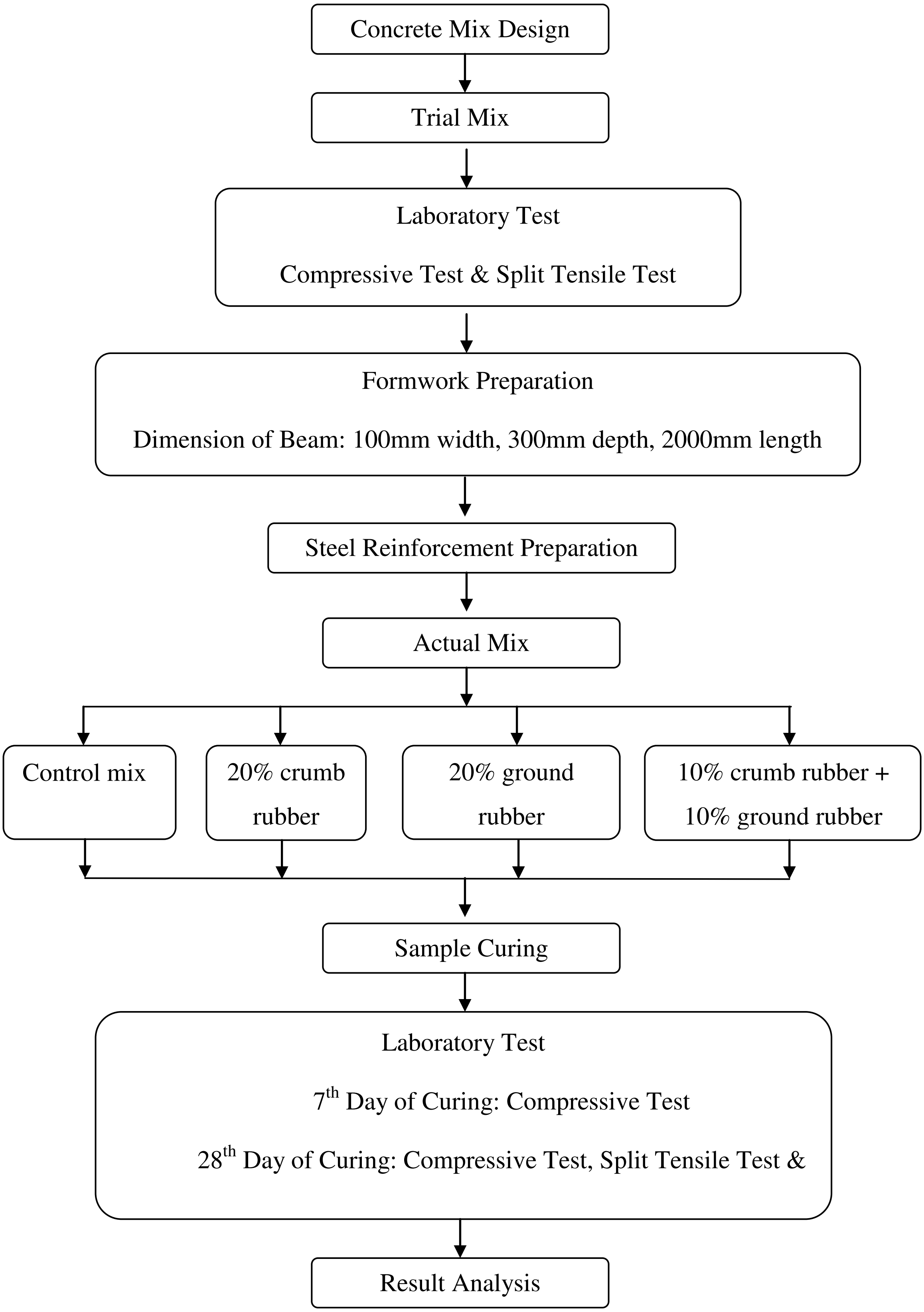


Figure 3.1: Flow chart of the research methodology.

3.3 Materials and mix design

The materials used to develop the concrete mixes in this study were Ordinary Portland Cement, fine aggregate which was natural river sand and crushed aggregate with a size ranged from 10mm to 20 mm. Two types of tyre rubbers were used to replace fine aggregates which were crumb rubber and ground rubber. Crumb rubber used had a size range of 1.15mm to 2.36 mm while the ground rubber was 80 mesh which is equivalent to 0.177mm (Chemsain Consultant Sdn Bhd, 2011). The materials used are as shown in Figure 3.2.

(a) Portland Cement (b) river sand (c) gravel

(d) crumb rubber (1.15-2.36mm) (e) ground rubber (0.177mm)

Figure 3.2: Materials used.

The mixture used in this study was adopted from the work of Khatib and Bayomy (1999). A normal Portland cement concrete of targeted compressive strength of 35MPa is designed. The results of the mix design are given in Table 3.1.

Table 3.1: Mix design of Portland cement concrete control mix.
(Khatib and Bayomy, 1999)

Material	Weight (kg/m^3)	Volume (m^3/m^3)
Coarse aggregate (gravel)	1,024	0.386
Fine aggregate (sand)	786	0.294
Portland Cement	388	0.123
Water	186	0.186
Air Voids	-	0.010
Total	2384	1.000

From the findings of Khatib and Bayomy (1999), it was suggested that the rubber content should not exceeded 20 percent of the aggregate volume. This was supported by the findings of other researchers such as Bakar et al. (2016), Ismail and Hassan (2016), Li et al. (2016) and Holmes et al. (2014). Hence, in this study, the percentage of aggregate volume replaced by the rubber was fixed at 20. Normal concrete mix developed in this study was marked as Controlled which acted as the control set in this study. For 20 percent of fine aggregate replaced by crumb rubber, the rubberized concrete was marked as CR20 while GR20 was the label for concrete mix with 20% ground rubber substitution. Another rubberized concrete mix was prepared with the combination of both rubber types where 10 percent of fine aggregate replaced by crumb rubber and 10 percent of fine aggregate replaced by ground rubber. This type of mix was marked as CR10GR10. In order to develop the rubberized concrete mix, beside the aggregate content, all the other mix design parameters were kept constant and the rubber was replacing an equal part of the aggregate by volume. The specimens' mixture proportions are shown in Table 3.2.

Table 3.2: Controlled and rubberized concrete mixture proportions.

Specimen	Portland Cement (kg/m^3)	Water (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	Crumb Rubber (kg/m^3)	Ground Rubber (kg/m^3)
Controlled	388.00	186.00	1,024.00	786.00	0	0
CR20	388.00	186.00	1,024.00	628.80	46.20	0
GR20	388.00	186.00	1,024.00	628.80	0	46.20
CR10GR10	388.00	186.00	1,024.00	628.80	23.10	23.10