PERFORMANCE OF WASTE CRUMB RUBBER STEEL FIBER CONCRETE UNDER DYNAMIC LOADINGS

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Specially dedicated to you…..

Ibu, Ayah, Adik, Family and Friends
Thank You for Your Very Supportive Words,
Those Words Make Me More Stronger,
You Guys are My Flashlight.

Thank you so much

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ABSTRACT

Production of sustainable concrete is the most crucial factor to be considered in construction fields. The utilization of waste treated crumb rubber and steel fiber can mitigate the problematic issues of Normal Concrete (NC) which is brittle, low tensile, and low damping performance. The purpose of this research is to characterize the properties of treated crumb rubber and steel fiber from waste tires, to determine the formulation of Treated Crumb Rubber Steel Fiber Concrete (TCRSFC), to investigate the mechanical properties of NC and TCRSFC, and to evaluate the damping ratio and study the response of NC and TCRSFC column subjected to dynamic loading (seismic ground motion). In this research, the percentage of treated crumb rubber as a fine aggregates substitution varied from 10%, 20%, and 25% while 0.5% and 1% of steel fiber as additional material. The tests consist of compressive strength, flexural strength, splitting tensile strength, modulus of elasticity, microstructure, free vibration, and seismic testing. Based on analysis, dynamic modulus and damping ratio of TCRSFC has improved considerably by 5.18% and 109% when compared with NC respectively. Overall, this research demonstrated the potential use of treated crumb rubber and steel fiber as sustainable concrete that can enhance the damping performance of concrete structure, which is suitable for seismic resistance structure under dynamic loadings.

ABSTRAK

Penghasilan konkrit lestari merupakan faktor yang paling penting perlu dipertimbangkan dalam bidang pembinaan. Penggunaan sisa getah remah yang dirawat dan gentian keluli dapat mengurangkan masalah konkrit biasa (NC) yang rapuh, kurang penyerapan tenaga, kurang tegangan dan kurang keupayaan terikan. Tujuan kajian ini adalah untuk mengkaji sifat getah remah yang dirawat dan gentian keluli dari tayar terpakai, untuk menentukan formulasi getah remah dirawat gentian keluli konkrit (TCRSFC), untuk menyiasat sifat mekanikal NC dan TCRSFC, dan untuk menilai nisbah redaman serta mengkaji tindak balas tiang NC dan TCRSFC apabila terdedah kepada pembebanan dinamik (pergerakan tanah akibat seismik). Dalam kajian ini, peratusan getah remah yang dirawat sebagai penggantian agregat halus berbeza dari 10%, 20%, dan 25% manakala 0.5% dan 1% daripada gentian keluli sebagai bahan tambahan. Ujian ini terdiri daripada kekuatan mampatan, lenturan, dan tegangan, modulus keanjalan, mikrostruktur, getaran bebas, dan ujian seismik. Berdasarkan analisis, modulus dinamik dan nisbah redaman TCRSFC telah meningkat dengan ketara sebanyak 5.18% dan 109% berbanding dengan NC. Secara keseluruhan, kajian ini menunjukkan potensi penggunaan getah remah yang dirawat dan gentian keluli sebagai konkrit lestari yang dapat meningkatkan prestasi redaman struktur konkrit, yang sesuai untuk struktur rintangan seismik di bawah beban dinamik.

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LIST OF ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
BS	-	British Standard
BS-EN	-	Eurocode Standard
CH	-	Calcium hydroxide
CRC	-	Crumb Rubber Concrete
CRISFC	-	Crumb Rubber Industrial Steel Fiber Concrete
CRSFC	-	Crumb Rubber Steel Fiber Concrete
C-S-H	-	Calcium-Silicate-Hydrate
ISFRC	-	Industrial Steel Fiber Reinforced Concrete
ITZ	-	Interfacial Transition Zone
MS	-	Malaysian Standard
NaOH	-	Sodium Hydroxide
NC	-	Normal Concrete
OPC	-	Ordinary Portland Cement
PLC	-	Programmable Logic Control
PSD	-	Power Spectrum Density
RC	-	Reinforced Concrete
RSFRC	-	Recycled Steel Fiber Reinforced Concrete
SCC	-	Self-Consolidating Concrete
SEM	-	Scanning Electron Micrograph
SFRC	-	Steel Fiber Reinforced Concrete
TCRSFC	-	Treated Crumb Rubber Steel Fiber Concrete
TCRSFC-M		Treated Crumb Rubber Steel Fiber Concrete-Modified

LIST OF SYMBOLS

0.1M	-	Sodium Hydroxide (NaOH) concentration
$A1$	-	First amplitude
An	-	Amplitude after next cycle
d	-	Diameter
E	-	Elastic modulus
E_D	-	Dynamic modulus
Es	-	Secant Modulus
f_y	-	Characteristic steel strength
g	-	Ground acceleration
Hz	-	Frequency
ε	-	Strain
ζ	-	Damping
σ	-	Stress

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Earthquake is a natural phenomenon that occurs due to sudden movement of plate tectonics from the earth's outermost crust. Earthquakes mostly occur when the fault at the edge of plate tectonic collide into each other or slide past each other. During earthquake, a building experiences dynamic motion because it is subjected to inertia force which is acting in an opposite direction towards earthquake acceleration and this inertia force is known as seismic loading and is assumed to be an external force to the building.

Each building has its own natural period or frequency which is dependent on the height of the building (Figure 1.1). The natural period of the ground motion is dependent on the type of soil. However, natural period of common building is within the range of ground motion period, thus creating a resonance in which the building acceleration response can go up to 1.0g when the ground motion is vibrating with 0.02g. Therefore, the building is suffering from earthquake damage when the frequency of ground motion is close or equal to the frequency of the building (Federal Emergency Management Agency 2006).

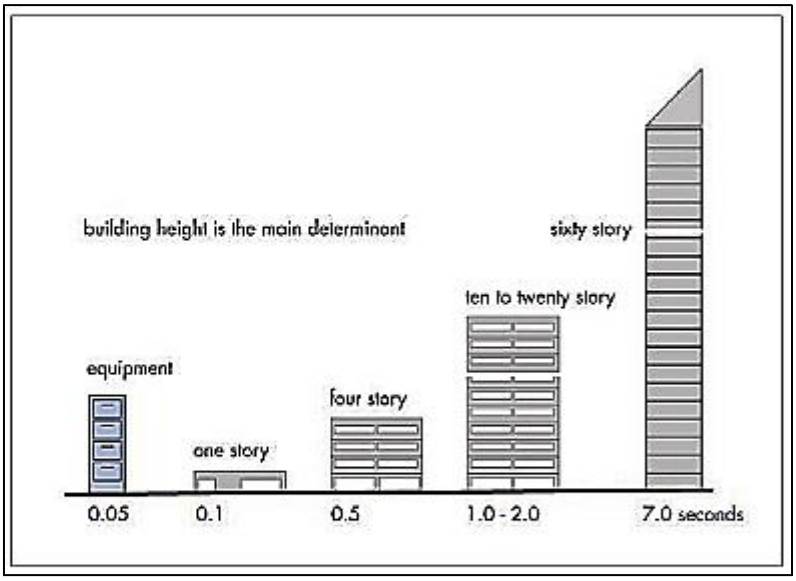

Figure 1.1 Building period based on building height (Federal Emergency Management Agency 2006)

Figure 1.2 shows the building performance level and stage of damage during earthquake event. Based on Figure 1.2, intermediate occupancy performance level is referring to the building structure that can retain its strength and stiffness during pre-loading of earthquake. In this stage, there is light structural damage. In addition, the life safety performance level is the building shows a significant damage with strength and stiffness losses compared to intermediate performance level, thus the structure probably cannot be used after earthquake event. Last but not least, collapse prevention performance level occurs when the building system cannot resist the lateral load and the building is near to collapse caused by loss of strength and stiffness (Abd-Elhamed & Mahmoud 2016).

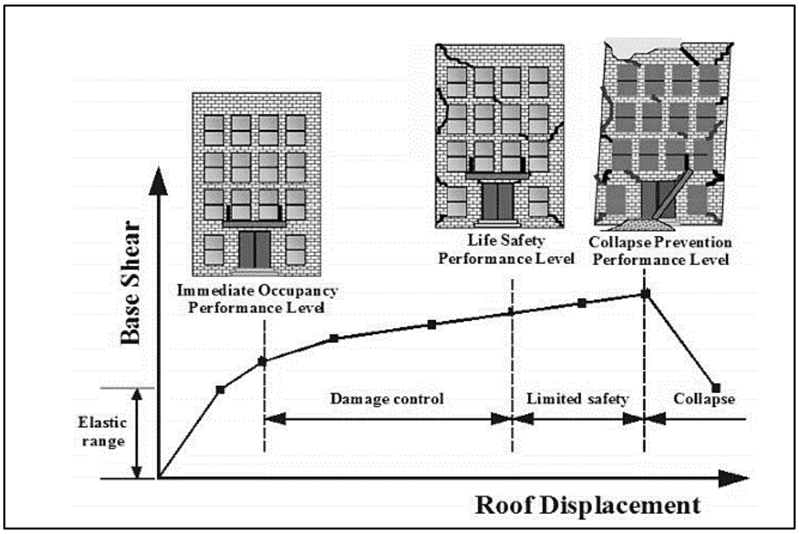

Figure 1.2 Performance of building during earthquake (Abd-Elhamed & Mahmoud 2016)

Damage to the building during earthquake can be categorized as damage due to seismic motion and damage due to ground deformation. Examples of building damage by seismic motion include falling brick or wall, damage to materials and exterior wall, and story collapse. Meanwhile, foundation damage and the ground breaking up or collapse of the building is caused by ground deformation (Building Research Institute 2011). Figure 1.3 (a) non-structural (wall) and (b) structural (column) shows the typical shear failure of building when earthquake occurs.

(a) Non-structural (wall)

(b) Structural (column)

Figure 1.3 Shear failure of (a) Non-structural and (b) Structural (column) (Building Research Institute 2011)

Many efforts have been made to improve the damping properties by improving the seismic performances. Energy dissipation control system can generally be divided into two, which is active control system (active damper) and passive control system (passive damper). Basically, a continuous energy from outside is supplied to operate the mechanism for active control system. These systems were composed with electronic device such as actuator, starter, and computer.

There are three types of active control system, which are active mass damper, active variable stiffness, and active passive composite tuned mass damper. In active mass damper, the computer system will be controlling the acceleration, displacement and velocity by forming the actuator control force. Active variable stiffness does not require formation of actuator control force but the appropriate selection for the system rigidity can make corresponding design by elimination of resonance from ground motion period. Lastly, active passive composite tuned mass damper, or hybrid control system, is a combination of active and passive systems. The advantages of these systems is the building acceleration, displacement or velocity can be controlled, and the disadvantages is the cost of these systems is very high (Torunbalci 2004).

In contrast, the passive damper does not use any energy from outside. In this system, the certain limit of displacement can be controlled because the system was designed according to a certain earthquake magnitude. Damper, isolator and some device are required in this system but can easily be found. This means that any materials that can absorb energy can be used in these system, either individually or in combination with other materials. There are several types of passive damper such as irreversible displacement system and plastic system. Balls or rolls are required for irreversible displacement system, meaning that these materials can help the structure to move horizontally when earthquake occurs. Basically, it is beneficial to construct, and using this system thus reduces the economic cost. However, there is possibility of the structure moving from its original place after earthquake event.

Next is plastic system that is composed of cylinder containing lead and piston. The energy absorption can be achieved by limitation of piston motion by the lead in cylinder. The major displacement can be controlled by lead extrusion damper. The advantage of these systems is that the plasticity of lead materials can provide the energy absorption (Torunbalci 2004).

Generally, dampers are installed between the foundations and when the building is excited by seismic motion, the induction of friction will decrease the lateral load on the top floors. In addition, it can be installed on the top of the building, such as mass damper, where it will convert the kinetic energy and stored by additional mass, thus reducing the earthquake effect. When the effect of the earthquake can be reduced, the building damage will also be reduced, but the issue of damper installation is one of long-term reliability and high costs in maintenance.

Therefore, innovations have been made to improve the passive damper compared to active damper, which would improve cost-effective design, building construction and maintenance. This research is focused on concrete properties modification to perform in a more ductile manner as passive damper by replacing fine aggregates using treated crumb rubber and the addition of randomly distributed discrete steel fiber from waste tire in the concrete matrix, which prevents and limits the initiation, propagation and integrate of cracks, thus increasing the energy dissipation by improvement of damping performance.

Generally, crumb rubber has high elasticity behavior in that can improve the deformability and ductility when it is utilized in concrete mixtures. Previous research has shown that the utilization of crumb rubber has improved its damping ratio, which is low in seismic response, but gives reduction in compressive strength and elastic modulus (Xue & Shinozuka, 2013). Meanwhile, addition of steel fiber from waste tire will help in improving the concrete properties. Previous research has shown that the inclusion of steel fiber in concrete mixtures improves the energy dissipation capability, tensile capacity, toughness and reduce surface cracking (Atiş & Karahan 2009).

On the other hand, production of waste tire is one of the main problems faced by most countries (Eldin & Senouci 1993; Zheng et al. 2008). Their production cause many environmental pollution, especially when stored in landfills or stockpile, and burning activities of waste tires causes a health hazard from excessive smoke and toxins during the burning process (Herman & S. Bisesi 2002; Issa & Salem 2013; Moustafa & Elgawady 2015).

Therefore, the innovation of crumb rubber and steel fiber from waste tire can be utilized in concrete mixture and it could improve the concrete properties especially damping performance, thus reducing the environmental problem caused by excessive production of waste tires. This study was using crumb rubber and steel fiber from waste tire in concrete mixture for seismic performance by improving damping ratio of concrete materials. In this research, crumb rubber will undergo the treatment process that will be discussed in chapter 3, and crumb rubber will be called treated crumb rubber. The replacement of treated crumb rubber in concrete mixture is not new in concrete mixtures, but this study explores the static and dynamic performance of TCRSFC to be performed as seismic structural material in construction industry.

The development of passive damper was done in this research with innovation in the structure materials by using treated crumb rubber as fine aggregate replacement and steel fiber as addition in concrete mixture, thus it could improve the ductility and damping performance of structure material and be beneficial for structures in earthquake regions.

1.2 Problem Statement

In general, building structure in earthquake regions were designed with seismic design code for structure protection. However the problem is NC properties are quasi-brittle failure, offer less ductility and less damping performance, where the nearly complete loss of loading capacity, once failure is initiated, and it could cause major damage or total collapse (catastrophic failure) of the structure especially during high intensity earthquake event.

To assuage this problem, a material that has capabilities to improve damping performance is needed in concrete materials. Generally crumb rubber has capability to dissipate energy due to its elastic behavior. Past research has proved that the rubberized concrete from waste tires can absorb energy by delaying crack propagation thus helps to improve the damping performance but the reduction in compressive strength caused by low bonding adhesion between cement paste and crumb rubber particles has become a main concern. Low bonding of crumb rubber in Interfacial Transition Zone (ITZ) can affected the concrete strength which is will be discussed in chapter 2 (section 2.62 and 2.64).

Therefore, some modification in concrete properties by replacement of treated crumb rubber and addition of steel fiber with modified water cement ratio has been made in this research to overcome this problem. This research is different from previous works which are concerned about mechanical properties of concrete containing treated crumb rubber, as this study is focused on potential of TCRSFC as seismic resistance structure. Lastly, TCRSFC will increase the energy dissipation by increasing the damping coefficient under various intensity of seismic loading under earthquake event.

1.3 Aims and Objective

The aim of this study is to analyze treated crumb rubber and steel fiber from waste tire to improve the damping performance of concrete structure to be performed as seismic resistance structure in earthquake region. The main objectives of this research are as follows:

i. To characterize the properties of treated crumb rubber and steel fiber from waste tires.

ii. To determine the formulation of mix proportion of TCRSFC.

iii. To investigate the mechanical properties of NC and TCRSFC.

iv. To evaluate the damping ratio and analyze the response of NC and TCRSFC structure (column) subjected dynamic loadings (seismic ground motion).

1.4 Scope of Study

The establishment of scope of study is to achieve the objectives from experimental works. All testing procedures followed the Malaysian Standard (MS), British Standard (BS), Eurocode Standard (BS-EN), American Society for Testing and Materials (ASTM), and some of the procedures were proposed by previous researchers.

The scopes of this study are as follows:

i. The designed (mix) strength of concrete is 30 N/mm^2 at 28 days.

ii. The maximum size of treated crumb rubber is 4.75 mm with 10% replacement of fine aggregates.

iii. Average length of steel fiber is 2.35 cm with diameter of 0.30 mm as 1% addition by volume fraction.

iv. Addition of 1% superplasticizer in Treated Crumb Rubber Steel fiber Concrete-M (TCRSFC-M) by cement density.

1.5 Significance of Study

The significance of this study is to improve the damping properties of concrete structure by utilization of the recycled materials from waste tires to be used in concrete as structural materials that improve seismic performance. This TCRSFC will benefit the construction industry especially in earthquake region area. Thus, the environment problem can be resolved to ensure the clean air for the future generation.

1.6 Thesis organization

There are five chapters in this thesis in order to achieve four objectives of the research. The arrangement of thesis is shown below:

Chapter 1: Introduction
Chapter 2: Literature Review
Chapter 3: Research Methodology
Chapter 4: Result and Discussion
Chapter 5: Conclusion and Recommendation

Chapter 1 is explain the background of study, problem statement, aims and objectives, scope of study, significance of the study regarding building performance of concrete structure when subjected to dynamic loadings which is earthquake loadings.

Chapter 2 is a review study regarding research project such as properties of crumb rubber and steel fiber from waste tires, dampers, properties of Crumb Rubber Concrete (CRC), Steel Fiber Reinforced Concrete (SFRC), and Steel Fiber Reinforced Concrete (CRSFC) that were related to TCRSFC for development of research gap.

Chapter 3 is explains the research method and standard used for conducting the experimental test that consisted of mechanical properties (compressive strength, flexural strength, splitting tensile strength, and modulus of elasticity test) and dynamic properties (free vibration and seismic test).

Chapter 4 is an analysis results and discussion on how the utilization of treated crumb rubber and steel fiber from waste tires can improve damping performance and reduce the acceleration response of concrete structure when subjected to several earthquake intensities.

Chapter 5 is a conclusion of research project that were presumed based on research objectives.

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