# EFFECT OF CRUMB RUBBER INCORPORATION ON THE BEHAVIOUR OF CONCRETE BEAM SUBJECTED TO IMPACT LOAD

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**UNIVERSITI SAINS MALAYSIA**

**2013**

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**by**

**MUSTAFA M. M. ALTAYEB**

**Thesis submitted in fulfillment of the requirement for the degree of Doctor Philosophy**

**2013**

**بسم الله الرحمن الرحيم**

**(قُلْ إِنَّ صَلَاتِي وَنُسُكِي وَمَحْيَايَ وَمَمَاتِي لِلَّهِ رَبِّ الْعَالَمِينَ , لَا شَرِيكَ لَهُ وَبِذَلِكَ أُمِرْتُ وَأَنَا أَوَّلُ الْمُسْلِمِينَ)** (الأنعام:162-163)**.**

**عن أمير المؤمنين أبي حفص عمر بن الخطاب رضي الله عنه قال سمعت رسول الله صلى الله عليه وسلم يقول "إنما الأعمال بالنيات , وإنما لكل امرئ ما نوى , فمن كانت هجرته إلى الله ورسوله فهجرته إلى الله ورسوله , ومن كانت هجرته إلى دنيا يصيبها و امرأة ينكحها فهجرته إلى ما هاجر إليه " متفق عليه**

# *DEDICATION*

*To my loving parents Maher and Sabah Al-Tayeb who supported me at all the way; to my wife Heba Al-Tayeb for her unlimited love, patience and encouragement; to my children whose innocent energy was and still a source of inspiration; to all my sisters; to all my family members; to all of my friends and colleagues who stood beside me with great commitment; I dedicate this work hoping that I made all of them proud.*

*Mustafa Maher Altayeb*

## ACKNOWLEDGEMENTS

First of all, Alhamdulillah I praised to Allah S.W.T for the blessing granted to us……

I would like to give my deepest gratitude and appreciation to my supervisor Professor Badorul Hisham bin Abu Bakar, not only for his support and motivation during the research ,but also for his high humanity feelings with his students and other people and to my co-supervisors; Professor Hanafi bin Ismail and Professor Hazizan bin Md bin Akil for guided and advised me in this study.

Thank you very much goes to the School of Civil Engineering and Universiti Sains Malaysia for science and financial support. A farther debt of gratitude is due to the Ministry of Higher Education of Malaysia for the Malaysia International Scholarship (MIS).

Thank you very much goes to the staff and lab technicians of School of civil, Materials & Mineral Resources Engineering and Mechanical Engineering at Universiti Sains Malaysia.

Finally, I would like to express my sincere appreciation to brothers, friends and all the people who helped me throughout this research.

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## LIST OF SYMBOLS

| | |
|---|---|
| A | Area of cross section |
| $a_o$ | Notch depth of the beam |
| $[B_i]$ | Strain- deflection matrix |
| b | width of the beam |
| $C_i$ | Initial compliance |
| D | Diameter of cylinder |
| $[D]^{-1}$ | Isotropic elasto-plastic matrices |
| d | Depth of the beam |
| E | Young's modulus |
| $E_b$ | Fracture energy |
| $E_f$ | Fracture Young's modulus |
| $F_{i1}(t)$ | Equivalent force for the distributed forces inside the support |
| $F_{i2}(t)$ | Equivalent force for the distributed forces outside the support |
| $\{f\}$ | Loading vector |
| $f(\alpha)$ | Geometry correction for bending load |
| G | Modulus of rigidity |
| g | Gravitational acceleration |
| $H$ | Drop height |
| $[K]$ | Stiffness matrix |
| $K_{IC}$ | Stress intensity factor |
| L | Length of the beam |
| $L_c$ | Length of cylinder |
| $l$ | Span length of the beam |

| | |
|---|---|
| [M] | Mass matrix |
| $M_c$ | Moment at the center |
| m | Mass of the hammer |
| $[N]$ | Element shape function array |
| $n$ | Number of bows |
| $P_b(t)$ | Generalized bending load history |
| $P_c$ | Compression load |
| $P_i(t)$ | Generalized point inertial load history |
| $P_{max}$ | Maximum bending load |
| $P_T$ | Tensile load |
| $P_t(t)$ | Total tup load history |
| R(t) | Reaction at the support |
| U | Total impact energy |
| {u} | Deformation vector at any location over the element |
| $\{u_i\}$ | Deformation vector at the specified node of the element |
| $u_i$ | Displacements of the point in the directions of the Cartesian x axes |
| $u_c(t)$ | Time history of the central deflection |
| u(x, t) | Deflections history of the portion of the beam inside the supports |
| u(y, t) | Deflection s history of the portions of the beam outside the supports |
| $\ddot{u}_c(t)$ | Time history of the central accelerations |
| $\ddot{u}(x, t)$ | Acceleration history of the portion of the beam inside the supports |
| $\ddot{u}(y, t)$ | Acceleration history of the portions of the beam overhanging the supports |
| $\delta u(x)$ | Virtual deflections of the portion of the beam inside the supports |
| $\delta u(y)$ | Virtual deflections of the portion of the beam inside the supports |

| | |
|---|---|
| $v$ | Velocity of the hammer immediately before the contact |
| $v_i$ | Displacements of the point in the directions of the Cartesian y axes |
| W | Self-weight of the beam |
| $w_i$ | Displacements of the point in the directions of the Cartesian z axes |
| $\alpha$ | $a_0/d$ |
| $\Delta E$ | Kinetic energy lost by the hammer |
| $\varepsilon$ | Normal strains |
| $\{\varepsilon\}$ | Strain vector |
| $\gamma$ | Tangential strains |
| $\rho$ | Mass density |
| $[\rho]$ | Density matrix |
| $\sigma_c$ | Compression stress |
| $\sigma_T$ | Tensile stress |
| $\sigma_x$ | Normal stresses on the x plane |
| $\sigma_y$ | Normal stresses on the y plane |
| $\sigma_z$ | Normal stresses on the z plane |
| $\tau_{xy}$ | Shearing stresses on the x plane and y direction |
| $\tau_{xz}$ | Shearing stresses on the x plane and z direction |
| $\tau_{yz}$ | Shearing stresses on the y plane and z direction |
| $\upsilon$ | Poisson's ratio |
| $\xi$ | Local coordination in the directions of the Cartesian x axes |
| $\xi_i$ | Displacements of the node in the directions of the Cartesian $\xi$ axes |
| $\eta$ | Local coordination in the directions of the Cartesian y axes |

$\eta_i$ Displacements of the node in the directions of the Cartesian $\eta$ axes

$\zeta$ Local coordination in the directions of the Cartesian z axes

$\zeta_i$ Displacements of the node in the directions of the Cartesian $\zeta$ axes

## LIST OF ABBREVIATIONS

| | |
|---|---|
| ASTM | American Society for Testing and Materials |
| CMOD | Crack Mouth Opening Displacement |
| Cr | Concrete with replacement of sand volume by percentage of crumb rubber |
| CrT | Hybrid concrete beams in case of casting the top layer of the beam by rubberized concrete with percentage of crumb rubber |
| EN | European Union standard |
| Fr | Concrete with replacement of sand volume by percentage of fine crumb rubber |
| FrT | Hybrid concrete beams in case of casting the top layer of the beam by rubberized concrete with percentage of fine crumb rubber |
| ITZ | Interfacial Transition Zone |
| MS | Malaysian Standard |
| OPC | Ordinary Portland Cement |
| Pr | Concrete with replacement of sand volume by percentage of rubber powder |
| PrT | Hybrid concrete beams in case of casting the top layer of the beam by rubberized concrete with percentage of rubber powder |
| SEM | Scanning Electron Microscopy |

**KESAN PENAMBAHAN CEBISAN GETAH TERHADAP SIFAT RASUK KONKRIT DI KENAKAN BEBAN HENTAMAN**

## ABSTRAK

Konkrit yang mengandungi cebisan getah di dalamnya telah diketahui umum menambahbaik sifat keanjalannya serta kemampuan untuk menyerap tenaga. Walau bagaimana pun, tenaga lentur sebenar di bawah beban hentaman masih dipertikai dan diperdebatkan. Tambahan pula tingkah laku hibrid (getahan di atas-konkrit biasa dibawah) struktur konkrit hibrid di bawah beban hentaman atau dalam keadaan beban statik masih dikaji.  Oleh itu dalam kajian ini, eksperimen dan analisis tak linear dinamik konkrit dengan penambahan cebisan getah dikaji. Penambahan cebisan getah (5%, 10% dan 20%) berasaskan isipadu pasir atau simer dilakukan terhadap konkrit. Tiga saiz cebisan getah yang berbeza digunakan cebisan getah (1 mm), cebisan getah halus (0.4-0.9 mm) dan serbuk cebisan getah (0.15-0.6 mm). Tiga jenis spesimen iaitu konkrit biasa, konkrit berlapis getah,  dan konkrit lapisan berganda disediakan dan dilakukan ujian hingga gagal menggunakan mesin hentaman beban jatuh seberat 20 N dari ketinggian 300 mm, dan tiga lagi spesimen yang sama telah digunakan untuk ujian beban statik. Dalam kedua-dua ujian, beban-pesongan dan keretakan setiap spesimen telah dikaji. Simulasi unsur terhingga telah juga dilakukan untuk mengkaji tingkah laku dinamik sampel dengan menggunakan perisian LUSAS V.14. Rasuk dimodelkan sebagai elemen heksagon dan mempunyai lapan nod. Bahan elastoplastik telah digunakan untuk memodelkan kedua-dua struktur konkrit biasa dan konkrit bergetah tersebut. Skim dinamik tak tersirat telah digunakan untuk menentukan peningkatan pesongan dengan masa. Secara umum keputusan menunjukkan beban impak semakin meningkat dengan peningkatan dalam

peratusan getah. Pemerhatian menunjukkan bahawa kesan ini adalah lebih ketara untuk spesimen lapisan berganda. Secara umum, kekuatan dan tenaga keupayaan menyerap konkrit berlapis getah adalah lebih baik di bawah pembebanan hentaman daripada pembebanan statik. Beban simulasi terhadap tingkah laku pesongan semua sampel telah disahkan oleh keputusan eksperimen.

# EFFECT OF CRUMB RUBBER INCORPORATION ON THE BEHAVIOUR OF CONCRETE BEAM SUBJECTED TO IMPACT LOAD

## ABSTRACT

It is well known that concrete containing crumb rubber would enhance the elastic properties of concrete as well as ability to absorb energy. However, the actual flexural energy under impact load is still questionable and debatable. Moreover, the behavior of hybrid (rubberized top-plain bottom) concrete structures under impact or static load conditions are yet to be investigated. In this study, experimental and nonlinear dynamic analysis of rubberized concrete under impact load was investigated. Rubberized concrete samples were prepared by partial substitution (5%, 10% and 20 % replacements by volume) of sand or cement by two size of crumb or powder rubber respectively, and tested under impact three-point bending load, as well as static load. Three types of specimens namely, plain concrete, rubberized concrete, and double layer concrete were loaded to failure in a drop-weight impact machine by subjecting to 20N weight from a height of 300mm, and another three similar specimens were used for the static load test. In both tests, the load-deflection and fracture energy of each specimen were investigated. Finite-element simulations were also performed to study the dynamic behaviours of the samples, by using LUSAS V.14 software. The concrete beam was modeled to be built with eight node hexahedron elements and elasto-plastic material was used to model both plain and rubberized concrete structures. Explicit nonlinear dynamic scheme was used to determine the deflection increments for each time step.In general the result was noticed that, the impact loads increased with the increase in the percentage of rubber. It was interesting to observe that these effects were more significant in the double layer specimen. In general, the strength and energy absorbing capability of

rubberized concrete was better under impact loading than under static loading. The simulated load against deflection behaviours of all the samples were validated by the experimental results.

# CHAPTER ONE

# INTRODUCTION

## 1.1 General introduction

Concrete is the most commonly used construction material. In the context of the current construction requirements, the properties of concrete in terms of its flexibility, toughness, energy absorption and impact resistance needs further improvement (Topcu, 1995 and Wang et al., 2000). On the other hand disposal of waste rubber is a serious environmental issue all around the globe, on account of its health hazard and difficulty in land filling. The high cost of disposal and the requirement of large landfill area often result in random and illegal dumping of waste rubber (Siddique and Naik, 2004) and over 281 million scrap tires are generated in United States every year (Baker et al., 2003). According to "Markets for Scrap Tires"1991 edition, published by the US Environmental Protection Agency (EPA), only 7% of the tires are recycled into new products and about 11% are converted into energy. Over 77.6%, or about 218 million tires per year, are land filled, stockpiled, or illegally dumped and the remaining 5% are exported. In Malaysia, a number of project involving a huge investment in waste rubber recycling has been monitored. For instance, in 2002 a project totaling RM4.47 billion was approved by Malaysian Industrial Development Authority (MIDA) to proceed with the recycling project of scrap tires to manufacture synthetic rubber powder and thermoplastic elastomer (TPE) (Awang, 2008).

Figure 1.1 shows one such dump yard in Thailand reflecting the gravity of the problem. Figure 1.2 shows that the flow chart detailing the distribution of the scrap tire.

Landfilling of scrap tires in open piles causes a number of problems such as degradation of the landscape, health diseases vectored by mosquito, and serious open tire fires which is difficult and need long time to extinguish (See Figure 1.3). Moreover it has serious impact on health and the environment due to dangers of air emissions via black and carbon smoke and also contamination of water and soil due to the run-off water and pyrolytic oil released from the burning tires (EPA, 1991 and Siddique and Naik, 2004). Due to the high cost of disposal and the requirement of large landfill area for waste rubber, the issue of random and illegal dumping is alarming (Siddique and Naik, 2004).

Fig. 1.1: Piling yard of abandoned tires in Thailand (Sukontasukkul and Chaikaew, 2006)

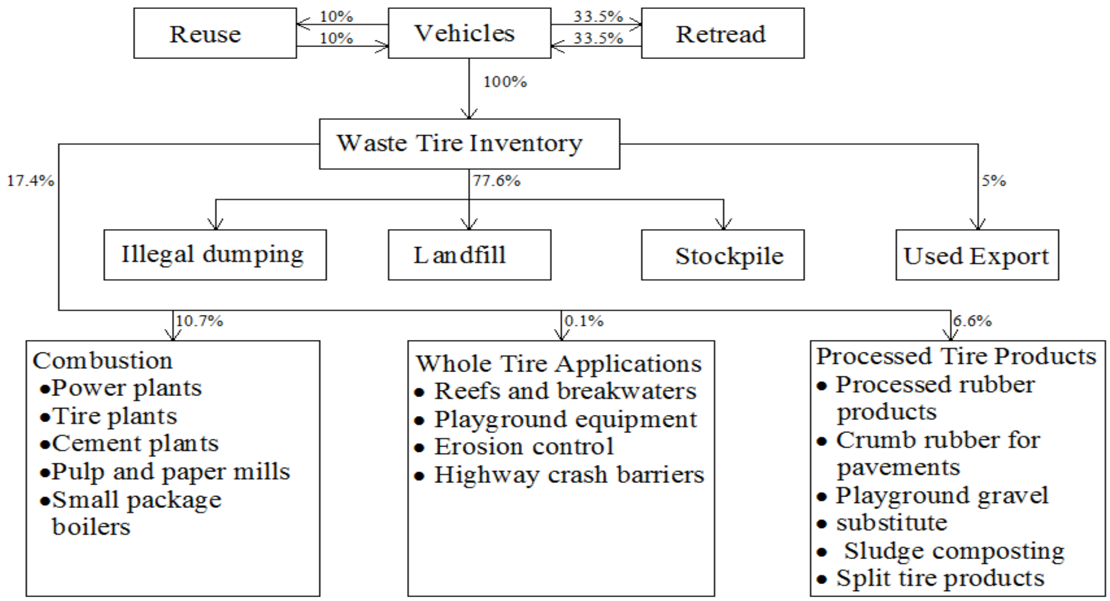


Fig. 1.2: Flow chart of destination of scrap tires (EPA, 1991).

Fig. 1.3: Fire accident due to wasted tires in Stanislaus County, CA. (Sukontasukkul and Chaikaew, 2006)

Driven by this situation, efforts are on, to identify alternative solutions to reuse the waste rubber, and its use in concrete as partial substitutes for sand. This partial replacement of rubber in cement has been proven to be one of the promising options.

## 1.2 Classification of scrap-rubber

According to Siddique and Naik (2004), scrap-rubber can be classified into four types with regard to their particle size:

### 1.2.1 Slit tires

The tires are produced by separating the sidewalls from the thread of the tires or cutting the tire into two halves. This process was carried out in large amount of scrap tires in the factory (Siddique and Naik, 2004).

### 1.2.2 Shredded/chipped tires

It is produced by shredding tire into shreds or chips that vary from 300 to 460 mm long, 100 to 230 mm wide, and 100–150 mm length in the primary process. Production of tire chips, usually sized from 76 to 13 mm requires both primary and secondary shredding to achieve reduction of volume. Figure 1.4 shows the appearance of shred tire (Khaloo et al., 2008).

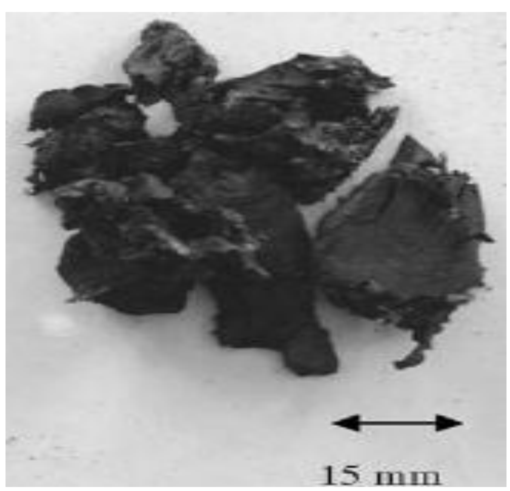


Fig. 1.4: Shredded/chipped tires (Khaloo et al., 2008)

### 1.2.3 Ground rubber

The two process involved in ground rubber are magnetic separation and screening process. Normally the size of ground rubber varies from 19 mm to 0.15 mm depending on the size of reduction, equipment and envisioned usage. Figure 1.5 shows the appearance of ground rubber (Khaloo et al., 2008).

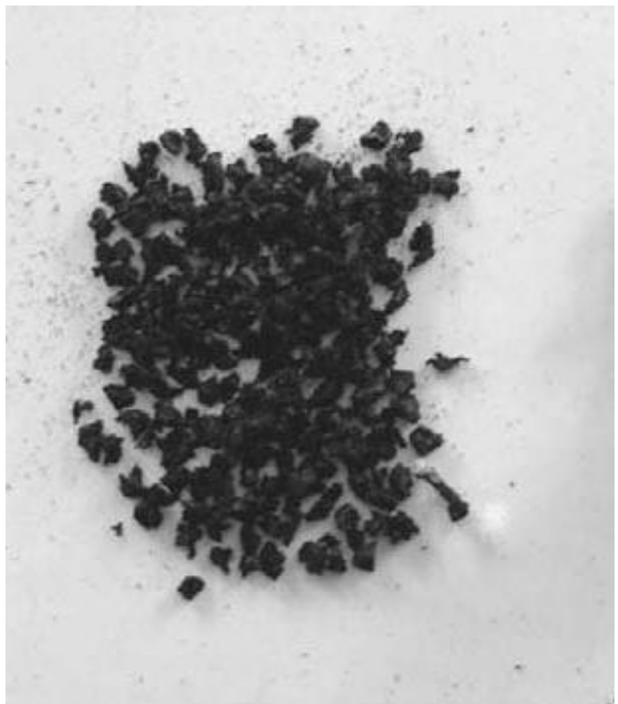

Fig. 1.5: Ground rubber (Khaloo et al., 2008)

### 1.2.4 Crumb rubber

The typical process in making crumb as in Figure 1.6 involves three stages. First, the scrap tire is reduced to particles ranging from 5 to 0.075 mm size shreds by reducing the size of tire rubber. This is generally accomplished by passing the material between rotating corrugated steel drums or the cracker mill process which tears it apart. Second, the screen and gravity separators are used to remove metal. And finally, aspiration equipment is used to remove fibers (Son et al., 2011).

Fig. 1.6: Crumb rubber (Son et al., 2011)

In this research three different sizes of crumb rubber which are crumb rubber of 1 mm particle size, fine crumb rubber of particle size 0.4–0.9 mm and powder crumb rubber of particle size 0.15–0.6 mm will be added to concrete. The mechanical properties of the concrete will then be investigated.

### 1.3 Cement and concrete history

Cement is defined as adhesive and cohesive material having capability to bond fragment or masses of solid material (Lea and Hewlett, 1998). The use of cementing materials can be dated back to very ancient times. The ancient Egyptians used lime mortar in the pyramid construction. The Greeks and Etruscans also used cement limestone. The first concrete in history was developed by Romans who improved the mortar properties by adding sand and crushed stone or brick and broken tiles to lime and water (Neville, 1995). One of the most remarkable examples of the concrete works is the Pantheon dome as seen in Figure 1.7 (Wilkins, 2004).

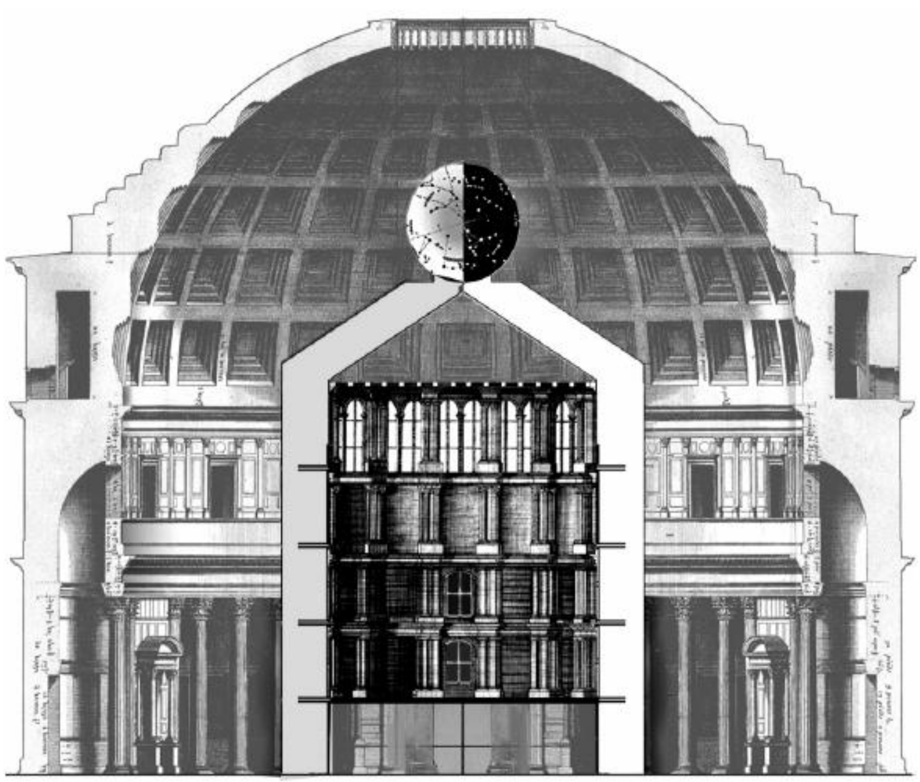

Fig. 1.7: Romans Pantheon dome (Wilkins, 2004)

The Romans discovered that lime mortar does not harden under water, so they milled lime and volcanic ash or finally ground burnt clay tiles to produce pozzolanic cement referring to village of Pozzuoli, near Vesuvius. Modern concrete technology took shape in the late 18th century. In 1756, it was discovered that the best mortar could be produced by mixing limestone with pozzolana which contains high production of clayey material. It was only in 1824, Joseph Aspdin discovered the Portland cement. This cement is formed by heating finely divided clay with ground limestone in a furnace until $CO_2$ has been driven off. Isaac Johnson in 1845 discovers the prototype of modern cement by burning its raw materials to clinkering temperatures in order to satisfy the reaction necessary for creating strong cementing compounds (Neville, 1995).

### 1.4 Rubberized concrete and impact load

Recently many researchers have carried out investigations on the ability of tire rubber in concrete as a replacement for sand or aggregates to improve the properties of concrete and to reduce the waste material dumping problems by utilizing these waste materials as raw material.

The ability to reuse rubber as partial replacement in concrete was studied by Eldin and Senouci (1993), in which they used two groups of rubberized mixes. In the first group, part of sand was substituted by crumb rubber in the range of 25, 50, 75 and 100 percentages. In the second group, a portion of coarse aggregate was substituted by chip rubber in similar percentage as in the first group. The result observed using 100% of crumb rubber as sand replacement leads to losses of up to 65% of the compressive stress and up to 50% of the tensile stress in the first group. However the study also concludes that the ductility of concrete was improved which makes rubberized concrete suitable for structure subjected to dynamic or impact loading. Topcu (1995) also demonstrated that using waste tire in concrete improves the toughness value and the plastic energy capacities. He concluded that high ductility of rubberized concrete leads to high strains under static and impact load.

The impact resistance of rubberized concrete was studied by Topcu and Avcular (1997) for highway barriers. They determined that the presence of rubber tire particles yields significant enhancement in the impact resistance. Similarly,Taha et al. (2008) observed enhancement in the impact resistance of concrete beams by adding crumb or chipped tire rubber particles. Nevertheless, almost all the previous studies investigated the impact resistance of rubberized concrete qualitatively by counting the numbers of blows that result in cracking or failure of the structure. However, this method was improved by Banthia (1985) method which is not followed by Taha et al (2008) to measure the load, deflection and acceleration of concrete beam under impact energy.

### 1.5 Finite element analysis

There are several difficulties in analyzing normal or rubberized concrete structures under dynamic load because of the nonlinear behaviour of structure and the nonlinear dynamic load with time. New approaches of nonlinear structural analysis have been introduced in the recent times owing to the development of powerful computers, where the structural response can be investigated in terms of the total loading range. The finite element approach is one of such important method which solves the numerical equations that govern the problems found in nature. The finite element method improved in the field of structural engineering where dimensional element to analyzed the stresses in continuous bars and beams was developed. Then the shape functions defined over triangular regions in the applied mathematics was developed. Then treatment of two-dimensional elements was developed by derived the stiffness matrix for triangular and rectangular elements in plane stress. After that matrix structural analysis was driven from the stiffness matrix of a plane stress rectangular panel. The formulations of element stiffness matrices by early investigators were not based on the field equations of the entire elastic continuum (Huebner et al. 2008).

In 1967 Zienkiewicz published the first book describing applications of the method in the analysis of material behaviour. After that the finite element method became one of the most important methods used in the engineering analysis and design. And it has become indispensable to analyzing structural problems with complex material behaviours and complicated boundary conditions (Oñate, 2009).

**1.6 Problem statement**

Disposal of waste rubber is a serious environmental issue all around the globe, on account of its health hazard and difficulty in land filling. The high cost of disposal and the requirement of large landfill area often result in random and illegal dumping of waste rubber (Siddique and Naik, 2004). This serious environmental and health issues associated with rubber demands urgent attention to develop alternative solutions for their reuse in other applications. In Malaysia, a number of projects involving a huge investment in waste rubber recycling have been observing. For instance, in 2002 a project total RM 4.47 billion was approved by Malaysian Industrial Development Authority to proceed with the recycling project of scrap tires to manufacture synthetic rubber powder and thermoplastic elastomer (Awang, 2008). On the other hand, normal concrete exhibits limited properties such as small resistance to cracking, low ductility, and low impact energy absorption (Wang et al., 2000). However, it was established that adding the waste tire to concrete would enhance its ability of crack resistance ductility and energy absorption (Topcu 1995).

According to the literature, no study has been reported on the static fracture toughness of concrete with assessment of crack resistance for rubberized concrete using crack mouth opening displacement (CMOD).

However, only Reda-Taha et al. (2008) investigated the effect of crumb and fine crumb rubber in the bending impact resistance to a rectangular beam. In this work, the impact energy was reported qualitatively by calculating the impact energy from a number of drops until failure. It was noted that there is no instrumented impact test using load cell and accelerometer to investigate the accurate impact load causing the failure or deformation of the rubberized concrete beams. Furthermore, previous investigations did not measure the actual fracture energy of the rubberized concrete beam under impact bending load.

Moreover, the nonlinear finite element dynamic analysis of rubberized concrete structures which is a promising contribution to facilitate realistic predictions the behaviour of rubberized concretes beams. Also, investigations into the behaviour of hybrid (rubberized top-plain bottom) concrete structures under impact or static load conditions are yet to be accomplished by any researcher. Thus, there are several gaps in the previous research, which needs to be addressed to arrive at a mix of concrete having best possible impact properties of concrete.

## 1.7 Objectives

The overall objective of the project is to investigate the feasibility of improving the impact resistance of concrete bream. This research will investigate the feasibility of used of waste rubber tire in concrete subjected to impact load and to investigate its properties of energy absorption and ductility.

Thus the main objectives of this work are:

i. To study the suitable size of rubber, its mixed proportion and material properties of rubberized concrete.

ii. To determine the static fracture toughness of rubberized concrete with assessment of crack resistance using crack mouth opening displacement (CMOD).

iii. To investigate the effect of crumb rubber incorporation on the impact tup, inertial load and bending load of rubberized concrete and hybrid beam experimentally.

iv. To analyze the impact energy and behaviour of rubberized concrete and hybrid structure beam subjected to impact load.

v. To verify finite element model for simulating the behaviour of rubberized and hybrid concrete beams based on the measured data.

## 1.8 Scope of work

In the present work, the impact load and displacement, and dynamic fracture energy are investigated for concrete beams containing fine crumb rubber, crumb rubber and powder rubber. The crumb rubber particle size 1 mm and fine crumb rubber particle size 0.4–0.9 mm are used in replacement ratio of 5%, 10%, and 20% by volume of sand and the same proportions of powder rubber 0.15–0.6 mm is added to the concrete with proportional decrease in the volume of cement.

Alongside this, double layer beam with rubberized top and plain bottom (hybrid structure), are tested under impact three-point bending load to investigate its impact behaviour and to improve its ability to absorb the impact energy. Numerical simulations are carried out to study the dynamic behaviour of all the samples. LUSAS V.14 tool is used to simulate the behaviour of rubberized concrete beams under impact load. In order to determine the properties of rubberized concrete, experiments has been carried out to study the material behaviour under compressive and tensile loadings. The concrete beam is assumed to be made of eight node hexahedron elements. And to substantiate the present finite element model, the predicted impact behaviour is compared with the experimental results.

In order to further accomplish the objectives of the present study, the fracture properties such as stress intensity factor ($K_{IC}$), Young's modulus (E), critical energy release rate ($G_{IC}$), and crack resistance using crack mouth opening displacement (CMOD) are investigated as preliminary test for the three group of rubberized concrete.

### 1.9 Thesis Outline

The present thesis is organized into five chapters. A brief outline of each chapter is given hereunder:

- Chapter one presents general information about the problems due to waste tire rubber, concrete, rubberized concrete and effect of rubber on the impact behaviour of the concrete. And also general finite element history is presented. This chapter also focuses on the problem statement, objectives, and the scope of work.

- The review of literature is presented in chapter two. This review focuses on the previous study that has been carried out on the rubberized concrete and discusses its properties. It also presents the most relevant studies with respect to the impact loading and its effect on the concrete behaviour.

- Chapter three is divided into two main parts. Part one covers the methodology for experimental works and describes the materials and laboratory investigations that are carried out to fulfill the objectives of the research. Part two describes the finite element formulation model of material and scheme of analysis for plain, rubberized and hybrid concrete beams subjected to bending impact load.

- Chapter four presents the analysis and discussion on the results obtained from the experimental tests. Comparisons between three types of rubberized concrete, between rubberized and hybrid structure and also between static and dynamic results were studied.

- Chapter five nonlinear analysis model of concrete subjected to impact load by using finite element method. Comparison is carried out between experimental and computational results.

- Chapter six provides the conclusions drawn from the result of both experimental work and finite element model. Finally the recommendations for the future work are also presented in this chapter.

# CHAPTER TWO

# LITERATURE SURVEY

## 2.1 Introduction

Cement consumption is increasing day by day owing to its wide use as construction material. The increased use of cement poses an environmental challenge because 5% to 8% of the global anthropogenic $CO_2$ emissions originate from cement production (Scrivener and Kirkpatrick, 2008). Another major problem haunting environmentalist is the increased generation of waste rubber all over the world. For example, in the United States alone, every year more than 281 million scrap-tires are produced, out of which over 77%, are landfilled, stockpiled, or illegally dumped (Baker et al., 2003). In Malaysia, a number of projects involving a huge investment in waste rubber recycling have been observing. For instance, in 2002 a project total RM4.47 billion was approved by Malaysian Industrial Development Authority to proceed with the recycling project of scrap tires to manufacture synthetic rubber powder and thermoplastic elastomer (Awang, 2008). The problem with this indiscriminate accumulation of waste tires is that it is dangerous and hazardous on account of its potential fire risks which generally demands longer time to extinguish. These fires are major source of the air, soil, and water pollution and have direct bearing on the surrounding communities (Sukontasukkul and Chaikaew, 2006).

This serious environmental and health issues associated with rubber demands urgent attention to develop alternative solutions for their reuse in other applications, and in this regard concrete has been identified as one of the feasible options.

## 2.2 Rubberized concrete

Recently many researchers have carried out experimental studies to identify the best suitable application of recycled rubber in the field of concrete technology. The primary objective of their study was to reduce the waste material dumping problems by utilizing these materials as raw material in concrete mixes and thereby improve their properties. In this chapter the works related to utilization of waste tire rubber in concrete is reviewed.

### 2.2.1 Properties of fresh rubberized concrete

#### 2.2.1.1 Concrete Density

Concrete density is one of the important properties of concrete. The fresh and hardened dry unit weight of aerated cement composites containing shredded rubber waste was determined by Benazzouk et al. (2006). Aerated cement composites mixes were prepared with replacements of cement volume in the range of 0% to 50% using shredded waste rubber. The absolute density of the shredded waste rubber is approximately 430 $kg/m^3$. They found that addition of shredded waste rubber will cause significant reduction in the fresh and hardened dry unit weight of the mixtures. In a similar work carried by Khaloo et al. (2008), they investigated the effect of replacing coarse aggregate and sand with chips and crumb rubber on the properties of concrete. They found that addition of waste tire in concrete significantly reduced the density of the concrete (see Figure 2.1).

The effect of addition of waste automobile tires on the unit weight of concrete was experimentally investigated by Topçu and Sarıdemir (2008). They also employed the artificial neural networkand fuzzy logic techniques ability to predict the unit weight of the concrete under study. In their study concrete without rubber and having15, 30 and 45% rubberized concrete were developed. The results showed that unit weight of concrete decreased with the increasing crumb rubber content.

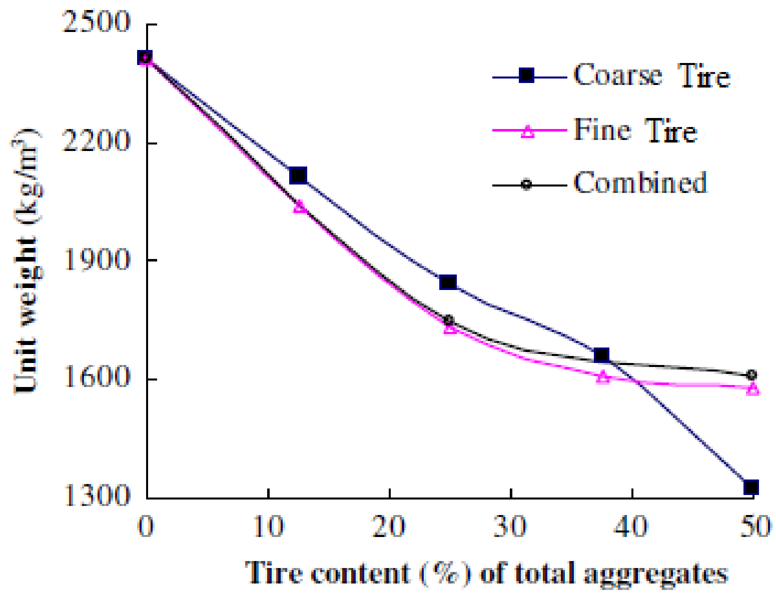


Fig. 2.1: Effect of tire content on the unit weight of the concrete (Khaloo et al., 2008)

Similarly, Pelisser et al. (2010) investigated the effect of replacing sand with recycled tire rubber on the density of concrete mix. The recycled rubber with maximum particles size of 4.8 mm was washed with sodium hydroxide ( NaOH) to increase the hydrophilicity of the rubber particle surface. Further, silica fume (microsilica) was added (15% mass fraction) to the recycled rubber as a surface modifier.

The combination of the rubber treatment by sodium hydroxide followed by the addition of silica fume was favorable for the porosity reduction in the interface of these aggregates. This contributed to the recovery of the concrete strength and a lower permeability.

#### 2.2.1.2 Air content

The effect of chipped and crumbed tire rubber particles as replacement of coarse and fine aggregates on the air content of concrete mix have also been studied Taha et al. (2008). They found that increase in the content of tire waste rubber increased the air content of the concrete mix (Figure 2.2). Several other researchers have also demonstrated that using waste tire in concrete increases the level of air content in the mix (Benazzouk et al., 2003; Khatib and Bayomy, 1999).

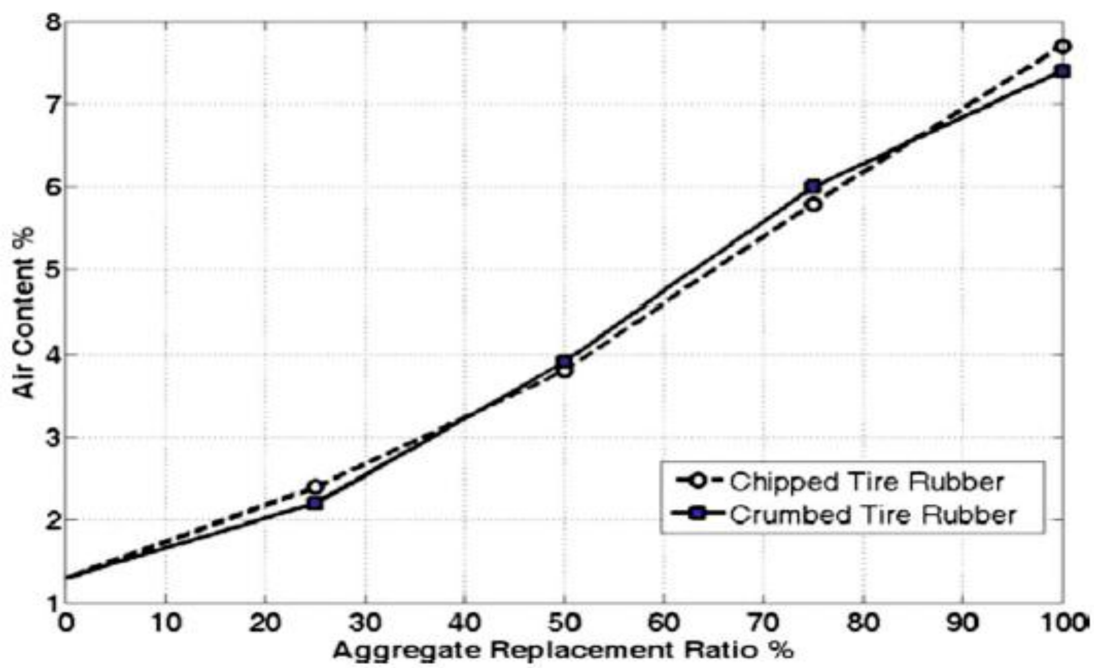


Fig. 2.2: Effect of aggregate replacement ratio on air content of rubberized concrete (Taha et al., 2008)

### 2.2.1.3 Workability

In order to study the workability of rubberized concrete, chipped and crumbed tire rubber particles as replacement of coarse and fine aggregates were used in the study by Khatib and Bayomy (1999). The result (see Figure 2.3) showed that the presence of crumb or chipped tire rubber particles decreased the workability of the concrete. Whereas, for the concrete mix with sand replacement, the slump increased with increase in rubber percentage and reached a maximum value when the rubber percentage was 15%, which on subsequent increase in rubber percentage the slump decreases.

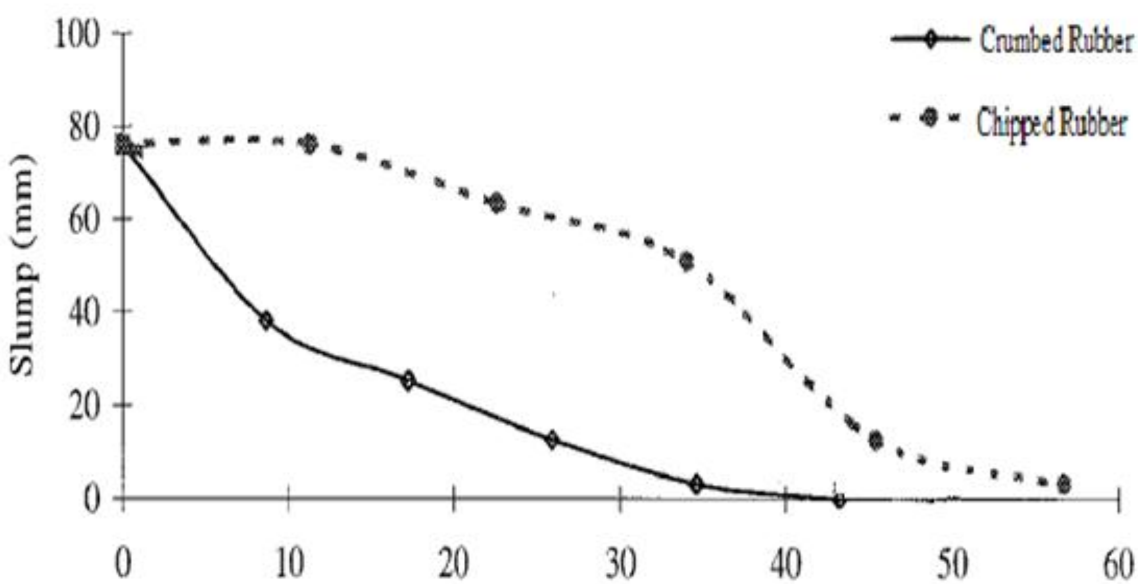


Fig. 2.3: Effect of rubber content on the workability of concrete (Khatib and Bayomy, 1999)

In a similar work carried out by Raghavan et al. (1998), the effect of adding shredded automobile and truck tires on the workability of mortar was investigated. The result showed that addition of rubber shreds improves the workability of the mortar. In another work by Albano et al. (2005), they observed that the values of slump decreased from a value of 8 cm for the controlled concrete mix to a value of 1 cm (88% slump reduction) for the scrap rubber concrete having 5 wt% rubber with 0.29 and 0.59 mm particle sizes. The value for 10 wt% rubber with 0.29 and 0.59 mm particle sizes was 0.5 cm (94% slump reduction). This reduction is due to the decrease on blend flow, because of the presence of a high portion of rubber particles, which have a very low density, hence greater volume.

### 2.2.2 Properties of hardened rubberized concrete

#### 2.2.2.1 Compressive and tensile stress

The compressive and splitting-tensile stress in terms of different particle size and amount of rubber in concrete mixture was studied byTopcu (1995). Two particle sizes of rubber 0-1 mm (fine) and 1-4 mm (coarse) were added to concrete mixes in varying percentages of 15, 30 and 45 %. As shown in Figure 2.4, the compression stress decreased approximately by 36, 43, and 56% when fine aggregate was replaced with fine rubber aggregate of 15, 30, and 45% volume, respectively. Whereas, for the case of using chipped tire rubber particles to replace the same percentage of aggregate the reduction in compressive stress was 50, 69, and 80%, respectively for similar volumetric additions.

For the splitting-tensile test, the plain concrete yielded at 3.21MPa, and it reduced to 32, 52, and 65% when replaced with fine aggregates having 15, 30 and 45 % of fine rubber and, 53, 67, and 74% when replaced with the coarse rubber chips.

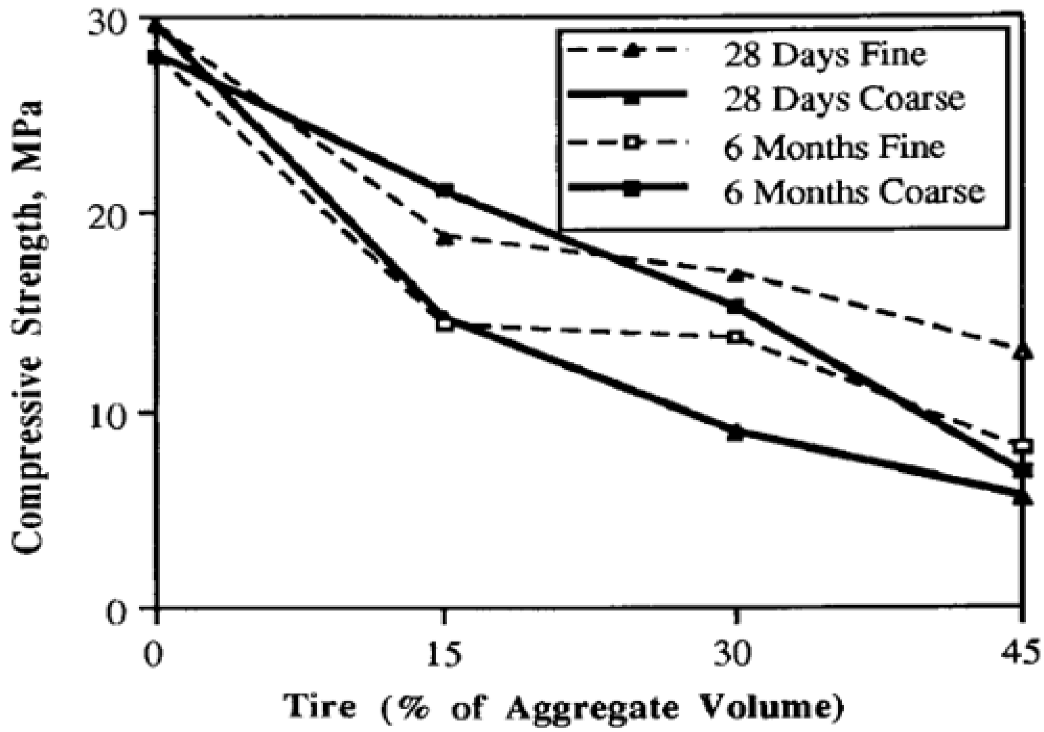


Fig. 2.4: Effect of fine (0-1mm) and coarse (1-4mm) rubber content on the compressive stress (Topcu, 1995)

Crumb rubber of particle size 0.15–4.75 mm was used by Batayneh et al. (2008) as partially replacement of sand in various percentages of 20%, 40%, 60%, 80%, and 100% to investigate the effect of rubber in the performance of concrete. The results indicate that the compressive stress for different rubber contents reduced from 10% to 75% of the control specimen, while the tensile stress decreased from 8% to 65% of the control specimen.

The mechanical properties of concrete containing high volume of tire rubber was investigated by Khaloo et al. (2008). Chipped, crumbed, and a combination of tire rubber particles were used to replace coarse and fine aggregate with different volume replacement levels. Natural sand and coarse aggregate were substituted by fine rubber and coarse rubber with 25, 50, 75 and 100%, respectively. The result showed that compression stress decreased by approximately 80% when sand was replaced with 25 % whereas, the ultimate stress for coarse replacement was slightly higher than that of sand replacement for rubber concentrations lower than 25%. This higher stress was attributed to the existence of fibers in coarse tire–rubber particles. Ultimate stresses of combined specimens appeared somewhere in between the ultimate stress of concrete with sand and coarse aggregate replacement, but it was found closer to concrete with sand replacement. They suggested replacement ratio not exceeding 25% of aggregate by tire rubber.

A new approach to predict the effect of tire rubber on the stress of concrete using a mathematical model was introduced by Vieira et al. (2010). Design of the model depends on study of the composition stress of concrete in a multivariate form using a completely random experimental design. The variables of model were grouped into two groups of variables, mixture variables (the properties of the mixture constituents such as aggregates, water and cement) and process variables (Tire rubber percentage and size in the concrete). In this study three different particle sizes of truck tires rubber (from 1.2 to 2.4 mm, from 2.4 to 4.8 mm, and greater than 4.8 mm) were used with the weight fraction of rubber 2.5–5.0–7.5%. The truck tires rubber was added to concrete mixes as a substitute for fine aggregate. The results show that by adding 2.5% rubber substitute having fine aggregate with 2.4 mm particle size, can account for the optimum stress of the concrete. Moreover, the result showed that a concrete having a compressive stress above 20 MPa for 28 days can be obtained. This indicates that these mixtures can be used in structures as well as pavements, dividers and other applications in civil engineering.

Another study by Ganjian et al. (2009), investigated the stress of concrete mixtures by incorporating 5%, 7.5% and 10% of discarded tire rubber as aggregate and cement replacements. Figure 2.5 shows that there is no major change in the compressive stress with 5% replacement of aggregate or cement by rubber. The significant reduction in compressive stress was with respect to 7.5-10% replacement by aggregates and cement leading to reduction of stress by about 10–23% and 20–40% in case of cement replacement.

Moreover, tensile stress of concrete was reduced with the increase in the percentage of rubber replacement in concrete as shown in Figure 2.6. It was also found that the reduction in the tensile stress of concrete containing powdered rubber was lower than that of concrete containing chipped rubber.

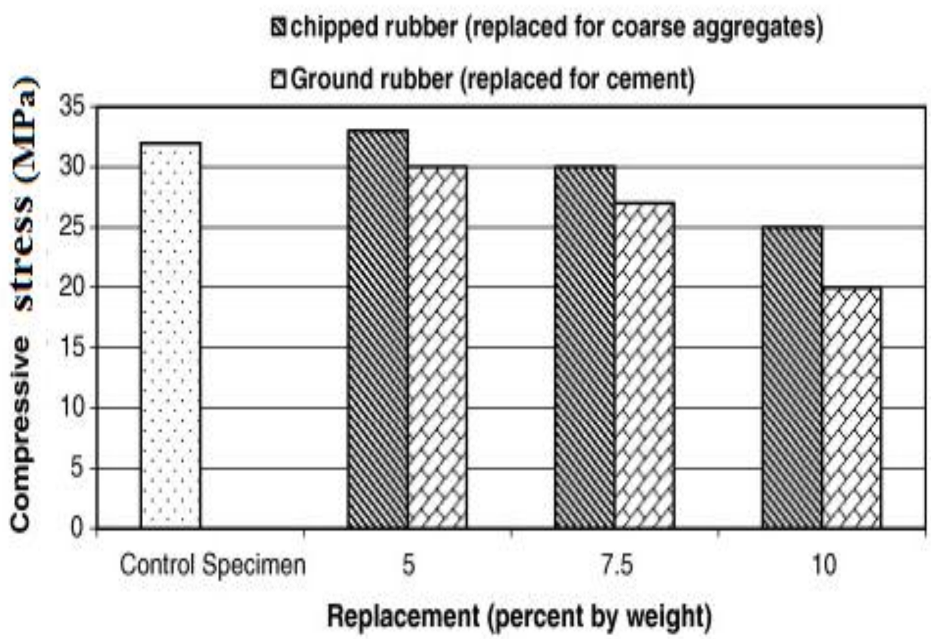


Fig. 2.5: Effect of chipped and ground rubber content on the compressive stress (Ganjian et al., 2009)