A STUDY ON THE CHARACTERISTICS OF WASTE-BASED GEOMATERIALS

by

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LIST OF SYMBOLS AND ABBREVIATIONS

σ	Flexural strength
ρ	Density
CMOD	Crack Mouth Opening Displacement
EFB	Empty Fruit Bunches
F	Load (Compressive strength)
FLAC	Finite Different Program
GPOA	Ground Palm Oil Fuel Ash
k	Coefficient of permeability
OPC	Ordinary Port Cement
OPEFB	Oil Palm Empty Fruit Bunches
PFA	Pulverized Fuel Ash
pH	Hydrogen ion Concentration
POA	Palm Oil Fuel Ash
Q	Flow Rate
RHA	Rice Husk Ash
SO_2	Sulphur Dioxide

KAJIAN TERHADAP CIRI-CIRI GEOMATERIAL BERASASKAN BAHAN TERBUANG

ABSTRAK

Dalam kajian yang dijalankan, bahan terbuang iaitu cebisan tayar, sekam padi dan tandan kelapa sawit kosong (OPEFB) telah digunakan secara berasingan dalam campuran mortar bagi tujuan penghasilan geomaterial sebagai medium penurasan. Campuran disediakan dengan nisbah berat dari 1:2:0.5:0.01 hingga 1:2:0.5:0.20 bagi simen, pasir, air dan cebisan tayar. Campuran bagi sekam padi adalah sama seperti campuran bagi cebisan tayar. Nisbah campuran bagi tandan kelapa sawit kosong pula adalah dari 1:2:0.5:0.01 hingga 1:2:0.5:0.05 bagi simen, pasir, air dan OPEFB. Campuran lain melibatkan cebisan tayar dan sekam padi juga ada yang ditambah busa. Daripada campuran-campuran ini, kiub dan rasuk dihasilkan, dan diuji untuk kekuatan mampatan, kekuatan lenturan, penyerapan air, keliangan dan ketumpatan. Beberapa campuran turut diuji untuk kadar alir melalui sampel. Daripada ujian yang dijalankan, kekuatan mampatan didapati berjulat diantara 1.6 N/mm^2 hingga 37.8 N/mm^2 bergantung kepada kandungan bahan terbuang dan masa pengawetan. Kekuatan lenturan didapati berjulat di antara 0.5 N/mm^2 hingga 4.5 N/mm^2, juga bergantung kepada kandungan bahan terbuang dan masa pengawetan. Ketumpatan pula berjulat diantara 2150 kg/m^3 hingga 1600 kg/m^3 dan ia juga bergantung kepada kandungan bahan terbuang dan masa pengawetan. Keliangan bagi campuran boleh mencapai 35% yang sebahagiannya menunjukkan bahan geomaterial mempunyai sifat saliran yang baik. Penggunaan busa telah berjaya meningkatkan sifat keliangan dan kadar penyerapan air. Secara perbandingan, cebisan tayar telah memberikan nilai tertinggi bagi kekuatan mampatan, kekuatan lenturan dan ketumpatan, manakala

tandan kelapa sawit kosong memberikan nilai tertinggi bagi keliangan dan penyerapan air. Melalui ujian kadar alir yang dijalankan, kadar alir melalui geomaterial didapati lebih rendah jika dibandingkan dengan melalui pasir kasar seragam, namun bahan geomaterial boleh dikatakan mempunyai sifat penyaliran yang baik, oleh itu sifat penurasan yang baik juga. Daripada ujian kebolehtelapan yang dijalankan, didapati bahan geomaterial boleh mencapai pekali kebolehtelapan maksimum 1.57×10^{-3} cm/s.

A STUDY ON THE CHARACTERISTICS OF WASTE-BASED GEOMATERIALS

ABSTRACT

In this research, wastes namely shredded rubber, rice husk, and oil palm empty fruit bunches (OPEFB) have been individually used with mortar mix to produce geomaterials that will function as filtration media. Mixes were prepared with weight ratios ranging from 1:2:0.5:0.01 to 1:2:0.5:0.20 for cement, sand, water, and shredded rubber respectively. Mixes for rice husk were of the same ratios as for shredded rubber. Finally, mixes for OPEFB were ranging from 1:2:0.5:0.01 to 1:2:0.5:0.05 for cement, sand, water, and OPEFB content respectively. More mixes involving shredded rubber and rice husks were prepared with foam added. Cubes and beams were cast out of the mixes and tested mainly for compressive strength, flexural strength, water absorption, porosity, and density. Certain mixes were tested for flow rate through the cast. The tests have resulted in compressive strengths ranging from 1.6 N/mm^2 to 37.8 N/mm^2, depending on waste content and period of curing. The flexural or tensile strengths ranged from about 0.5 N/mm^2 to 4.5 N/mm^2, also depending on waste content and period of curing. The densities ranged from 2150 kg/m^3 to 1600 kg/m^3, again depending on waste content and period of curing. The porosities of the mixes were as high as 35% which partly indicate good drainage property for the geomaterials. The presence of foaming agent has successfully enhanced the porosity and water absorption properties. By comparison, shredded rubber geomaterials have given the highest values in compressive strength, flexural strength, and density; while the OPEFB geomaterials provided the highest porosity and water absorption characteristics. Through the vertical flow rate tests, the rates of

flow through the geomaterials were lower in comparison than through coarse, uniform sand but the geomaterials can be considered as having good drainage characteristics to function as filtration media. A result from constant head permeability test has indicated that the geomaterial has achieved a maximum permeability constant of 1.57×10^{-3} cm/s.

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Land instability will always be a major problem in the construction sector especially in the geotechnical field. The poor condition and bad characteristic of soil not only posed problems during construction, but also danger to the public. Soil erosion is described as soil particles being shifted around due to devastating impact of rainfall, wind and ice melt. It is a naturally occurring process but in most cases, human activity can speed up the process. Land erosion and land instability produced sediment which destroying the plants and also clog the drainage system. Even worse, slopes instability can cause landslides resulting in the loss of human lives and damage to properties.

Solid waste disposal is a serious problem and threat to environment. Nowadays, the automotive sector has been rapidly developing which increasing the use of vehicles. Figure 1.1 shows the trend of registered vehicle in Malaysia in which the number of vehicles registered is increasing every year especially for motorcycle and car. The massive increment of vehicles usage has boosted the generation of waste tyre. According to Li et al. (2004), the U.S. Environmental Protection Agency has estimated that there is 2-3 billion scrap tyres accumulated in illegal stockpiles and uncontrolled tyre dumps throughout the country, with millions more scattered in ravines, desert, woods, and empty lots. Gaseous pollutants due to tyre fires could significantly contribute to the deterioration of the environmental condition (Shakya et al. 2008). Therefore, new methods for recycling or reuse the waste tyre is necessary to help ease the tyre disposal problem.

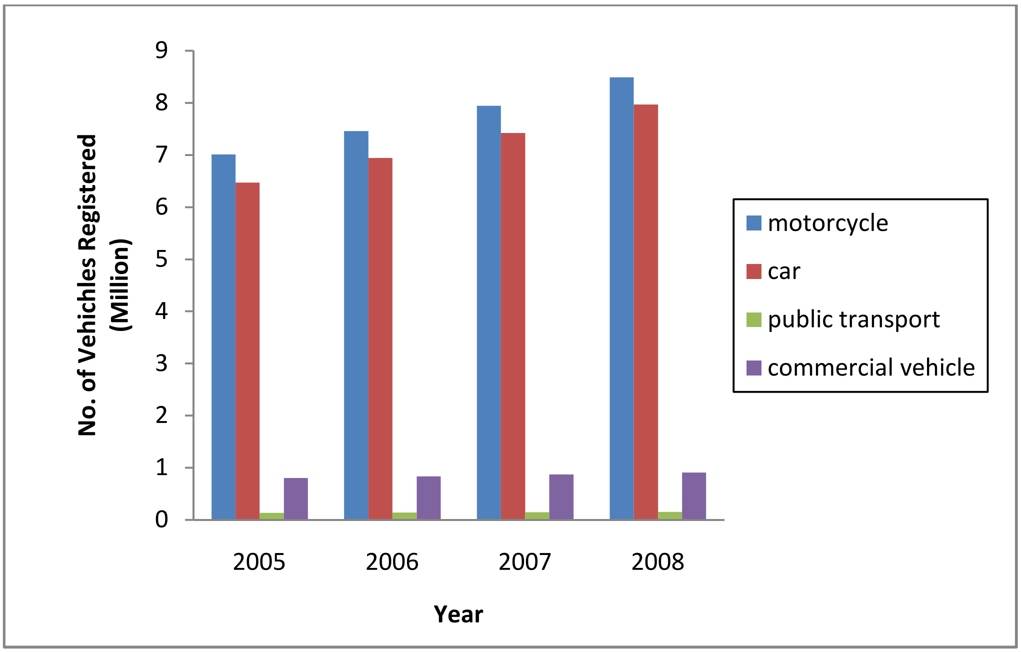


Figure 1.1: Trend of registered vehicle from 2005 to 2008

In Malaysia, two major plantations in the agricultural sector (paddy and oil palm) have been generating by products such as rice husk and oil palm empty fruit bunches (OPEFB). In paddy milling process for instance about 78% of weight is rice, broken rice and bran and remaining 22% of the weight of paddy is husk. About 75% from the husk contains organic volatile matter and the rest 25% is rice husk ash, which is produced during firing process.

Oil palm fibre is a non hazardous biodegradable material extracted from oil palm's vascular bundles of empty fruit bunch (EFB). As palm fibres are versatile and stable, it can be processed into various dimensional grades to suit specific applications such as production of mattress and cushion, erosion control, soil stabilization, landscaping and horticulture, ceramic and brick manufacturing, thermoplastic filler, flat board manufacturing, paper production, acoustic control, livestock care, compost, fertilizer and also for animal feed.

Usually, most of the rice husk and oil palm empty fruit bunches are disposed with no further concern and this has caused waste disposal problems. Burning rice husk and fibre for example can cause health and environmental problem. The fermentation of rice husk by microorganism produces methane that could contribute to global warming problem. Appropriate measures and actions to recycle these waste materials must be identified to solve this problem effectively.

1.2 Scope of Research

The scope of this research includes the characterization of properties of geomaterial such as compressive strength test, flexural strength test, water absorption and porosity test. The comparison between geomaterial and foamed geomaterial has been done to determine the effect of foam usage on the properties of geomaterial. The vertical flow rate model of geomaterial is also carried out to investigate the drainage characteristic of geomaterial on site.

1.3 Objectives of Research

The objectives of this research are:

1. To investigate the characteristic of geomaterial using different waste products.
2. To study the effect of different percentage of waste material used.
3. To evaluate the flow rate condition using vertical flow rate model.

1.4 Importance of Research

The importance of this research is its potential to prevent soil erosion and improve the soil stability. The use of waste material in geomaterial can contribute in reducing waste disposal problem and save the environment. With the development of this new geomaterial, the construction work can become much easier as the geomaterial can be precast and pre-designed in factory unlike the most materials that are already available. Moreover, the properties of geomaterial such as compressive strength and porosity can be controlled according to the needs. The geomaterial also can be used in the place where water is needed to be drained such as weep hole or installed in parking lot.

1.5 Thesis Organization

This thesis is arranged into five chapters. The literature review in chapter 2 discusses the previous and current study regarding the waste material; shredded rubber, oil palm empty fruit bunches (OPEFB) and rice husk. In this chapter, the usage of waste material will be discussed especially as geomaterial for geotechnical purpose. Description of previous material using waste material and laboratory work will also be presented. General overview on the research of geomaterial consisting waste material will also be interpreted in this chapter.

Chapter 3 describes the research approaches and methodology. The steps in the development of geomaterial and all the required laboratory tests for the geomaterial will be discussed in detail. The development of vertical flow rate model including the apparatus and its method will also be discussed.

In chapter 4, the parameters established form the laboratory and model tests will be discussed. The properties of geomaterial such as compressive strength, flexural strength, water absorption and porosity will also be presented. Performance of geomaterial in vertical flow rate model will be described and discussed. The comparison of different type of waste materials with different proportions were also analyzed. The effect of foam on the properties will also described.

The chapter 5 concludes the research work. The conclusion is made based on the results and findings from this research work. The potential of geomaterial for soil infiltration technique is also concluded in the chapter. Suggestions and recommendations for future work to improve the geomaterial developed in this study are also presented.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The disposal of waste tyre, rice husk and oil palm empty fruit bunches (OPEFB) has become major environmental problem worldwide. Stockpiling of scrap tyres is also undesirable because of potential fire hazard, consequent environmental damage and good breeding habitat of disease-carrying insects and vermin. This situation creates acute need for finding new and beneficial ways to recycle and reuse large volume of these waste materials. Many research efforts have been devoted to seeking environmentally acceptable ways of recycling waste material. Development of new material and concept especially those based on waste material have been increasing in order to find the solution for porous material in geotechnical engineering field. Most of the lightweight materials are utilized as filling materials for road construction purposes. Lightweight material can assist in reducing loads to the subsoil and helping reducing the earth pressure and differential settlement at bridge abutment.

Waste tyres can be used as recycled tyre chips to minimize dynamic earth pressure during compaction of backfill. This is due to its relatively high damping ratio and low stiffness values that are contributed by the natural properties of rubber (Lee and Roh, 2007). Raw recycled rubber shred exhibits properties such as damping and ability to allow free drainages. Some of the common uses of recycled tyres include backfill material, application in tyre rethreading, highway crash barriers, break waters, reefs and crumb rubber asphalt pavement (Chiu, 2008; Cao, 2007;

Bosscher et al. 1992; Ahmed and Lovell, 1993). However, these applications have not fully utilized waste tyres. Hence, additional practices which utilize scrap tyres are still demanded. Due to the lower weight of rubber tyre chip compared to sand, some possible practical applications which utilize shredded tyres alone or mixed with soil are as lightweight fill for embankments, retaining walls and bridge abutment constructed on soft ground. The engineering properties of the tyre chips and tyre chips mixed with sand have also been investigated. The full-scale embankments and reinforced wall were also successfully constructed with satisfactory behavior. The advantage of using shredded rubber tyre mixed with sand is that it can reduce the weight of the fill material and self-heating characteristics and also increases its strength. (Youwai and Bergado, 2004).

The concept of using fibres as reinforcement is not new. Fibres have been used as reinforcement material since ancient times. Historically, horsehair has been used in mortar whereas straw has been used in mud bricks. Fibres are usually used in concrete as reinforcement (Al-Oraimi et al. 1995; Ramakrishna and Sundararajan, 2005; Agopyan and Savastano, 2005; Tol do Filho et al. 2003). Generally, fibres do not increase the flexural strength of concrete, therefore it cannot replace the moment resisting or structural steel reinforcement. Some fibres can reduce the strength of concrete. In geotechnical field, natural fibre has been used as soil stabilization material (Ghavami et al. 1999; Prabakar and Sridhar, 2002). The oil palm empty fruit bunches, due to their low fuel value, are seldom used in the production of steam. Presently, the empty bunches are usually disposed of by incineration, which subsequently produces a substantial amount of ash. The organic waste, rice husk, can be used to produce light-weight concrete. Due to the beneficial pozzolanic effect, the fibres have the effect of improving the tensile strength of the material (Jauberthie et al. 2003). Although rice husk ash is very popular as additive in concrete mix, research about raw rice husk for geomaterial has been limited.

In this chapter, previous study and research about geomaterial especially that have used waste tyre, rice husk and empty fruit bunches will discussed. The summary will include the overview of geomaterial in civil engineering work especially in the geotechnical field, laboratory and material studies, especially those involving experimental procedures and testing of geomaterial.

2.2 Application of Waste Tyre in Civil Engineering

The increasing problem of waste tyre disposal can be solved if new and effective recycling approach can be established. One of the largest potential routes is in construction, but the usage of waste tyres in civil engineering is currently very limited. Table 2.1 summarizes the current research on application of waste tyre in the civil engineering field.

Table 2.1: Waste tyre applications

Application	Description
Earth reinforced structure (Bujang et al., 2008)	Scrap tyre reinforced earth system comprising whole tyres tied with polypropylene rope stacked on top of each other and backfilled with in-situ cohesive tropical residual soil fill showed excellent performance for repairing slope of up to 5 m high.
Air pollution control (Brady et al., 1996)	In this study, activated carbon has been developed from waste tyres and tested for its methane storage capacity and SO_2 removal from a simulated flue-gas.
Concrete pedestrian block (Sukontasukkul and Chaikaew, 2006)	Crumb rubber is used to replace coarse and fine aggregates in concrete pedestrian block. The crumb rubber block also performed well in both skid and abrasion resistance tests. The production process was economical, due to the simplicity of the manufacturing process.

Table 2.1, continued.

Application	Description
Recycled tyre rubber modified asphalt (Cao, 2007)	To reduce pollution and improve properties of asphalt mixtures, properties of recycled tyre rubber modified asphalt mixtures using dry process are studied in laboratory.
Backfill material for culvert construction (Lee and Roh, 2007)	Recycled tyre chips was applied on the culvert walls in backfill areas to reduce the dynamic earth pressure induced by the compaction loading as well as to improve the characteristics of compacted soils.

Lee et al. (2002) investigates the usage of waste tyre as light cemented scrap tyre chips in the construction of earth structures. Their study indicates that the material is suitable as backfill material in earth structure. The study also stated several applications that are suitable for that material:

1. Embankment
2. Backfilling behind retaining structure.
3. Fill-slope.
4. Road widening and raising.
5. Subbase or road-base.
6. Energy absorbing and earthquake-proof application.

2.2.1 Material Investigation and Laboratory Work of Rubber Element Material.

Many laboratory and material studies about waste tyre have been carried out recently. Most of these studies were directed towards the preparation and development of composite material and related laboratory testing. Table 2.2 summarizes the studies that have been carried out before. The table shows the description of studies, testing and source of information.

Table 2.2: Summary of material investigation and laboratory works

Description of Studies	Test and Material Details	Reference	Year
Shredded tyre-sand mixture was investigated as a lightweight backfill. With an increasing proportion of sand in the mixture, the density, unit weight, and shear strength of the mixture increased, but the compressibility decreased.	Laboratory investigation for engineering properties of shred tyre-sand mixture.	Youwai and Bergado	2003
Cement paste, mortar, and concrete (containing OPC or OPC and PFA) mixes using various proportions of either rubber crumb or low-grade rubber obtained from shredding scrap tyres were tested for the mechanical properties.	The laboratory test including density, compressive strength, impact and fire resistances.	Fattuhi and Clark	1996
Tyre shreds as lightweight fill for construction of road embankment.	One-dimensional constrained compression tests were performed to investigate the behavior of large size tyre shreds and to address the resilience of the material at high stress level, during cyclic loading and unloading.	Shalaby and Khan	2005
Experiment investigation of waste tyre modified concrete.	Two types of waste tyre were used, chips and fibre. Compressive strength, compressive modulus of elasticity, Poisson's ratio, and split tensile strength tests were conducted.	Li et al.	2004

Table 2.2, continued.

Description of Studies	Test and Material Details	Reference	Year
The durability of mortar and concrete, including aggregate of discarded car tyres under environmental conditions. Those conditions are freeze-thaw, seawater, and high temperature.	Physical, mechanical, and durability experiments were performed on mortar and concrete specimens.	Topcu and Demir	2007
Studied engineering properties of cement-based mortar with rubber. Incorporation of rubber particles as aggregates is detrimental to compressive and tensile strength.	Laboratory investigation of mechanical properties of cement-based mortar incorporating rubber aggregates.	Turatsinze et al.	2005
Studied on the properties of self compacting concrete consisting rubber aggregates. Incorporation of rubber aggregates increased the strain capacity.	Laboratory investigation of modulus of elasticity and strain capacity of concrete with rubber.	Turatsinze and Garros	2008
Investigate the effects of tyre rubber ash filler on properties of cement mortar. Results showed that tyre rubber ash could be used as a partial replacement of sand in mortar mixtures to produce workable mortar. The air content of the fresh mortar decreased with increasing tyre rubber ash content. The mortar containing different tyre rubber ash replacement levels showed higher compressive strength than control sample.	Laboratory investigation of properties of mortar with tyre rubber ash.	Al-Akhras and Smadi	2004

Table 2.2, continued.

Description of Studies	Test and Material Details	Reference	Year
Studied the properties of rubber-mortar composites. Flexural strength of rubber mortar was reduced.	Flexural strength laboratory test of rubber mortar composites.	Segre and Joekes	2004
Study of rubberized concretes designed by replacing coarse aggregate in normal concrete with scrap tyre rubber in various volume ratios. Investigate the effect of rubber types and rubber content on strength and deformation properties. The compressive strength, the static modulus of elasticity, and the dynamic modulus of elasticity of the rubberized concrete decreased considerably with the increasing amount of rubber content.	Compressive strength, static, and dynamic modulus of elasticity of rubberized concrete were tested and studied.	Zheng et al.	2008

A research conducted by Lee et al. (2002), has discovered that rubber chip derived from scrap rubber tyres can be incorporated in cementations material to produce rubberized, lightweight and porous geomaterial. The mixture can be used either as cast-in-place material or molded as lightweight construction blocks as infill or backfill material in earth structures. The geomaterial is composed of wire-free rubber crumbs/chips derived from scrap rubber tyres, which are bonded by Portland cement, PFA, water, and elastic binding compound into a porous matrix construction material. The size of rubber used in their research was ranged from 10 to 20mm. Rubber bits of nearly uniform grade or gap-graded particle sizes were used to improve the porosity. To improve the strain compatibility of the cementations material and the rubber bits, binding compounds (such as polymer powder and polymer fibre) were also included in the mixture.

From their study, the compressive strength of geomaterial was varied from 1 MPa to 300 kPa with a cement-to-rubber ratio of 1:0.8 to 1:2.0, respectively. The dry density of geomaterial varies from about 1300 kg/m^3 to 800 kg/m^3 at the respective cement-to-rubber ratios. The density and compressive strength of geomaterial are given in Figure 2.1.

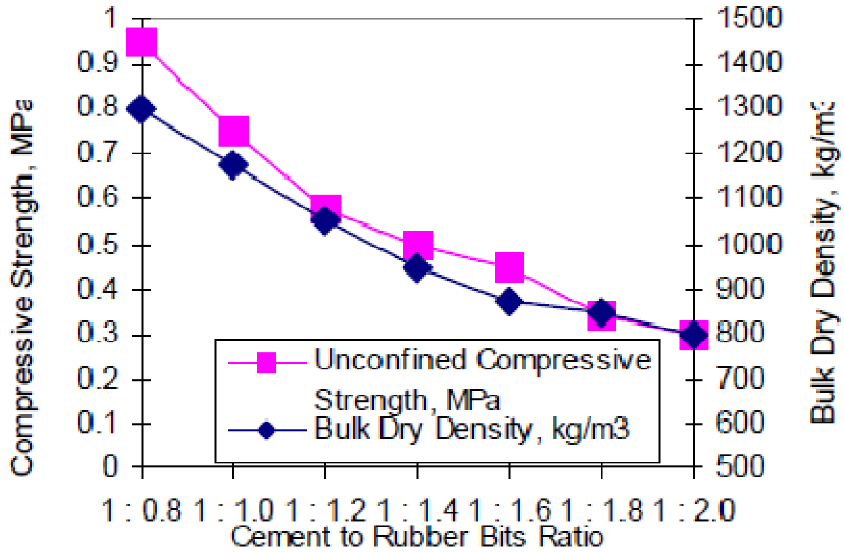


Figure 2.1: Relationship between unconfined compressive strength and bulk dry density with the cement-to-rubber bit ratio (Lee et al. 2002)

Turatsinze et al. (2007) have discovered that the incorporation of rubber aggregates which made from shredded non-reusable tyres in cement-based mortars is suitable to limit their propensity of cracking. Despite some drawbacks, such as large decrease in tensile and compressive strengths and increased free shrinkage length change, their tests have demonstrated that rubberized mortars exhibit enhanced strain capacity. For many decades, ring tests have been performed to evaluate the propensity of cement-based materials in undergoing shrinkage cracking. The cement-based material was cast around a steel ring which provides restraint when the material shrinks. A video microscope was used to detect cracks as soon as they started, to monitor their propagation and eventually, to measure their opening. Figure 2.2 shows the steel ring test results. Ring-test illustrates the balance between enhanced strain capacity and increased free shrinkage which demonstrates a clear benefit from rubber aggregate incorporation.

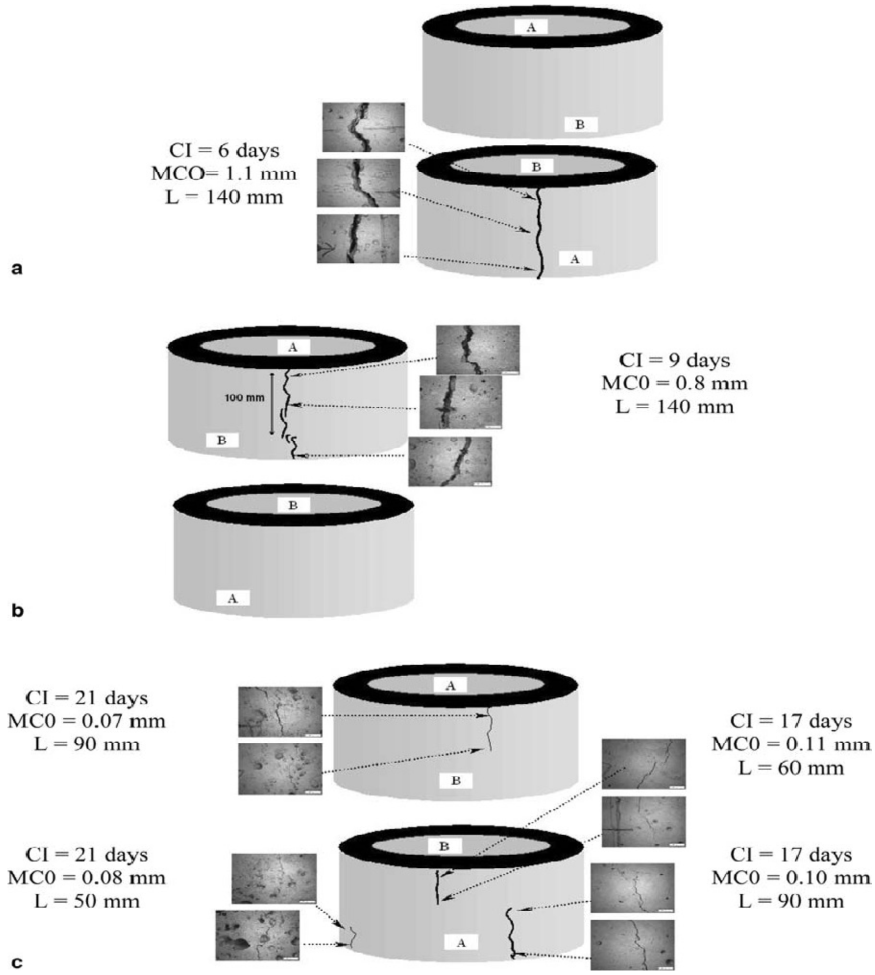
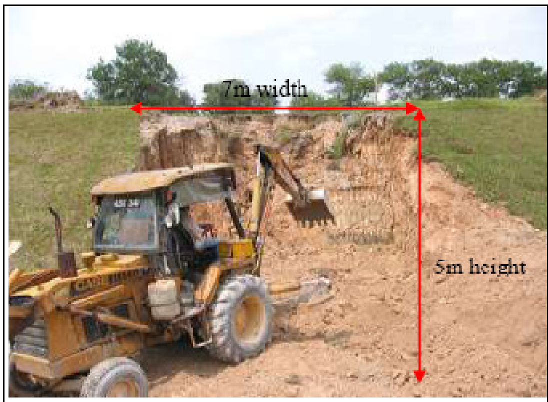


Figure 2.2: Restrained shrinkage cracking after 55 days: (a) control mortar (M0); (b) mortar incorporating 20% of rubber aggregates (M20) and (c) mortar incorporating 30% of rubber aggregates (M30). (Turatsinze et al. 2007)

Bujang et al. (2008) have used scrap car tyre to construct earth retaining structure for slope repair. Their study describes the work that was carried out on testing for tensile strength of scrap tyres, design and test of suitable attachment to tie the tyre together, and also the construction and performance of field trial of the propose scrap tyre reinforced earth system. Figure 2.3 illustrates the construction of earth retaining structure using scrap tyre. According to their research, scrap car tyre retained its high tensile strength although its service life as car tyre had expired. It offered a 99.08% probability tensile strength greater than 20kN with its tyre thread alone. From their study, they suggested that this material can become excellent construction material especially as reinforcement element in reinforced earth. In their research, polypropylene rope was also found to be the most suitable attachment system to tie the scrap tyres to produce a mat configuration. The polypropylene offered a superior strength that is compatible with the scrap tyre. Moreover, their material was flexible and inexpensive.



(a) Test site in Ikram Park, Selangor

(b) Laying first tyres in mat configuration, with each tyre tied together with polypropylenes rope

(c) Backfilling tyre mat layer with in situ cohesive material and compaction

(d) The completed structure

Figure 2.3: Construction of earth retaining structure (Bujang et al., 2008)

An experiment of numerical analysis on reinforced wall using rubber tyre chip-sand mixtures as backfill material conducted by Youwai and Bergado (2004) stated that with the increasing rubber tyre chip portion in the mixtures, the lateral wall movement and the coefficient of lateral earth pressure has increased. The effect of the reinforcement stiffness on the tensile force of reinforcement and the deformation of the reinforced wall are illustrated in Figure 2.4 and 2.5, respectively. The effects of the shear stiffness at the interface on the behavior of reinforced wall are lower compared to the reinforcement stiffness. Figure 2.6 shows the effect of the interface stiffness on lateral deformation of reinforced wall. With the increasing rubber tyre chip portion in the mixtures, the lateral deformation of the reinforced wall and the normalized force in the reinforcement increased.

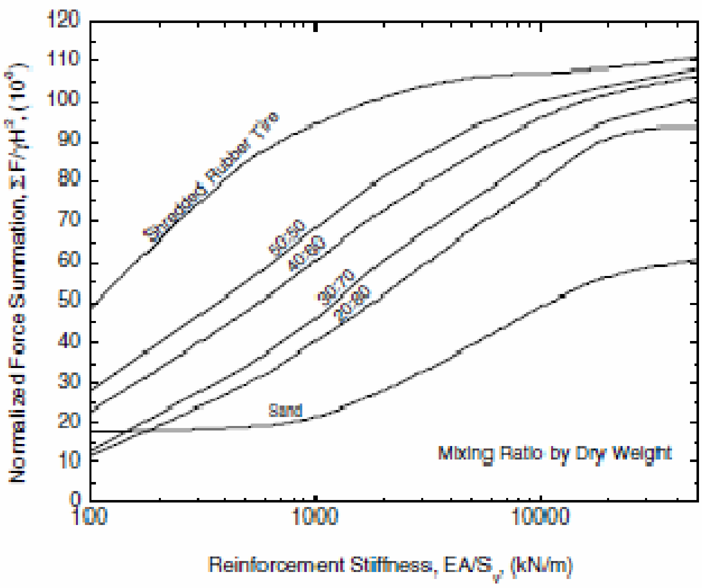


Figure 2.4: Normalize force summation versus reinforcement stiffness
(Youwai and Bergado , 2004)

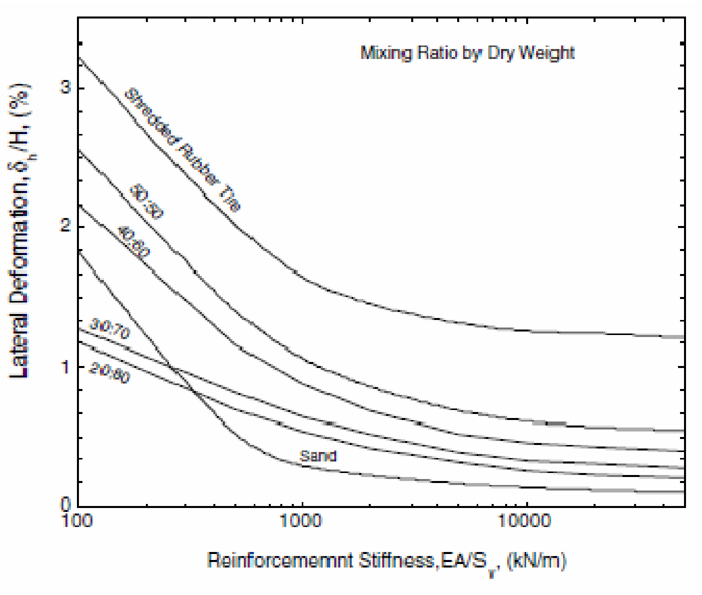


Figure 2.5: Lateral deformation of reinforced wall using rubber tyre chip–sand mixtures lightweight fill as a function of reinforcement stiffness (Youwai and Bergado, 2004)

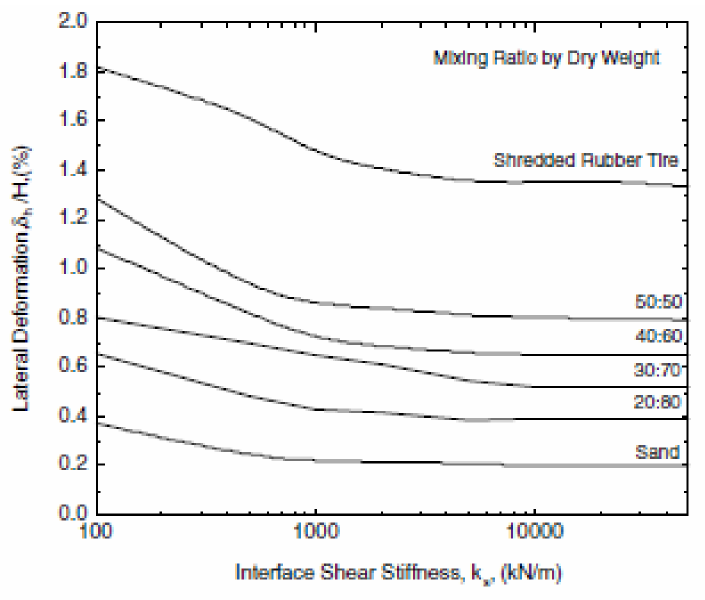


Figure 2.6: Lateral deformation versus interface shear stiffness (Youwai and Bergado, 2004)

2.2.2 Properties of Rubber-Cement Material

Concrete is a vital material for the construction industry. The utilization of concrete has increased considerably over the last few decades. This inevitably leads to mass quarrying of natural materials which are the main component in the production of concrete. Consequently, this has caused public concern over the quarrying of natural resources. Environmentalists have raised concern for protecting the environment and preserving the natural resources by using alternative materials such as recycled or waste materials. However, there is always a need for cheaper alternative materials for making new concretes with special properties.

The use of rubberized concrete in constructions is beneficial due to high durability and lightweight characteristic. The unique qualities of rubberized concrete will find new areas of usage in highway constructions as a shock absorber, sound absorber and also in buildings as an earthquake shock-wave absorber.

(Sukontasukkul and Chaikaew, 2006), in their studies have suggested it is possible to manufacture concrete block containing rubber crumb up to about 20% by weight. It is also suggested in their study that the performance of concrete block could be affected differently depending on the type and content of the rubber particles. In the case of mechanical properties, both compressive and flexural strength can decrease depending on the rubber content, while increasing the toughness.

The flexural responses of concrete block with and without rubber crumb are given in Figure 2.7. The flexural strength of crumb rubber concrete blocks was found to be weaker than the plain concrete block. However, the responses were found to possess greater flexibility and toughness with larger deflections at peak load, longer post-peak responses and higher fracture energy. The fracture toughness is shown in Figure 2.8. The larger fracture toughness of crumb rubber concrete block indicated that the block was able to absorb larger quantities of energy after the peak load and prior to the final failure.

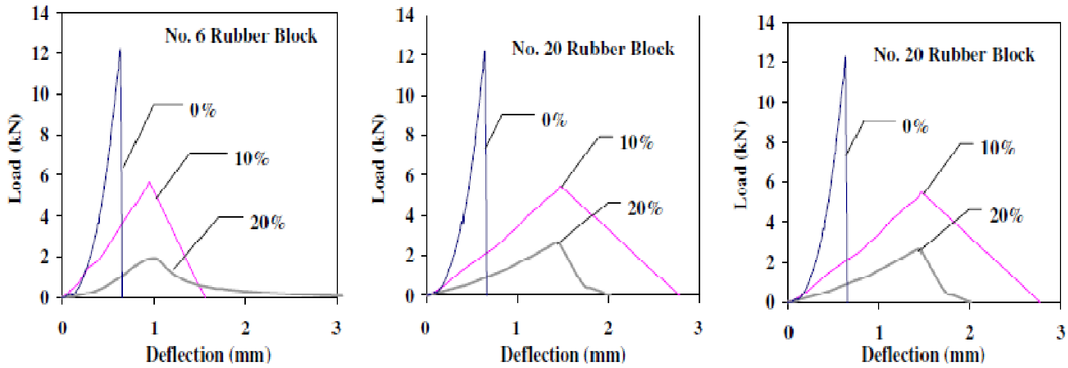


Figure 2.7: Flexural responses of crumb rubber blocks.
(Sukontasukkul and Chaikaew, 2006)

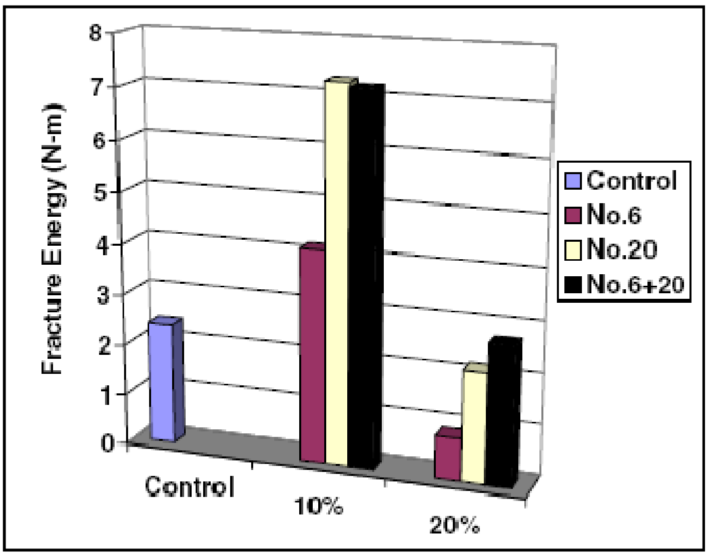


Figure 2.8: Fracture energy of crumb rubber blocks
(Sukontasukkul and Chaikaew, 2006)

It was found that for OPC concrete containing the largest amount of added rubber, the density and compressive strength were reduced by nearly 20% and 70% respectively, compared to the ordinary concrete. Also, the results indicated that concrete containing rubber with fine grading has lower compressive strength than that of coarse grading (Fattuhi and Clark, 1996).

Experiment by Ganjian et al. (2009) showed that compressive strength was reduced with increasing percentage of rubber replacement in concrete especially for the higher amount of replacement. The highest reduction was related to 7.5% and 10% replacement for both grades of rubber used as shown in Figure 2.9.

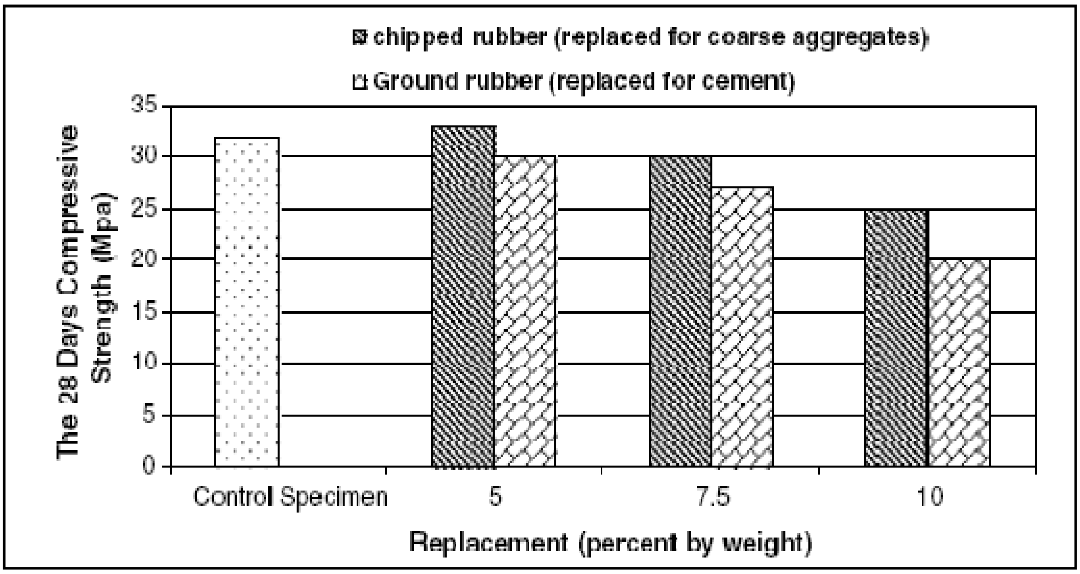


Figure 2.9: Results of 28-day compressive strength test (Ganjian et al, 2009)

In Figure 2.10, the replacement of rubber for aggregate or cement in concrete has caused reduction in its flexural strength for both grades, but the rate of reduction was different. The reduction was about 37% for coarse aggregates replacement and 29% for cement replacement.

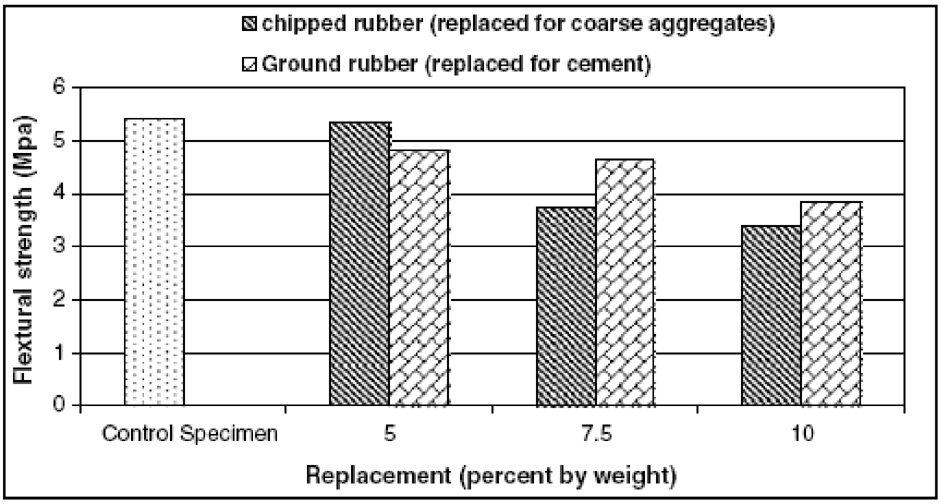


Figure 2.10: Results of flexural strength test (Ganjian et al, 2009)

The result of permeability test which is shown in Figure 2.11 shows that the replacement of rubber increases water permeability depth in the concrete mixtures. The increase of water permeability is due to reduction of cement content which causes reduction in bonding between particles in the concrete mix. In Figure 2.12 the water absorption in the concrete containing rubber appears to be non-uniform in such a way that even though water absorption is lower than that of the control mixture, its water permeability increases. The reason for this behavior is believed to be due to the existence of capillaries filled with water in the concrete containing rubber. This is also due to the lack of good bonding between rubber particles and cement paste where interface surfaces between cement paste and rubber grains act as bedding for the pressurized water to flow in the concrete containing rubber.

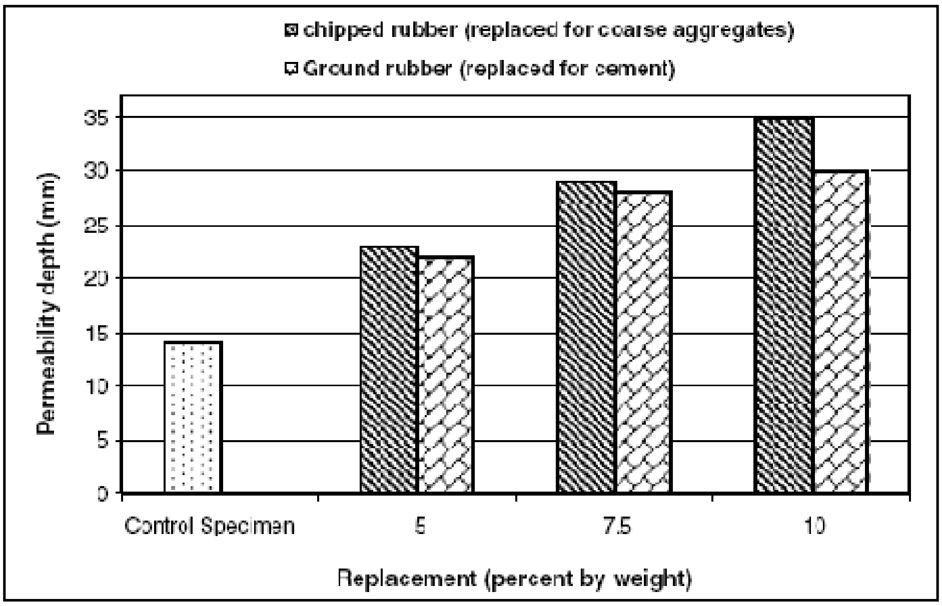


Figure 2.11: Water permeability depth results (Ganjian et al, 2009)

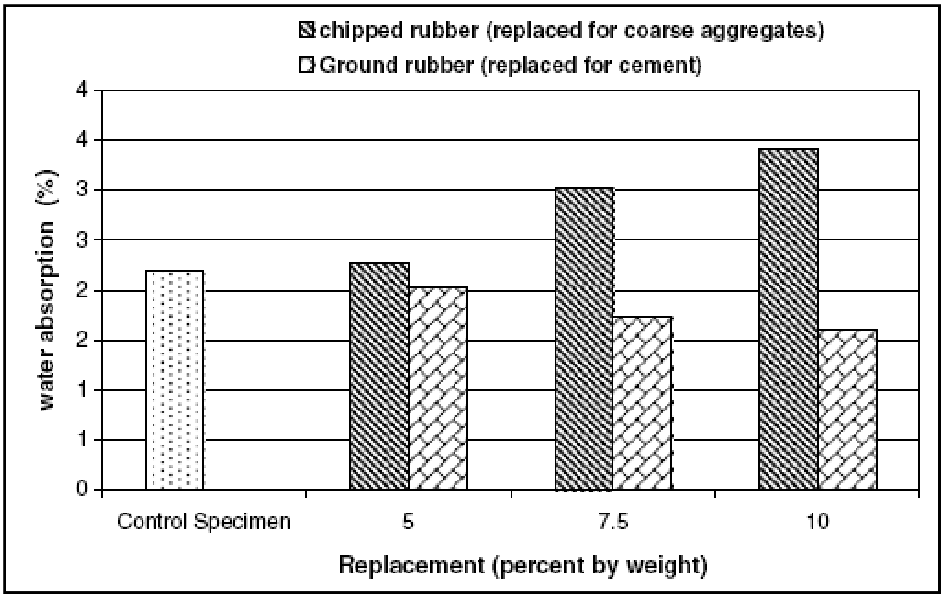


Figure 2.12: Results of water absorption test (Ganjian et al, 2009)

2.3 Natural Fibre Incorporation in Cement Based Material

Interest in using natural fibres in concrete-based material has been growing recently. Natural fibres have been used to reinforce inorganic material for thousands of years. During this century, fibres such as bamboo, wood and fruit fibres have been incorporated in cement based products. Research have been carried out in many countries on various mechanical properties, physical performance and durability of concrete reinforced with natural fibres from coconut husk, sisal, sugarcane and other vegetable fibres. These investigations have shown encouraging prospects for new distinct group of materials for potential application in various types of constructions. Natural fibre reinforced concrete is essentially a special purpose concrete which consist of natural fibre of different origin randomly distributed in a cementations matrix. The uniform dispersal of fibres in a cementitious matrix distributes stresses and enhances resistance to cracking, impact and shock loadings, and also improves ductility for better acoustic and thermal properties.

Reis (2006) has discovered that natural fibres can be used as reinforcement for polymer concrete. Coconut, sugar cane bagasse and banana fibres were used in his research. Figure 2.13 shows a fracture toughness comparison graph between coconut, sugar cane bagasse and banana fibres. The fracture toughness of unreinforced and synthetic reinforced epoxy polymer concrete is compared to the natural fibre-reinforced polymer concrete. Coconut fibre-reinforced polymer concrete fracture toughness and fracture energy are higher than that of others natural fibres reinforcement and those of unreinforced epoxy polymer concrete.