# MECHANICAL, DURABILITY AND DAMPING PROPERTIES FOR OPTIMUM RUBBERISED CONCRETE PERFORMANCE

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For my beloved mother, father, wife, daughter and family.

PERPUSTAKAAN TUNKU TUN AMINAH

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#### ABSTRACT

Waste tyres pose significant health and environmental concerns if there are not recycled or appropriately discarded. Partial replacement of natural aggregate with waste tyres in the concrete mixture has been proven to be more economical and sustainable. Many researchers have study on mechanical and durability properties of rubberised concrete. However, there are lack of study on damping properties of rubberised concrete. Previous study has shown that incorporating rubber in concrete mix caused significant reduction on mechanical and durability properties of rubberised concrete and thus discourage its commercialisation. Large rubber particle and high percentage of rubber replacement causes substantial reduction on mechanical and durability properties of rubberised concrete. The goal of this research is to investigate the mechanical, durability and damping properties by using small rubber particles, namely rubber ash and rubber crumb, to partially replace sand in concrete at low percentage namely 3%, 5%, 7% and 9%. The material properties of sand, rubber ash and rubber crumb, namely: (1) bulk density; (2) specific gravity; (3) particle size distribution; (4) morphology; and (5) chemical composition, are determined by using five different tests. Further eight tests were conducted to determine the engineering properties of the concrete mix with rubber ash or rubber crumb, namely: (1) workability; (2) bulk density; (3) compressive strength; (4) flexural strength; (5) splitting tensile strength; (6) modulus of elasticity; (7) water absorption; and (8) water permeability. Damping properties of the concrete mix with rubber ash or rubber crumb, namely: (1) frequency; (2) mode shape; and (3) damping ratios, are determined by using impact hammer test. The mechanical, durability and damping properties of rubber ash concrete and rubber crumb concrete are compared with the control concrete. The results show that the rubber ash and rubber crumb are suitable to partially replace sand in the concrete mix. Both the mechanical, durability and damping properties have improved by up to 15%. This study found that the optimum content for rubber ash to replace sand in concrete mix is found to be at 5%, whilst the rubber crumb is at 3% for



achieving improved engineering properties. The optimised rubber ash or rubber crumb to replace sand in concrete mix are 3% and 9%, respectively, for achieving improved damping properties. The experimental results of damping properties for rubber ash concrete and rubber crumb concrete are validated by computational modelling, and thus the damping properties of any rubberised concrete structure within the range of this study can be determine by computational modelling. The results of this study indicate the huge potential of the waste rubber to be recycled and used to partially replace sand in concrete mix, and hence reduce dumped tyre waste as well as reduce the use of natural resources (sand).

#### ABSTRAK

Sisa buangan tayar menimbulkan kebimbangan kesihatan dan persekitaran yang signifikan jika tidak dikitar semula atau dibuang dengan sewajarnya. Penggantian sebahagian batu baur semula jadi dengan sisa buangan tayar dalam campuran konkrit telah terbukti lebih ekonomi dan lestari. Ramai penyelidik membuat kajian terhadap sifat mekanikal dan ketahanan konkrit getah. Namun kurang kajian mengenai sifat redaman konkrit getah. Kajian terdahulu menunjukkan bahawa memasukkan getah dalam campuran konkrit menyebabkan pengurangan yang ketara pada sifat mekanikal dan ketahanan konkrit getah dan dengan itu tidak menggalakkan pengkomersialannya. Partikel getah yang besar dan peratusan penambahan getah yang tinggi menyebabkan penurunan ketara pada sifat mekanikal dan ketahanan konkrit getah. Tujuan penyelidikan ini adalah untuk mengkaji sifat mekanikal, ketahanan dan redaman dengan menggunakan partikel getah kecil, iaitu abu getah dan remah getah, untuk menggantikan sebahagian pasir dalam konkrit dengan peratusan rendah iaitu 3%, 5%, 7% dan 9%. Sifat bahan pasir, abu getah dan serbuk getah, iaitu: (1) ketumpatan pukal; (2) graviti tentu; (3) taburan saiz zarah; (4) morfologi; dan (5) komposisi kimia, ditentukan dengan menggunakan lima ujian yang berbeza. Selanjutnya lapan ujian telah dijalankan untuk menentukan sifat kejuruteraan campuran konkrit dengan abu getah atau rumah getah, iaitu: (1) kebolehkerjaan; (2) ketumpatan pukal; (3) kekuatan mampatan; (4) kekuatan lenturan; (5) kekuatan tegangan membelah; (6) modulus keanjalan; (7) penyerapan air; dan (8) kebolehtelapan air. Sifat redaman bagi campuran konkrit dengan abu getah atau remah getah, iaitu: (1) frekuensi natural; (2) bentuk mod; dan (3) nisbah redaman ditentukan melalui ujian tukul impak. Sifat mekanikal, ketahanan dan redaman konkrit abu getah dan konkrit remah getah dibandingkan dengan konkrit kawalan. Dapatan ujian menunjukkan bahawa abu getah dan remah getah adalah sesuai untuk menggantikan sebahagian pasir dalam campuran konkrit. Sifat mekanikal, ketahanan dan redaman telah bertambahbaik sehingga 15%. Kajian ini mendapati kandungan optimum untuk abu getah untuk menggantikan pasir dalam



campuran konkrit didapati pada 5%, manakala serbuk getah adalah pada 3% untuk mencapai penambahbaikan sifat mekanikal dan ketahanan. Kandungan optimum abu getah atau remah getah untuk menggantikan pasir dalam campuran konkrit adalah masing-masing pada 3% dan 9% untuk mendapatkan sifat redaman yang terbaik. Hasil eksperimen sifat redaman untuk konkrit abu getah dan konkrit remah getah disahkan oleh pemodelan komputasi, dan oleh itu sifat redaman apa-apa struktur konkrit getah dalam julat kajian ini dapat ditentukan dengan pemodelan komputasi. Dapatan kajian ini menunjukkan sisa tayar mempunyai potensi yang besar untuk dikitar semula dan digunakan untuk menggantikan sebahagian pasir dalam campuran konkrit, dan sekali gus mengurangkan lambakan tayar buangan selain mengurangkan penggunaan sumber semula jadi (pasir).

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### LIST OF SYMBOLS AND ABBREVIATIONS

%	-	Percentage
<	-	Small/ Less Than
>	-	Larger/ More Than
-	-	Negative
С	-	Degree Celsius
Н	-	Hour
mm	-	Millimetre
Hz	-	Hertz
AS	-	Australian Standards
ACI	-	American Concrete Institute
ASTM	-	American Society for Testing and Materials
Ctrl	-	Control
BS	-	British Standards
BS EN	-	British Adoption of European Standards
MK		Metakaolin
MS EN	RPU	Malaysian Standards
OPC	-	Ordinary Portland Cement
RAC	-	Rubber Ash Concrete
RCC	-	Rubber Crumb Concrete



### **CHAPTER 1**

#### **INTRODUCTION**

Nowadays, road authorities struggle to maintain a substantial number of ageing

bridges, which do not comply with the current standard. This can be due to: (1)

#### 1.1 Background of Study

deterioration and structural deficiencies developed over time; or (2) the escalating demands imposed by increased traffic intensity and higher axle loads (Mara *et al.*, 2014). As a result, the maintenance of bridges is costly and has turned into a very challenging task for the road authorities. Bridge maintenance is even more expensive and complicated in urban areas compared to rural areas, with the additional indirect costs due to traffic disruption. New maintenance methods that minimize the traffic disruption and disturbance in highly populated areas are therefore beneficial for road authorities or owners. One aspect that can be further improved is the use of durable material for concrete deck on bridge structure.

Portland cement concrete is one of the most versatile materials commonly used in construction industry. The widespread use of this type of cement had facilitated industrial growth in the last century and also contributed to environmental issues (Petersen *et al.*, 2015). Gupta *et al.* (2014) argued that concrete industry is one of the most environmentally demanding industries as its production processes involved mining of natural aggregates, use of increasingly scarce freshwater resources, and development of new chemical admixtures. Most of the research today and the current state-of-practices related to resource productivity in structural concrete are limited to cement conservation through the partial replacement of cement with industrial byproduct, for example, fly ash, ground granulated blast furnace slag, and silica fume



(González-López *et al.*, 2015). Unfortunately, there has been a slight overlook on the development of suitable substitution materials to the concrete mixture, such as industrial and agricultural wastes, that resulted in concrete mixture with superior mechanical properties.

The National Solid Waste Management Department, Ministry of Housing and Local Government of Malaysia reported that approximately 300,000 tonnes of scrap tyres are generated annually (Chemisian Konsultant Sdn. Bhd., 2011). This value is estimated to increase at about 5% every year, in line with the percentage increment of vehicle usage. Through this study, it can be estimated that by 2021, the volume of scrap tyres generated is expected to be approximately 471,221 tonnes. This problem, however, is not localised as other countries such as the United States of America generates approximately 300,000,000 scrap tyres annually, about 40% of which are used as fuel for generating energy, 26% ground into crumb rubber, 13% discarded in landfills, and only about 5.5% used in civil engineering applications (Shu & Huang, 2014). In the meantime, Xiong *et al.* (2021) reported that approximately 1 billion tyres end their service life every year around the world and more than 50% are discarded without any treatment.



The significant increase in the number of vehicles worldwide and the lack of both technical and economical mechanisms resulting in waste tyres are considered serious pollution problems in terms of waste disposal. The best way to dispose of waste tyres is to reuse them (Lv *et al.*, 2015). The interest in recycling tyre is due to its availability and the high generation volume. The rate of scrap tyre generation is expected to continue growing as the world population and vehicle usage increase (Onuaguluchi & Panesar, 2014). Throughout the United States, there were still 128,000,000 tyres remain stockpiled (Xue & Shinozuka, 2013). Waste tyre management and disposal are major environmental concerns in many countries. Stockpiling is dangerous, not only due to potential adverse environmental impacts, but also because it poses a fire hazard and provides breeding for vector such as rats, mice, vermin, and mosquitoes (Elchalakani, 2015). Also, when such tyres dumbs catch fire it is notoriously difficult and costly to extinguish (Youssf *et al.*, 2014).

Rubber is also one of the industrial wastes that attracts the interest of many researchers. For example, Pelisser *et al.* (2011) mixed rubber into concrete mixture to produce a concrete product with low density and increased thermal insulation and soundproofing. The increase in the waste tyre content in the concrete mixture was

found to lower the density of concrete to as low as 75% of the normal concrete weight (Abd. Aziz *et al.*, 2014). Nadal Gisbert *et al.* (2014) found that the addition of rubber particles produces lighter concrete, which can be used for specific applications and have the characteristic of occluding a large amount of air inside that further improves its workability. Furthermore, the increased capacity to dissipate and absorb energy favours its usage in many applications, including the production of sound barriers (Nadal Gisbert *et al.*, 2014). Rubber has a high resistance to cracking in which it does not only improves the resistance of the cementitious to cracking from impact load but also enhances the overall impact strength (Dehdezi *et al.*, 2015).

Construction materials used for engineering applications including the airport runway, road pavement, bridge deck and other structural systems are expected to be concrete structure of high impact resistance. These applications are often exposed to dynamic impact loading thus making its energy-absorbing ability or durability very important. It is established that incorporating rubber to a concrete mixture contributes to a significant improvement in its durability, and hence resistant to impact (Liu et al., 2012). However, the main disadvantages of adding waste tyre rubber in concrete are reduction of the compressive strength and elastic modulus (Hilal, 2017; Khorami & Ganjian, 2011; Thomas & Gupta, 2016; Youssf et al., 2016). Eldin and Senouci (1993) were the first to study concrete consisting tyre aggregate of 38, 25 and 19 mm, in 1993 they found that concrete exhibits lower compressive strength and splitting tensile strength. A notable result was that the failure mode of the concrete was ductile rather than brittle. Thomas et al. (1994) further investigated the effects of adding rubber into a concrete mixture by replacing fine (1 mm) and coarse (6 mm, 19 mm, 25 mm and 38 mm) aggregate. Their results supported the findings of the previous study, in that the concrete type aggregate had lower compressive and tensile strength. Several studies (Thomas et al., 1994; Bravo & de Brito, 2012) have shown that the increase in the size of the tyre aggregate will result in decreasing compressive strength. They also observed that the loss of compressive strength increased with the size of the tyre aggregate (Bravo & de Brito, 2012). The greater the size of rubber particles added to the concrete, the lower the strength of the concrete, and vice versa (Li et al., 2014; Liu et al., 2012).

The increasing amount of waste tyres worldwide makes the disposal of tyres a crucial problem to be solved. One of the most critical environmental issues all around the world is the disposal of waste materials. Accumulations of discarded waste tyres



have been a major concern because waste rubber is not easily biodegradable even after a long period of landfill treatment. However, there are material and energy that can be extracted from waste rubber. Other researchers propose to use it as fuel material or as raw materials of rubber goods (Sukontasukkul & Tiamlom, 2012). Recycled used rubber conserves valuable natural resources and reduces the amount of rubber entering landfill (Youssf *et al.*, 2015).

The use of recycled rubber particles as alternative aggregates in concrete has received significant attention over the last two decades. This is due to the massive quantities of scrap vehicle tyres that have already accumulated and the increased annual production estimated to be one billion tyres produced worldwide in 2011 (Hall & Najim, 2014). Utilization of rubber wastes in the construction industry is now well developed for sustainability in two ways. First, reuse the materials which otherwise would become a burden to the environment and occupy scarce land resource. Second, it minimizes the degradation of land and the environment because of comparatively less digging. Recycling is an all-prevailing practice now as it conserves the planet resources (Gesoğlu & Güneyisi, 2011). Rubberised concrete has become an emerging research topic in recent years. To date, most research is focused on the evaluation of mechanical properties of the rubberised concrete mixture (Xue & Shinozuka, 2013).



The replacement of fine aggregate with waste tyre rubber, at a volume of 5%, causes the strength to increase up to 10% (da Silva *et al.*, 2015). The addition of shredded scrap tyres to concrete provides some favourable characteristics for concrete and alters some of the concrete properties. The ordinary cement-based concrete is generally brittle, however, the addition of rubber in the concrete material increases its ductility and impact resistance (Moustafa & ElGawady, 2015; Pham *et al.*, 2020). The rubberize concrete is recommended to be used in circumstances where vibration damping is required, such as for bridge construction as a shock-wave absorber (Chou *et al.*, 2010; Li *et al.*, 2020). Experimental studies on rubberised concrete materials have shown that using rubber in concrete as partial replacement of mineral aggregates enhances its ductility, toughness, impact resistance, energy dissipation, and damping ratio (Youssf *et al.*, 2015). A recent study by Moustafa & ElGawady (2015) investigated the methods for increasing the damping capacity of concrete by replacing up to 20% of the fine aggregate with shredded rubber. Generally, the study reported an increase in damping and a decrease in compressive strength (Moustafa &

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### **List of Publications**

- 1. Characterization of tyre rubber ash and crumb as fine aggregate resource Shahidan, S., Mangi, S.A., Senin, M.S., Mohd Zuki, S.S., Ibrahim, M.H.W. Journal of Engineering Science and Technology, 2021, 16(1), pp. 510–526
- 2. Properties of Concrete Containing Rubber Ash and Rubber Crumb as Partial Replacement of Sand

Shahidan, S., Mangi, S.A., Senin, M.S., Mohd Zuki, S.S., Ibrahim, M.H.W. International Journal of Advanced Science and Technology, 2020, 29(9), pp. 2053–2059

3. The effect of using different substitutes of rubber ash on compressive strength of cement mortar

Senin, M.S., Shahidan, S., Ghafar, N.H.A., ...Ibrahim, M.H.W., Nazri, F.M. Malaysian Construction Research Journal, 2018, 4(2 Special Issue), pp. 72–83

- A review on the suitability of rubberized concrete for concrete bridge decks
   Senin, M.S., Shahidan, S., Abdullah, S.R., Guntor, N.A., Leman, A.S.
   IOP Conference Series: Materials Science and Engineering, 2017, 271(1), 012074
- 5. The durability of concrete containing recycled tyres as a partial replacement of fine aggregate

Senin, M.S., Shahidan, S., Leman, A.S., ...Ibrahim, M.H.W., Mohd Zuki, S.S. IOP Conference Series: Materials Science and Engineering, 2017, 271(1), 012075

- 6. The optimum content of rubber ash in concrete: Flexural strength Senin, M.S., Shahidan, S., Shamsuddin, S.M., ...Khalid, F.S., Nazri, F.M. IOP Conference Series: Materials Science and Engineering, 2017, 271(1), 012009
- 7. Analysis of Physical Properties and Mineralogical of Pyrolysis Tires Rubber Ash Compared Natural Sand in Concrete material

Mohamad Syamir Senin, Shahiron Shahidan, Alif Syazani Leman and Nurul Izzati Raihan Ramzi Hannan

IOP Conference Series: Materials Science and Engineering, 2016, 160(1), 012053

8. Properties of Cement Mortar Containing Rubber Ash as Sand Replacement Mohamad Syamir Senin, Shahiron Shahidan, Alif Syazani Leman and Nurul Izzati Raihan Ramzi Hannan

IOP Conference Series: Materials Science and Engineering, 2016, 160(1), 012055