Waste Tyre Rubber Application in Semi-Rigid and Flexible Pavement

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Abstract

Increasing traffic requires durable and low-noise road surfaces. Urban residents complain about excessive traffic noise that leads to an unhealthy environment. Understanding techniques to produce durable, low-noise pavement has led to the development of rubberized concrete block pavement (RCBP) and rubberized asphalt concrete pavement (RACP). The chapter examines morphology and chemical properties of waste tyre rubber using FESEM, XRF, and TGA/DTA. Authors discuss characteristics of RCPB and RACP and conclude application of RCBP and RACP can lower traffic noise.

Introduction

In view of a conventional waste management system, waste tyres are basically either disposed in the landfill or burned. Tyre stockpiles caused severe health problem to human due to mosquito, vermin, and rats breeding. Fire hazard from the tyre burning activity also can cause uncontrollable burning and air pollution. However, tyre disposal and burning in landfills are banned in most countries (Martínez et al., 2013). According to Shah (2006), the current “conservation of natural resource concept”, i.e. the reuse (retread) first, then reuse of rubber prior disposal, does not accommodate the ever-increased dumping of tyres. Due to the high cost of legal disposal for tyres, illegal dumping may increase. Disposal of tyres is becoming more expensive, while this trend is likely to continue as landfill spaces become insufficient. Tyres take up landfill space.

The challenge of scrap tyre management arises mainly from the technical and commercial issues relating to tyres both as a product and as a waste. What is tyre? Tyres are made of materials including synthetic and natural rubber, textiles, steel, carbon black, aromatic extender oils and various chemical additives, which are “vulcanised” at a high temperature during the manufacturing process (Chemsain, 2011). The main components of car and truck tyre as shown in Figure 1 is particularly a stable product that requires a great energy to properly break the material down to useful product. In this chapter, we’ll look into the component of a tyre, the chemical and physical properties, waste tyre management, and waste tyre application in pavement industry.

Chapter 1

Waste Tyre Rubber Application in Semi-Rigid and Flexible Pavement

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ABSTRACT

Increasing traffic requires durable and low-noise road surfaces. Urban residents complain about excessive traffic noise that leads to an unhealthy environment. Understanding techniques to produce durable, low-noise pavement has led to the development of rubberized concrete block pavement (RCBP) and rubberized asphalt concrete pavement (RACP). The chapter examines morphology and chemical properties of waste tyre rubber using FESEM, XRF, and TGA/DTA. Authors discuss characteristics of RCPB and RACP and conclude application of RCBP and RACP can lower traffic noise.

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INTRODUCTION

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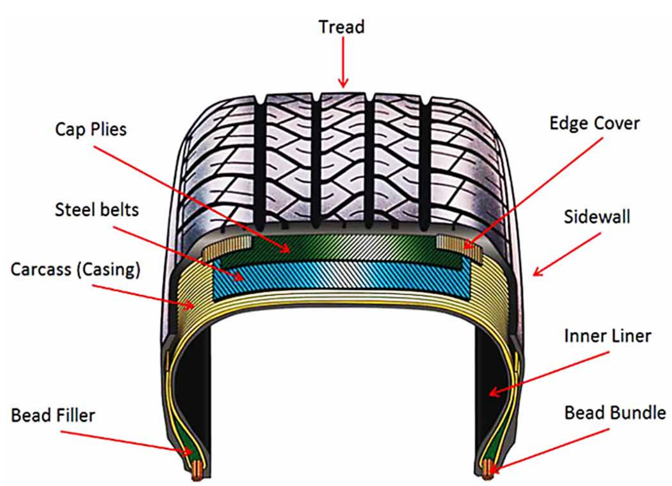
WASTE TYRE MANAGEMENT APPROACH

Waste tyres are managed in various approaches to ensure the by-product can be used as a new energy sources or produced as new material. Szentannai *et al*. (2015) and Lopez *et al.* (2017) investigated ways to reclaim the virgin components and recover energy and new materials from waste tyres through the high technology oriented and excessive heat processes such as the de-vulcanisation, pyrolysis, gasification,

Figure 1. Components of a tyre
Source: https://kitchendecor.club/files/radial-tire-cross-section.html



and hydrogenation processes. Besides that, Mavroulidou and Figueiredo (2010) also suggested several waste tyres recycling alternatives which include a) combustion/pyrolysis of waste tyres; b) shredding or grinding tyres; and c) re-treading and reuse of old tyres.

PYROLYSIS OF WASTE TYRES

Waste tyre pyrolysis is an endothermic process whereby the waste tyres were exposed and absorbed the surrounding heat provided in a reactor vessel containing an oxygen-free atmosphere. For the reactor, Lopez *et al.* (2017) suggest using conical spouted bed reactor (CSBR) that perform adequate pyrolysis for different waste materials. In addition, Kwon *et al.* (2015) recommend the utilization of CO_2 as the pyrolysis reaction medium. According to Miranda *et al.* (2013), WTR pyrolysis leads to the formation of non-condensable compounds, light liquids, and solid products. Similar observation found by Martínez *et al.* (2013) where 40% of the pyrolysis by-product is in the form of a solid fraction (char or carbon black and steel) and another 60% removed as a volatile fraction. These vapours can be burned directly to produce power or condensed into an oily type liquid, generally used as a fuel. Some molecules are too small to condense. They remain as a gas which can be burned as fuel. Figure 2 shows the primary and secondary products of WTR pyrolisis observed by Akhil et. al. (2018).

ACTIVATED CARBON

Activated carbon has an incredibly large surface area per unit volume and a network of submicroscopic pores where adsorption takes place. Activated carbon is a material that is produced from carbonaceous source materials, such as coal, coconuts, nutshells, peat, wood, lignite, and waste tyre. The carbon-based

Figure 2. Primary and secondary products of waste tyre rubber
Source: Akhil et. al. (2018)

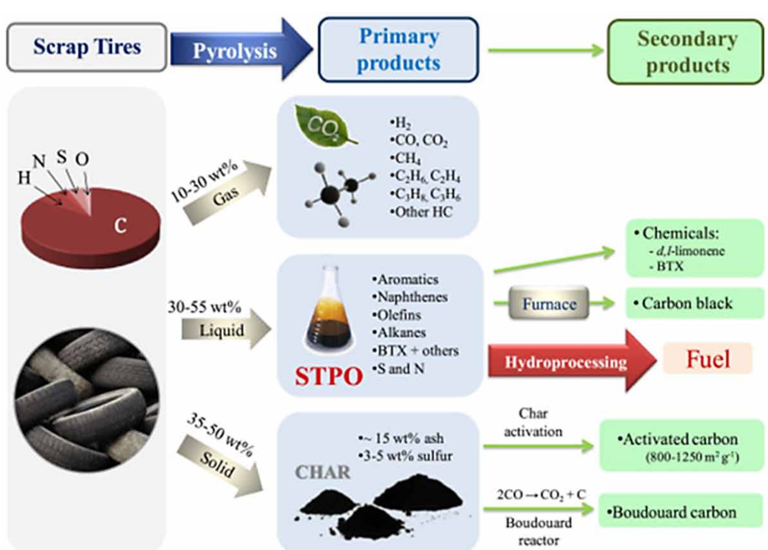
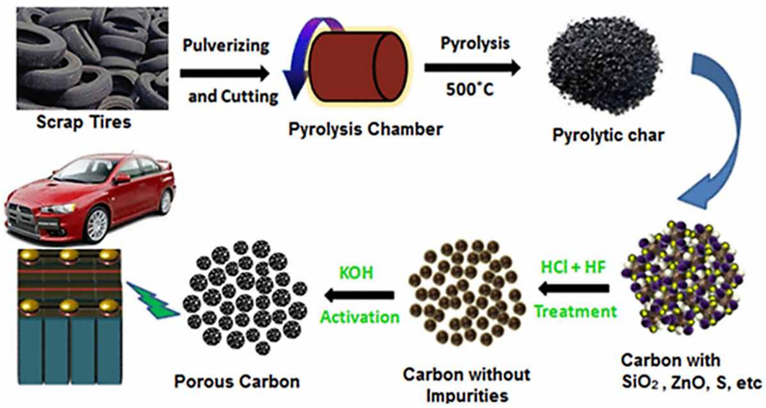


Figure 3. Activated carbon product derived from waste tyre rubber
Source: Shilpa (2017)

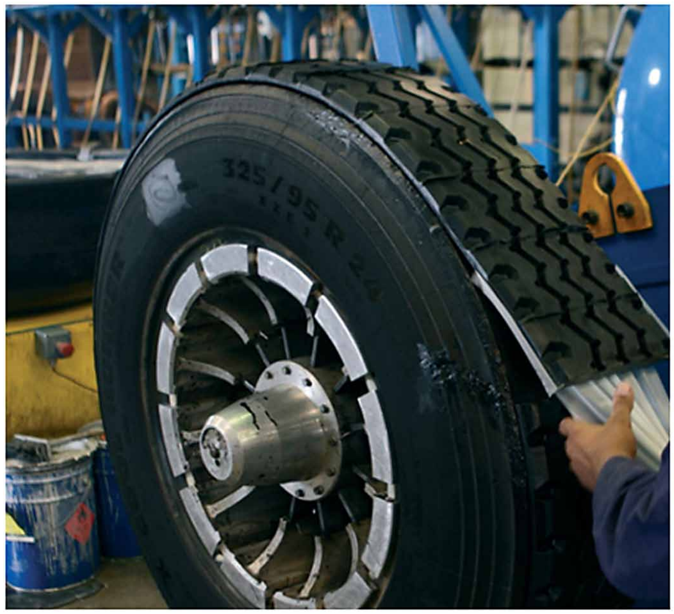


material is converted to activated carbon through physical modification and thermal decomposition in a furnace, under a controlled atmosphere and temperature (Figure 3). The finished product has a large surface area per unit volume and a network of submicroscopic pores where adsorption takes place. The potential of these products as possible adsorbents for various pollutants has been assessed and found to be very successful.

RECYCLING AND RETREATMENT OF WASTE TYRES

Waste tyre recycling may be used in many forms according to its suitable application. It is widely known that tyre recycling offers the most resource efficient strategy for used tyre recovery, saving both material and energy. Amari *et al.* (1999), Aniza *et al.* (2013), and Shu and Huang (2014) explained that the reuse of scrap tyres can be recycled whole or size-reduced for civil engineering applications and agricultural uses and for composite materials. The most common application in civil engineering practices are using scrap tyres as a lightweight filler in Portland cement concrete and also asphalt paving mixtures' modifier. Ground rubber from tyres can be added to other polymers (rubber or plastic) to extend or modify properties of thermoplastic polymeric materials. Whole tyres are used for applications where their physical form, resilience to impact, and longevity are beneficial, for example in marine docks, highway crash barriers, bumpers, landscape use, load-bearing walls, road sub-base, retaining wall, weights for silage cover sheets, erosion protection for walls and steep slopes, acoustic walls, and artificial reefs. Bound rubber product like a rubberized playground and sports field surfaces, roadways and drainage schemes also can be produced. Retreading of used tyres (Figure 4) is the most preferable way of making use of old tyres. On average, only 15% of crude oil is needed to produce a retread instead of a new tyre. Thus, the price of a tyre is reduced up to 45% without any loss in quality (Vest, 2000).

Figure 4. Waste tyre retreading
Source: http://www.bensontire.com/products.html



PROPERTIES OF WASTE TYRE

Physical Properties

Recent research has been devoted to the possibility of using rubber derived from scrap tyres to replace natural aggregates in concrete and asphalt. Research related to rubberized concrete and asphalt maybe varies in terms of rubber content, size, types, grinding method, manufacturing process and applications. For both rubberized concrete and rubberized asphalt, the effect of tyre rubber size and replacement ratio seems to be more dominant as compared to other factors. Since more aggregates were replaced with a softer material (rubber particles), it was predictable that the intensity of the concrete to resist compression forces will degrade. However, owing to the elastic nature of this material, it will help to increase the flexibility of the pavement.

In general, vehicles tyres can be divided into two types: passenger car and truck tyres. Waste tyres, especially for civil engineering application, were categorized based on the particles size and production or recycling process applied for that particular tyre. There are four broad categories of recycled or reprocessed waste tyre rubber (Figure 5) considered in most research civil engineering research.

Besides the shapes and sizes of tyre rubber particles, the density of the rubber may vary according to the source of the rubber as summarized in Table 1. Possible reasons for the variations in densities could be due to rubber quality, types of waste tyres (automobile or truck) and also types of shredding process.

The recycled waste tyres used in civil engineering application is mainly used as replacement of aggregate, filler or cement. Replacement of natural resources namely aggregate and cement with the WTR shows a very promising result. For every engineering structure, the strength cannot be compromised. Thus, it is also important to study the factors that may affect the strength of the concrete. First, we'll

Figure 5. Recycled waste tyre rubber

look into the surface texture or morphology of the WTR (Figure 6). The WTR surface is covered with layers and these layers contribute to hydrophobic nature of rubber which tends to trap air and bubbles. Obviously, air bubbles are easily trapped in between the pores and rough surface. This factor generally contributes to the increment of pore structures in hardened cement concrete, hence reducing the density of the concrete thus also affecting the strength of the cement concrete. For the case of asphaltic concrete, the roughness of WTR was found to increase the viscosity of asphalt that using WTR as filler.

CHEMICAL PROPERTIES

The chemical compositions of WTR (Figure 7) are distinguished using XRF analysis. From the results adopted from Euniza (2018), it is noticed that the WTR is mainly composed of 49% SBR synthetic rubber, produced from a copolymer of styrene and butadiene. Generally, SBR component is used in great quantities in automobile and truck tyres production as an abrasion-resistant replacement for natural rubber (produced from polyisoprene). Furthermore, the WTR is also made of 48% carbon black. Carbon black is used as a pigment and reinforcing phase in automobile tyres. In addition, carbon black also helps to conduct heat away from the tread and belt area of the tyre, reducing thermal damage and increasing tyre life.

As for extender oil, about 1.9% of the total tyre composition is also added to soften the rubber and improve workability. Extender oil is a mixture of an aromatic hydrocarbon. A small amount of sulfur (0.8%) was also detected. Sulfur is used in tyres production to cross-link the polymer chains within the rubber and also hardens and prevents excessive deformation at elevated temperature. The accelerator of 0.7% is typically an organosulfur compound which acts as a catalyst for the vulcanization process is also identified. Lastly, zinc oxide and stearic acid compounds help to control vulcanization and enhance

Table 1. Densities of waste tyre rubber

Categories	Density (g/cm³)	References
Rubber particles from recycled tyres with sizes ranging from 4.0 mm to 11.2 mm and obtained by mechanical grinding process.	1.15	Duarte *et al.* (2016)
Tyre rubber powder (600 μm) Tyre rubber (0.8 – 4 mm)	1.05 1.13	Thomas *et al.* (2016)
Granular samples of waste tyre rubber particles without any treatment or contaminants, sourced from a local recycling plant.	1.111 – 0.909	Su *et al.* (2015)
Crumb rubber from mechanical shredding of worn tyres.	1.15	Eiras *et al.* (2014)
Tyre-rubber particles obtained from the mechanical shredding of rubber automotive industry waste.	1.16	Bing and Ning (2014)
Rubber particles from shredding process.	1.089 ± 0.036	Aiello and Leuzzi (2010)
The crumb rubber produced by grinding recycled vehicle tyres into small particles.	0.62 – 0.96	Sukontasukkul (2009)
Coarse and fine Tyre-rubber particles produced by mechanical shredding.	1.16	Khaloo *et al.* (2008)
Tyre section without steel fibre by using cracker mill process.	1.05	Turgut and Yesilata (2008)
Rubber powder of ground tyre (2.36 mm)	0.56	Zheng *et al.* (2008)
Crushed rubber or used tyre chips (15 mm to 4 mm)	1.15	
Rubber particles of less than 1 mm in size and contains approximately 20% by volume of polypropylene fibers	0.43	Benazzouk *et al.* (2007)
Scrap and crumb tyres with size ranges 0.5 to 2 mm and 0.05 to 0.7 mm.	0.90	Bignozzi and Sandrolini (2006)
Crumb rubber of 3.35 mm and 0.85 mm.	0.88 – 0.97	Sukontasukkul and Chaikaew (2006)
Waste tyre chips or particles.	0.84	Li *et al.* (2004)
Crumb rubber produced from recapping truck tyres.	0.40	Pierce and Blackwell (2003)
Two types of rubber, obtained from the shredding processes of truck tyres.	0.46 – 0.525	Fattuhi and Clark (1996)
Shredded rubber tyres, produced by Envirocrete 2000®.	0.61	Toutanji (1996)
Rubber aggregate, obtained by mechanical grinding from the outer surface of scrap tyres.	0.656	Topcu (1995)
Two types of tyre chips: mechanical grinding (Edgar chips) and the other by cryogenic grinding (Preston rubber).	0.80 – 0.96	Eldin and Senouci (1993)

Source: Euniza (2018)

the physical properties of the rubber. Combinations of high abrasion-resistant and heat-resistant material component in tyre rubber obviously explain why waste tyre is extremely difficult to biodegrade compared to other types of waste.

The TGA application is for optimizing the acceleration of aging conditions and predictions of thermal aging of a material. Bystritskaya *et al.* (2013) emphasis by determining the lifetime of polymer and composite materials helps to provide the optimum combination of safety requirements and technical and economic considerations for manufacture. Thermal analysis of WTR alleviates determination of kinetic parameters related to the thermal aging of polymeric materials and to estimate the service life of these materials.

Figure 6. FESEM image of waste tyre rubber

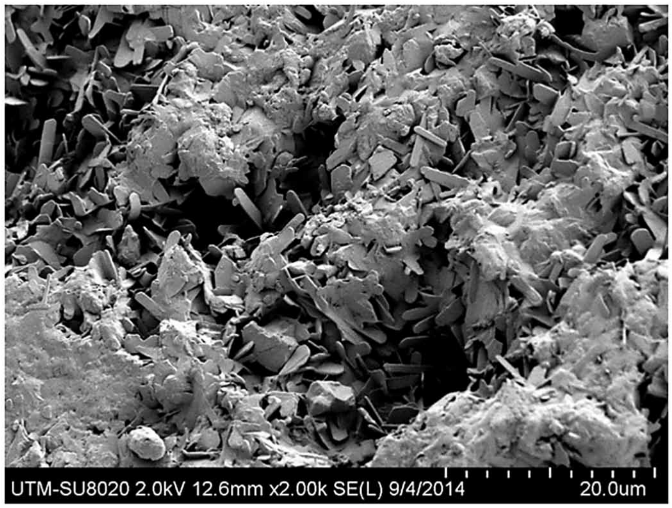


Figure 7. Waste tyre rubber chemical compositions

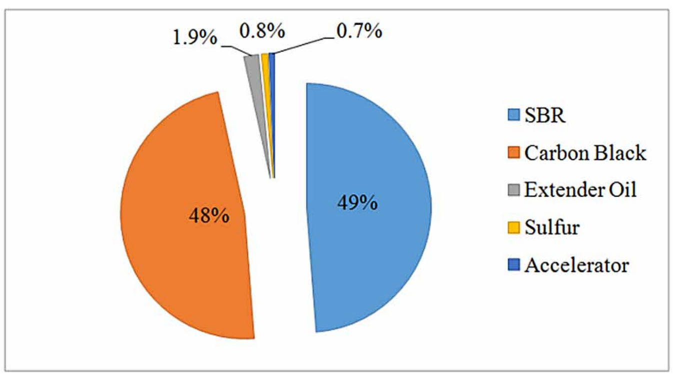
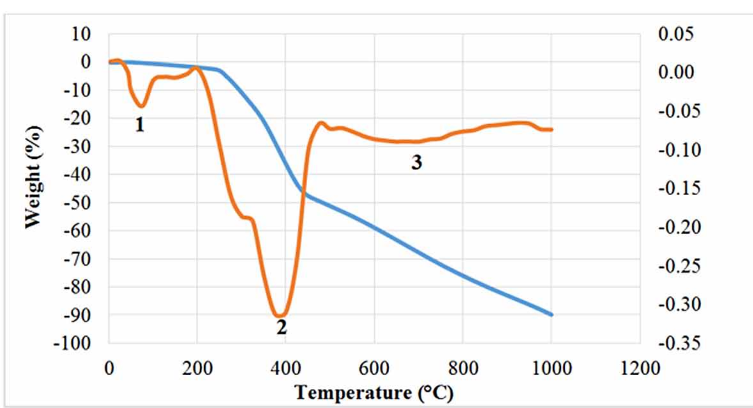


Figure 8. TGA/DTA curves of waste tyre rubber fired to various temperature regimes
Source: Euniza (2018)



As reflected in Figure 8, there are three peaks detected from the TGA/DTA specimen. Decomposition of organic material is reflected in the first endothermic peak which located between 50 °C and 225 °C. As reported by Cui *et al.* (1999); and Knappe and Urso (1993), the process of decomposition begins with the emission of volatile plasticizers and residues of the vulcanization system and incorporated antioxidants. Fernández-Berridi *et al.* (2006) added that the first endothermic peak (at temperature 200 – 300 °C) is associated to volatilization of processing oil. At the temperature between 250 °C to 550 °C where the second peak takes place, it corresponds to the decomposition natural rubber (NR) and styrene rubber (BR or SBR). The result obtained is comparable to Belgacem *et al.* (2013) and Islam *et al.* (2009). Furthermore, Januszewicz *et al.* (2017) found at temperature 427 °C, the hydrocarbon oil is fully destroyed and pyrolitic oil transforms into gas. In addition, by referring to this finding, oil and gas derived from waste tyre can be extracted and used as alternative energy source. Lastly, the third endothermic peak spotted at the temperature of 600 °C to 900 °C, is attributed to the decay of carbon black and zinc oxide (Belgacem *et al.,* 2013). The detected weight loss and maximum peak were tabulated in Table 2.

From the TGA data in Table 2, the thermal decomposition starts at approximately 65 °C where 5% of weight loss is detected. It follows by two major losses of weight during the main devolatilization and pyrolysis which occurs at 385 °C and 675 °C, respectively. Most researchers also agree that major losses of 50 – 70% corresponds to decomposition NR, and BR or SBR (Januszewicz *et al.,* 2017; Belgacem *et al.,* 2013; Islam *et al.,* 2009; Fernández-Berridi *et al.,* 2006; Cui *et al.*, 1999). From the TGA-DTA result of WTR pyrolysis, it is found that the weight loss is relatively high due the presence of inorganic compounds.

PAVEMENT INDUSTRY

In general view of road pavement industry, the demand for producing low noise pavement has increased worldwide. Currently, optimum balance between the road primary function and higher noise reduction performance are essential, especially for the urban area. People living in the urban area begin to complain about the excessive noise disturbance which leads to an unhealthy environment (Tiesler *et al.,* 2013). Increasing road traffic requires road surfaces that are simultaneously durable and low noise. It is noted that tyre/road interaction noise is more dominant when a passenger car travel exceeding 55 km/h. The noise which derived from the engine and exhaust system is easier to handle since today's automobile technology has transformed engine and exhaust system to be more efficient and less noise. The remaining factor to be terminated is rolling noise. Heutschi *et al.* (2016) suggest rolling (tyre/road interaction) noise can be lowered by the installation of low noise road pavements to increase noise reduction at source.

Table 2. Weight Loss of tyre rubber compounds at different temperature

Compound	Temperature (°C)	Maximum Peak (°C)	Weight Loss (%)
Oil, plasticizer, organic additive	50 – 225	65	5
NR, BR, SBR	250 – 550	385	57
Fillers, Carbon Black	600 - 900	675	38

Source: Euniza (2018)

Traffic noise is a general term of unwanted sound generated by the traffic. It is all the sounds that are heard as a result of vehicles traveling down a road and includes the combination of all possible sources of noise on a vehicle. In particular, traffic noise has been spotted as an environmental stressor that causes sleep disturbance and annoyance to the society. According to Guski *et al.* (2016) questionnaire and quantitative meta-analysis results, it shows that people get annoyed about three times higher when the road traffic noise level increases by 10 dB. Furthermore, among the direct and most obvious effects of road traffic noise interferes negatively with the individual's speech communication, on their concentration ability, and consequently on the performance of tasks (Ouis, 2001).

TYRE/ROAD INTERACTION NOISE

Tyre/road interaction noise as shown in Table 3, arises from a combination of physical processes which consist of mechanical, aerodynamical, frictional and propagation. Mechanical effect involved the impacts and shocks resulting from the contact between the tyre tread and road surface that lead to vibrations. Moreover, the aerodynamical effect is related to the processes between, and within, the tyre tread and road surface patterns such as air turbulence, cavity resonance in tyre tube, air-pumping, and Helmholtz resonant radiation and pipe resonance. Frictional noise is due to the adhesion and micro-movement effects of the tread during its contact with the road, such as 'Stick-slip' and 'Stick-snap'. Lastly, propagation effect is an acoustical impedance related properties of the surface that influence transmission paths, such as horn effect, absorption, and directivity of sound frequency.

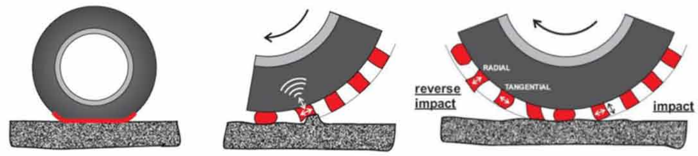
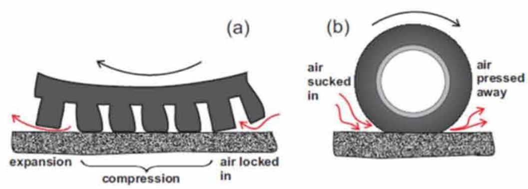
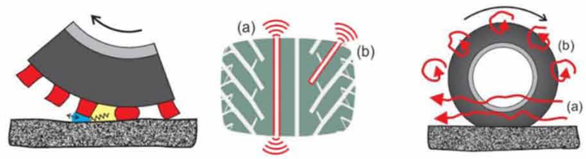
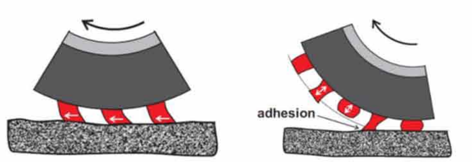
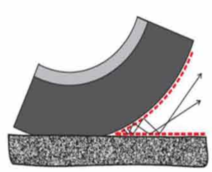
The tyre/road interaction noise is influenced by road surfacing characteristics as well tyre characteristics. According to Sandberg and Ejsmont (2002), road surfacing characteristics that influence tyre/road noise generation are megastructure, macrostructure, and porosity. Megastructure and macrostructure of road surface corresponding to the wavelength range of the texture between 50 mm and 0.5 mm, and 50 mm and 0.5 mm, respectively. Megastructure is also associated with the unevenness of road surface, while macrostructure is associated with the size of aggregates used in the pavement. Porosity is referring to the pore of the road surfacing. The percentage and connectivity of pore also influence the absorption of noise associated with the reflection and propagation of tyre/road interaction noise.

Propulsion noise which derived from the engine and exhaust system is easier to handle since today's automobile technology has transform engine and exhaust system to be more efficient and less noise. The remaining factor to be concerned is the rolling noise which mainly attributed to the tyre-road interaction noise. A noise barrier is also applicable to mitigate traffic noise along a busy road; however, that effectiveness of the noise barrier is somehow debatable. Height is an important variable both in regard to the barrier, the noise sources in need of attenuation, and the anticipated receiver point. Noise barrier must be taller than the tallest noise source in order to be effective. Hence, due to the limitation of noise barrier other noise reducing medium has to be used. Heutschi *et al.* (2016) suggested rolling noise can be lowered by the installation of low noise road pavements.

RESEARCH DEVELOPMENT

Praticò and Anfosso-lédée (2012) identify several types of low-noise pavement that currently available to mitigate traffic noise issue which consist of poro-elastic road surfacing (PERS) or rubberized

Table 3. Tyre/road noise generation

Interaction Effect	Mechanism
Mechanical	 *Running Deflection* *Road texture impact* *Tread element impact*
Aerodynamical	 *Air displacement*  *Helmholtz resonator* *Pipe resonator* *Air turbulence*
Frictional	 *Stick – slip adhesion* *Stick – snap adhesion*
Propagation	 *Horn amplification*

Source: Sandberg and Ejsmont (2002); Kindt et al. (2016)

asphalt (RA); porous asphalt (PA); thin or very thin asphalt concrete (VTAC); and stone mastic asphalt (SMA). Most of the developed low-noise pavement is mainly of asphalt based. Goubert and Sandberg (2016) reported among all bituminous pavement, PERS or RA seems to generate impressive acoustic performance. According to Goubert (2014), the PERS is able to reduce noise up to 12 dB(A) while the others only reduce less than 8 dB(A). The PERS is designed with a minimum of 20% air voids and 20% rubber by weight of modified binder.

Besides asphalt pavement, cement concrete pavement has also commercially used as traffic noise reducer medium. Application of asphalt pavement always deals with durability issue. Durability could be best provided by concrete roads, but standard concrete road surfaces do not achieve noise reductions better than 2 dB, which is not sufficient to compensate the increase of noise levels due to increasing overall traffic volume. Kim and Lee (2010) stated that material such as concrete is classified as 'sound shielding materials' due to their acoustic reflection behaviour. It has been claimed that, at higher speed, where tyre noise is the dominant noise generating mechanism, segmental pavements may be associated with noise levels 5 to 8 dB(A), higher than asphalt surfaces (Ohio Department of Transportation, 2006).

Low-noise concrete pavement starts to evolve as a response to the limitation of asphaltic concrete especially in terms of durability. The WTR material was adopted as a pavement material in powder or granulated form. Research development in semi-rigid and flexible pavement has grown progressively and shows promising outcome. The implication of waste in producing new product will help in reducing waste tyre and saving the environment.

APPLICATION OF WASTE TYRE IN SEMI-RIGID PAVEMENT

Rubberized Concrete Block Pavement

The rubberized concrete paving block (RCPB) was developed by Ling (2011) to utilize waste material and reducing the use of natural material in concrete paving block (CPB). Developing an innovative RCPB product lead to better engineering properties and comparable service performance compared to the existing CPB. The feature of the blocks was shown in Figure 9 and Table 4. The highest percentage of replacement is up to 30% to tolerate the reduction of strength due to the substitution of WTR as aggregate. The WTR ranged from 1 – 5 mm was used to replace the fine aggregate in CPB.

Figure 9. Rubberized concrete paving blocks
Source: Ling (2011)

Table 4. Rubberized concrete paving blocks features

Mix. Notation	Rubber Content (%)	Depth (mm)	Top Surface (mm)	Weight (kg)	Strength (MPa)
CCPB	0	59.6	5.5	2.82	64
10-RCPB	10	59.8	5.0	2.82	63
20-RCPB	20	59.2	5.0	2.74	26
30-RCPB	30	59.8	3.3	2.68	23

Source: Ling (2011)

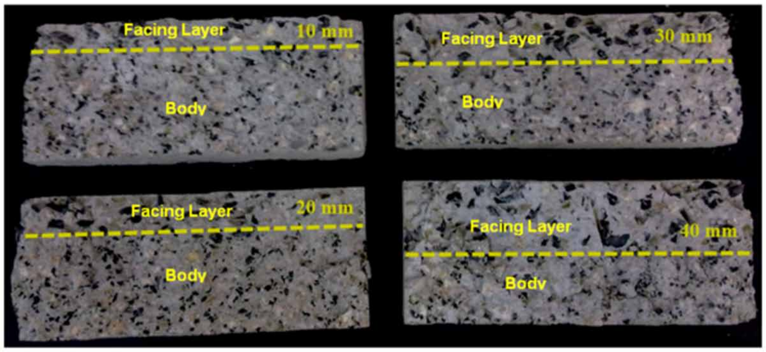
According to Shatanawi (2008), the peak of sound absorption coefficient for low and high-speed traffic occur at a frequency of approximately 600 Hz and 1000 Hz, respectively. In general, the RCPB containing crumb rubber was found to have slightly higher sound absorption coefficients than without crumb rubber over the entire frequency range (100–1600 Hz). This can be attributed to the fact that RCPB containing crumb rubber contributes a higher porous surface layer and less density, resulting in good characteristic in resonant absorbency.

DOUBLE-LAYER RUBBERIZED CONCRETE BLOCK PAVEMENT

The application of WTR in CPB was further improved by Euniza (2018) with the development of double-layer rubberized concrete paving block (DRCPB). The block was designed to provide an alternative type of block with better sound absorption properties. It consists of different facing layer (FL) thicknesses with different percentage of WTR replacement. The sound absorption level of the blocks was measured to simulate the level of tyre-pavement interaction noise that possibly be absorbed. The usage of waste material such as WTR was adopted as it produces positive effects on both environmental and economic prospect. The block and its cross-section are shown in Figures 10 and 11.

Figure 10. Double-Layer Rubberized Concrete Paving Block
Source: Euniza (2018)

Figure 11. Cross section of DRCPB
Source: Euniza (2018)



Acoustic parameters for DRCPB specimens showed that concrete pavement blocks have one peak of sound absorption located at a low frequency of 500 to 700 Hz. This indicates that it suitable for application of mitigation of low traffic speed condition. Two sound absorption prediction models are developed to predict absorption level at optimum and 600 Hz frequency.

Parameters of rubber content, FL thicknesses and porosity are statistically tested and proven to be significant ($p < 0.05$) for model 1. For model 2, only FL thicknesses and RG content give a significant effect on the prediction model. These two models are only applicable of predicting the optimum sound absorption and sound absorption at 600 Hz of DRCPB, if the FL thicknesses, the percentage of RG and the curing condition used are within the tested range. In addition, two equations as suggested by (Hamet, 2004) were used to indicate the prediction values of tyre-road noise on DRCPB. The predicted values using Equation 1 clearly showed that the only DRCPB specimens with TL thickness of 40 mm and RG of 40% able to reduce the tyre-block noise by 2 dB. This specimen block could be used as pathway application. However, if using Equation 2, the predicted noise reduction of DRCPB with TL thickness greater than 30 mm and percentage of RG equal or greater than 20% would be 3 dB which is the impact is noticeable.

$$\triangle L_{PB}\left(f,\theta\right) = 20\log\{\left|1 + Q\left(f,\theta\right)\right| / 2\}\ \mathrm{dB} \quad (1)$$

$$\triangle L_{PB}\left(f_c, 81\right) = -11.9 * \left\langle \alpha_0\left(f_{sh}, 0\right)\right\rangle\ \mathrm{dB} \quad (2)$$

Where, α_o is sound absorption coefficient at shifted frequency, $f_{sh} = f_c$ (1/3 octave band) /0.91.

COMPOSITE CONCRETE PAVING BLOCK

Composite CPB consist of PERS as the block facing and normal concrete as the block body. The idea of developing the PERS-CPB is as a medium to reduce tyre-road interaction noise for a semi-rigid pavement. It shows a very promising result, as the surfacing of the block was replaced with a more flexible

Table 5. Optimum sound absorption and sound absorption at 600 Hz and 1000 Hz.

Facing Layer Thickness (mm)	Rubber Granules (%)	Optimum Sound Absorption Coefficient (α_{opt})	Frequency at Optimum Sound (Hz)	Sound Absorption Coefficient at 600 Hz (α_{600})	Sound Absorption Coefficient at 1000 Hz (α_{1000})
10	10	0.16	600	0.16	0.06
10	20	0.19	559	0.19	0.06
10	30	0.22	543	0.20	0.07
10	40	0.25	540	0.23	0.06
20	10	0.18	634	0.19	0.07
20	20	0.20	550	0.19	0.07
20	30	0.23	531	0.21	0.06
20	40	0.29	559	0.26	0.06
30	10	0.19	500	0.15	0.09
30	20	0.22	625	0.21	0.08
30	30	0.26	643	0.24	0.08
30	40	0.30	618	0.29	0.07
40	10	0.21	500	0.16	0.10
40	20	0.25	613	0.25	0.06
40	30	0.28	634	0.26	0.09
40	40	0.34	640	0.31	0.07

Source: Euniza (2018)

material. The PERS is produced from the combination a minimum of 20% air voids and 20% rubber by weight modified binder. Figures 12 to 14 show the application of PERS on the concrete block in Japan and Slovenia, respectively.

APPLICATION OF WASTE TYRE IN FLEXIBLE PAVEMENT

Rubberized asphalt (RA) is a noise reducing pavement material that consists of regular asphalt concrete mixed with crumb rubber made from tyre rubber. Such pavement has been used in different countries such as the USA, Portugal, Spain, the Netherlands, and Japan. Praticò and Anfosso-lédée (2012) and Goubert (2014) discovered that the noise reduction result of RA ranged from 6.6 to 12 dB(A). According to Vázquez and Paje (2016), at the medium sound frequencies (around 800 Hz) it seems to be strongly correlated to the megatexture and the roughness of the surface studied. The researchers also indicate that high frequency sound could be attenuated inside the voids between particles whose upper surfaces form a nearly flat plane. A sound reduction is due to dispersion and multiple reflections of the tyre/ pavement sound emitted.

Figure 12. Two types of concrete paving block with PERS tested in R46 Akita, Japan
Source: Sandberg et al. (2007)

Figure 13. Poro-elastic block pavement made of PERS glued on concrete blocks and test track in Nova Gorica, Slovenia
Source: Sandberg and Karman (2015)

PORO-ELASTIC ROAD SURFACING (PERS)

Incorporation of waste tyre rubber was implemented in SILVIA and PERSUADE projects, whereby road surface studied are poro-elastic road surface (PERS) and rubberized surfaces. The PERS is an improved rubberized asphalt incorporating voids and channels to reduce traffic noise (Sandberg *et al*., 2014). The PERS is a surface with high elasticity where it is essentially made of aggregate and rubber granules or fibres bound with a polymer modified asphalt or polyurethane binder. In general, PERS is used as wearing course of a road and designed with high porosity. It was proposed by Sandberg and Ejsmont (2002), and Sandberg and Karman (2015) that the term PERS shall only be used for surfaces with a design air voids content of no less than 20% and a proportion of rubber of at least 20% by weight. Figures 15 and 16 show three type of prefabricated rubber panels produced by Tokai, Rosehill, and Spentab Rubber Company that was tested in SILVIA project. The rubber materials used for all cases are from waste tyres.

Figure 14. Solvenian full scale test track in Nova Gorica
Source: D. Kokot

In the laboratory test, it was found that the Rosehill PERS was about 9 dB(A) quieter than the other two PERS . However, a different result was observed for the field test. The Rosehill PERS was found to be less efficient in reducing noise as compared to the other two PERS.

The PERS as shown in Figure 17 provides an efficient combination of noise-reducing measures: (1) sound absorption and elimination of air pressure gradients by its high air voids content, (2) a smooth surface giving low vibration excitation to the tyre, (3) low contact angles in the leading and trailing edges of the tyre/road interface, and (4) low interaction impact between tyre tread and road surface elements. If the hysteresis losses in the deflection of the system can be made low (by material selection and design) the rolling resistance losses of such a system may be low or at least not higher than for a conventional tyre/road contact. Furthermore, according to Swedish-Japanese studies, PERS provides an effective reduction of tyre-pavement noise between 5 and 15 dB(A) compared with conventional dense asphalt surfaces (Praticò and Anfosso-lédée, 2012).

COST EVALUATION

A distinct advantage of using WTR as part of the materials used for pavement is its lower cost and its economic feasibility in comparison to the usage of natural aggregate. The WTR costs RM 40 – 42 per tonne while aggregate RM 70 per tonne (Malaysian supplier). From the material perspective, cost reduction up to 20 - 23% can be obtained.

Figure 15. Three types of PERS tested in SILVIA project
Source: Sandberg et al, (2007)

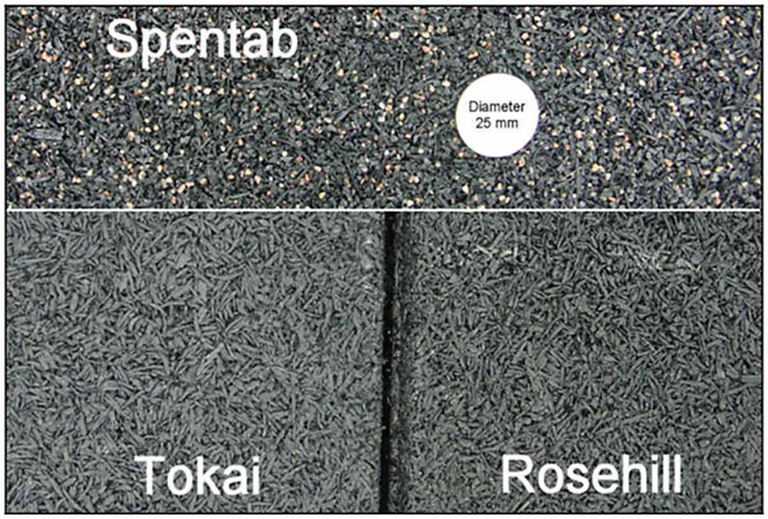


Figure 16. Test site in Stockholm with layout of different PERS surfaces
Source: Sandberg et al. (2010)

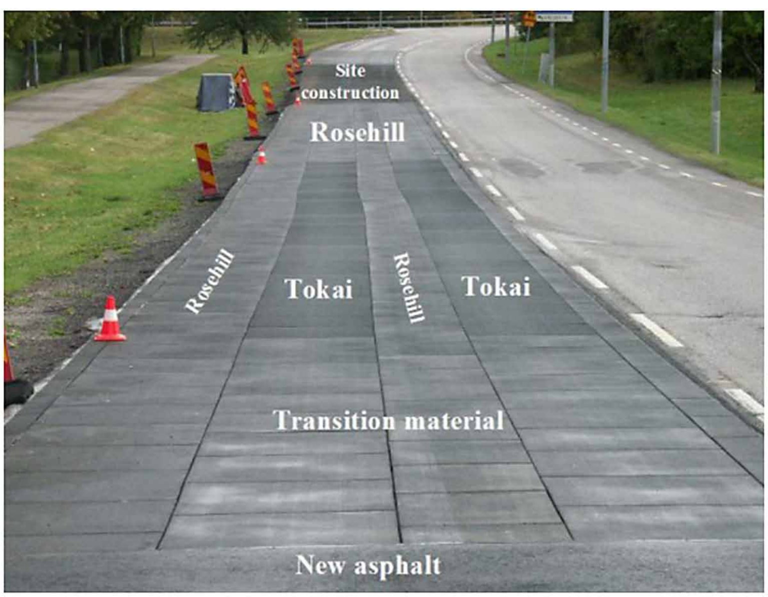
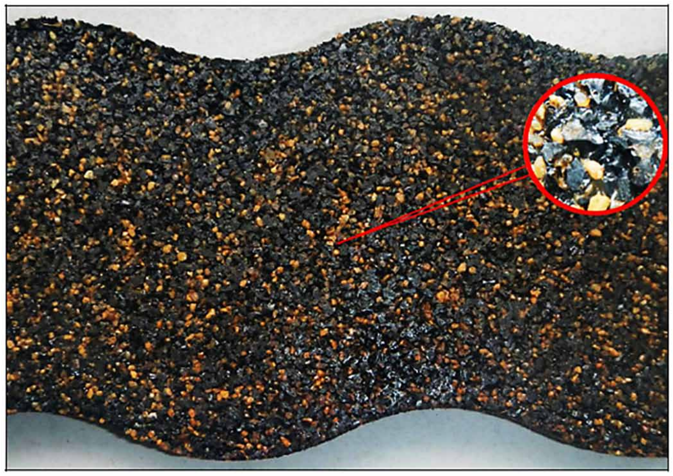


Figure 17. Close-up picture showing the PERS material texture
Source: Sandberg et al. (2013)



SUMMARY

A variety of research application lead to more innovative product derived from waste tyre. Application of waste tyre especially as part of pavement material gives very promising results. Incorporation of waste tyre rubber as one of the constituents used as pavement materials enhance the application of green and sustainable type of pavement. Improved performance of concrete, especially in terms of flexibility, can contribute to the utilization of RCPB and DRCPB as a substitution for the existing concrete block pavement. The rubberized concrete and rubberized asphalt show a positive impact in reducing tyre-road interaction noise thus, can be suggested to be used in the area where low noise is the main concern.

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