# PERFORMANCE OF HOT MIX ASPHALT INCORPORATING TREATED CRUMB RUBBER AND TREATED PLASTIC ADDITIVES USING DRY PROCESS

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy

School of Civil Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

FEBRUARY 2022

# ACKNOWLEDGEMENT

Alhamdulillah, with the will of Allah Almighty, all the hard work for 3 years and half came to an end and paid off. Thanks to Allah for His help and blessing to give me the strength to complete my thesis full of patience.

I would like to thank my supervisor, Prof. Rosli Hainin and my co-supervisors, Dr. Naqiuddin Warid and Dr. Idham Satar, for their guidance for all these years. All their advices and instructions were helped me a lot in the learning process and unforgettable.

A million thanks also to my sponsorships, Ministry of High Education (SLAB) and SLAM, for giving me a chance and trust to pursue my study.

Finally, thanks to all my friends who helped and be parted of my study either directly or indirectly, kak Azah, kak Doya, kak Ros, kak Mira, Hanif and Izzul. Also, not forget to Highway and Transportation Laboratory’s technicians who helped me accomplish my laboratory work, especially En. Azri, En. Izwan and En. Azman.

Thank you.

# ABSTRACT

Pavement defect shortens the service life of mixture, demonstrated by failures such as cracking, rutting, and stripping. Incorporating additives into conventional mixture is an approach to improve its performance and service life. Therefore, this research was conducted in three phases using treated crumb rubber (TCR) and treated plastic (TP) as additives in the mixture. In the first phase, both additives were characterised using thermogravimetric analysis (TGA), field-emission scanning electron microscope (FE-SEM) and energy dispersive x-ray (EDX). Eight different percentages of TCR from 0.25 % to 5.0 % and six different percentages of TP from 0.25 % to 3.0 % were incorporated into a 14 mm nominal maximum aggregate size (AC14) mixture using a dry process. Marshall test was carried out to determine the optimum percentage of the additives. Results show that the mixtures of 0.75 % TCR and 0.75 % TP met all the required specifications and were selected as the optimum percentage. The mixtures with 0.75 % TCR and 0.75 % TP improved the fatigue cracking and rutting resistance compared to the conventional mixture. In the second phase, mechanical tests such as resilient modulus, dynamic creep, rutting and moisture damage of compacted and uncompacted mixtures and scanning electron microscope (SEM) were conducted to evaluate the performance of the mixture containing TCR and TP. Although the modified mixtures with both additives showed better performance than the conventional mixture, the TCR mixture was susceptible to rutting and moisture damage, while the TP mixture was identified with stripping potential. To overcome the issues, a combination of TCR and TP was investigated in the final phase. A mixture with 50 % TCR and 50 % TP shows 37 %, 44 % and 4 % improvement in the fatigue, rutting and moisture damage resistance, respectively, compared to the conventional mixture. It can be concluded that the combination of TCR-TP in mixture using dry process can be used as an alternative mixture to improve pavement performance.

# ABSTRAK

Kerosakan turapan memendekkan jangka hayat campuran asfalt, yang ditunjukkan melalui kegagalan seperti retakan, aluran dan perlucutan. Penambahan aditif di dalam campuran asfalt konvensional adalah satu pendekatan untuk menambah baik prestasi dan jangka hayatnya. Oleh itu, kajian ini telah dijalankan dalam tiga fasa dengan menggunakan aditif getah serpihan terawat (TCR) dan plastik terawat (TP). Pada fasa pertama, kedua-dua aditif dicirikan menggunakan analisis *thermogravimetric* (TGA), *field-emission scanning electron microscope* (FE-SEM) dan *energy dispersive x-ray* (EDX). Lapan peratusan berbeza TCR daripada 0.25 % hingga 5.0 % dan enam peratus berbeza TP daripada 0.25 % hingga 3.0 % telah dimasukkan ke dalam campuran 14 mm saiz nominal maksimum agregat (AC14) menggunakan proses kering. Ujian Marshall dijalankan untuk menentukan peratusan optimum aditif. Keputusan menunjukkan bahawa campuran yang mengandungi 0.75 % TCR dan 0.75 % TP memenuhi semua spesifikasi yang ditetapkan dan dipilih sebagai peratusan optimum. Campuran dengan 0.75 % TCR dan 0.75 % TP telah meningkatkan rintangan terhadap retakan lesu dan aluran berbanding campuran konvensional. Pada fasa kedua, ujian mekanikal seperti modulus kebingkasan, rayapan dinamik, aluran dan kerosakan lembapan untuk campuran terpadat dan tidak terpadat dan ujian *scanning electron microscope* (SEM) telah dijalankan untuk menilai prestasi campuran yang mengandungi TCR dan TP. Walaupun campuran terubahsuai dengan kedua-dua aditif menunjukkan prestasi yang lebih baik berbanding campuran konvensional, campuran TCR terdedah kepada kerosakan alur dan lembapan, manakala campuran TP dikenal pasti dengan potensi pelucutan. Bagi mengatasi masalah tersebut, gabungan TCR dan TP telah disiasat pada fasa terakhir. Campuran dengan 50 % TCR dan 50 % TP menunjukkan masing-masing 37 %, 44 % dan 4 % peningkatan dalam rintangan keletihan, alur dan lembapan, berbanding dengan campuran konvensional. Dapat disimpulkan bahawa kombinasi TCR-TP dalam campuran menggunakan proses kering boleh digunakan sebagai campuran alternatif untuk meningkatkan prestasi turapan.

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| | | |
|---|---|---|
| AASHTO | - | American Association of State Highway and Transportation Officials |
| AC 14 | - | Asphaltic concrete of nominal maximum aggregate size 14 mm |
| ACV | - | Aggregate crushing value |
| AIV | - | Aggregate impact value |
| ASTM | - | American Society for Testing and Materials |
| BS EN | - | British Standard European Norm |
| CR | - | Crumb rubber |
| CRP | - | Crumb rubber powder |
| CSS | - | Creep stiffness slope |
| DWT | - | Double Wheel Tracker |
| EDX | - | Energy Dispersive X-ray |
| EVA | - | Ethene-Vinyl-Acetate |
| FE-SEM | - | Field-Emission Scanning Electron Microscope |
| HDPE | - | High density polyethylene |
| HMA | - | Hot mix asphalt |
| ITS | - | Indirect tensile strength |
| JKR | - | Jabatan Kerja Raya |
| LDPE | - | Low density polyethylene |
| LVDT | - | Linear variable differential transducers |
| NTCR | - | Non-treated crumb rubber |
| NTP | - | Non-treated plastic |
| OBC | - | Optimum bitumen content |
| OPC | - | Ordinary Portland Cement |
| PC | - | Post-consumer |
| PE | - | Polyethylene |
| PEN | - | Penetration |
| PET | - | Polyethylene terephthalate |
| PI | - | Post-industrial |

| | | |
|---|---|---|
| PP | - | Polypropylene |
| PS | - | Polystyrene |
| PVC | - | Polyvinyl chloride |
| RMS | - | Retained Marshall stability |
| RMSF | - | Retained Marshall stability and flow |
| SBR | - | Styrene-butadiene rubber |
| SBS | - | Styrene-butadiene-styrene |
| SEM | - | Scanning Electron Microscope |
| SPW | - | Solid plastic waste |
| TCR | - | Treated crumb rubber |
| TCR-TP | - | Treated crumb rubber and treated plastic |
| TGA | - | Thermogravimetric Analysis |
| TMD | - | Theoretical maximum density |
| TP | - | Treated plastic |
| TSR | - | Tensile strength ratio |
| UTM | - | Universal Testing Machine |
| VFB | - | Void filled with bitumen |
| VMA | - | Void in mineral aggregate |
| VTM | - | Void in total mix |
| WPM | - | Waste polymer modifier |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| $G_{mm}$ | - | Maximum specific gravity of the mixture |
| $F$ | - | Force |
| $M_R$ | - | Resilient modulus |
| $H$ | - | Horizontal deformation |
| $t$ | - | Thickness |
| μ | - | Poisson’ ratio |
| $E$ | - | Creep stiffness modulus |
| $\sigma$ | - | Stress |
| $\varepsilon$ | - | Strain |
| $S_t$ | - | Indirect tensile strength |
| $P$ | - | Load |
| $t$ | - | Height |
| $D$ | - | Diameter |
| G* | - | Complex shear modulus |
| δ | - | Phase angle/ indentation depth |
| $R^2$ | - | Regression |

## LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of the Study

Over the last few decades, the government has become concerned with the cost of initial construction and the cost of pavement throughout its service life, especially in developing countries. It is because highway road pavement construction and maintenance consume significant amounts of financial resources, materials and energy. It is necessary to accommodate growing transport demands to ensure that a road network is adaptable, automated, and resilient. Furthermore, the traffic density and the condition of road infrastructure remain at desirable levels also were needed (Bressi et al, 2019). A failure to do so will cause significant permanent and irreversible distresses such as rutting, fatigue cracking and stripping due to increased traffic loads, higher traffic volumes, and insufficient maintenance. Thus, there have been many efforts to design and construct hot mix asphalt (HMA) as a conventional pavement that performs better and lasts longer in service, as road infrastructure is an ideal target for effective sustainable design and construction initiatives.

The use of additive is one possible approach for enhancing the performance of conventional mixture. Recently several efforts have been dedicated to increase the percentage of recycled materials in road constructions to modify road mixtures such as crumb rubber and plastic bags. Many researchers have well known crumb rubber as an alternative to tire disposal for pavement modification for more than 50 years, and the number of published research articles has rapidly increased since 1970s (Zhu, Birgisson and Kringos, 2014). It has been reported that rubberized mixture has potential advantages due to their higher resistance to permanent deformation, thermal stability and noise reduction effect. Another alternative for modifying mixture is using plastic waste, a non-biodegradable product, which has been widely investigated over the past 10 years (White, 2019). The plastic mixture has the potential to improve the mixture performance due to its rigid mixture behaviour (Brasileiro et al, 2019a). Therefore, the mixture increased in resistance to permanent deformation and durability, which extends the service life of pavement with high traffic loads in countries with hot climates. Despite these advantages, using crumb rubber and plastic as an alternative to reduce the number of net discards and conserves both material and energy suggest a simpler way than dumping waste without any recovery or recycling process. Hence, by reducing the volume of waste produced, which is an issue of concern worldwide, a sustainable and environmental friendly road construction can be provided.

Two processes have been adopted for using additives in bituminous mixture, the wet process and the dry process. For the wet process, the additive is pre-blended with bitumen and then mixed with aggregates. In contrast, for the dry process, the additive is mixed with aggregates before the bitumen is added. The dry process has been claimed to has better performance than the wet process but is susceptible to cracking at low temperatures (Navarro et al, 2004). However, according to Buncher (1995), there was no difference between mixes when the additive was added either using a wet or dry process. Despite this, the dry process is more straightforward, more convenient to apply at plants, and has significant cost savings than the wet process (Lastra-González et al, 2016; Movilla-Quesada et al, 2019). This is because the dry process allows the additive to be added up like dry additives or mineral filler with larger size and amount than the wet process into a drum without special blending equipment, which requires more procedures and workers at plant.

## 1.2 Problem Statement

Pavement distress results in failures such as cracking, rutting and stripping, which shortens the service life of pavement mixtures (Kakar, Hamzah and Valentin, 2015; Liddle and Choi, 2007). These issues mainly occur due to higher traffic volumes as well as new axle designs with heavier loads and different configurations that annually change, especially in a developing country like Malaysia. At the same time, statistics in Malaysia shows that the allocated cost of road maintenance was over one hundred million per year by the government. Figure 1.1 shows the increase in the number of vehicles and the cost of road maintenance in Malaysia. Increases in traffic volumes and loads contribute to pavement distress in the conventional mixture, thus requiring expensive maintenance to be performed regularly. This is because when a conventional mixture experiences heavy traffic loads repeatedly and continuously, the pavement is prone to rutting, cracking and stripping failures (Hamzah, Kakar and Hainin, 2015).

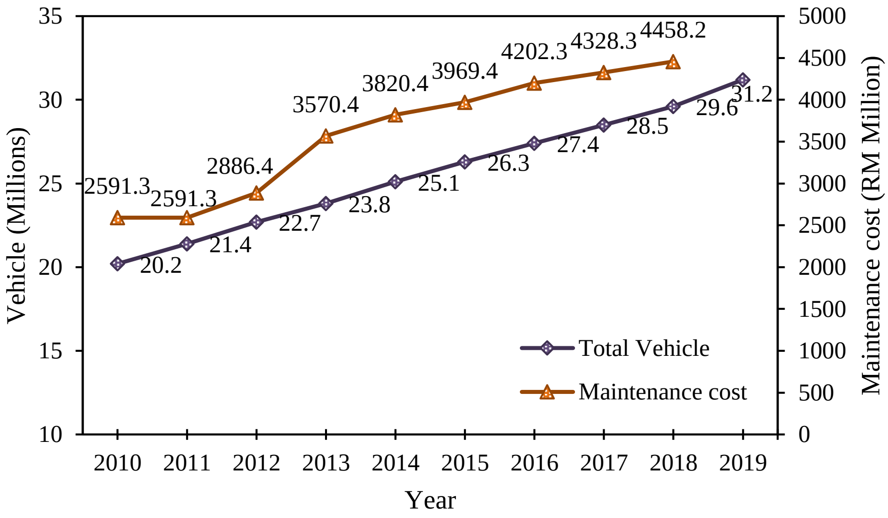


Figure 1.1 Number of registered vehicles (Lim, 2020) and state road maintenance allocation (JKR, 2018) in Malaysia

Consequences of the issues have forced road agencies and researchers to explore mixture modification to design and construct conventional pavement that perform better and last longer, besides assessing sustainable road construction as leading indicators (Bressi et al, 2019). The idea of using waste material in road construction had attracted many researchers interested in reducing environmental problems due to improper waste management in landfills, especially for waste tires and plastic bags (Wang, et al, 2017). In Malaysia, the number of waste tires generated annually was about 8.2 million, a combined volume of approximately 57000 tons, of which 60 % was disposed of in non – regular sites (Badr Khudhair et al, 2015; Kumar, 2006). Meanwhile, about 19000 tonnes of solid waste was produced annually by Malaysians; 24 % represent plastic waste (Asmuni et al, 2015). This trend has got worse over time, with the amount of generated waste increasing every year, contributing to global warming and making frequent flooding become a serious consequence in Malaysia (Afroz et al, 2017). The reuse of this material mainly involves re-extrusion and a series of mechanical treatments, resulting in different polymer qualities that depend on how the process was handled as alternatives to allow its usage in road construction (Movilla-Quesada et al, 2019).

The use of recycled waste polymer in mixture as an additive can be divided into two processes: wet and dry. Although the dry process is more practical in plants or laboratories and allows more additive content in the mixture, previous research has mainly concentrated on the wet process (Cao, 2007). This can be explained by the irregular performance of the dry process as the additive partially reacts during the mixing process. Thus, the efficiency of the dry process has been questioned by many researchers on how the particles of additive react with bitumen without blending process or act as an inert filler (Rodriguez-Fernandez et al, 2020; Buncher 1995).

It has been reported that the major problem for the dry process is the poor interaction between binder and additive leading to increasing air void content (Arabani, Tahami and Hamedi, 2018). The particle size, amount of additive, and temperature of the mixing significantly affect mixture performance. For crumb rubber, the mixture must be at a relatively high temperature (around 180 ºC) and the maximum amount has been suggested not to be more than 1.0 % by weight of the mix. A finer size of rubber particles would permit interaction between the crumb rubber and binder, thereby avoiding inadequate performance (Tahami et al, 2019; Dias, Picado-Santos and Capitão, 2014). Crumb rubber particles swell once they contact the binder and absorb the low molecular weight portion of the binder, and degradation occurs at high temperatures if continuously exposed (Rodriguez-Fernandez et al, 2020). Poor adhesive strength between crumb rubber particles and binder because of excessive amounts of crumb rubber in the dry process, resulting in a higher moisture sensitivity and reduce tensile strength in the mixture than conventional mixture (Jones, Liang and Harvey, 2017; Navarro and Gámez, 2012).

This differs for LDPE where it is polymer that is easy to melt in the dry process (temperature around 160 ºC). Its interaction with binder and aggregates has been reported to not appreciably alter the properties of those components (Movilla-Quesada, Raposeiras et al, 2019). However, previous research mentioned that plastic mixture exhibited cracking at low temperature. Nonetheless, a proper mix design is necessary to ensure good performance in mixture incorporating additive due to the unstable behaviour of the polymer during dry process (Lastra-González et al, 2016; Köfteci, Ahmedzade and Kultayev, 2014). Finer sized polymer should be considered in this procedure, allowing the polymer to adhere better and more significantly disperse to the aggregates and the binder to combine properly (Fakhri and Azami, 2017). The inadequate mix design creates various problems, resulting in premature pavement failure.

Although the use of crumb rubber and plastic in the mixture had been proven to increase mixture performance and extend its service life, the mixtures had issues in inconsistent mixture performance using the dry process. These various behaviours of crumb rubber and plastic polymers and the problems with conventional mixture motivated many researchers to treat the crumb rubber and plastic as additives. Several treatments had been conducted by previous studies, which mainly improve the surface morphology of both untreated additives with rougher and porous surface texture than untreated additives. This surface activation increased the reaction area of the treated additive with binder and aggregates during the mixing process. The treated additive is believed to improve the application of the dry process while allowing higher amounts of additive to be added to the mixture compared to the wet process. Not only that, the combination of these two additive types (treated crumb rubber and treated plastic) is also expected to have better performance than untreated crumb rubber and untreated plastic mixture separately, especially in terms of moisture damage and fatigue cracking resistance. Overall, this research is very significant to encourage relevant parties to investigate more studies and practices on the usage of waste polymer in the road construction.

## 1.3 Objectives of the Study

This study aims the performance of hot mix asphalt (HMA) incorporating treated crumb rubber (TCR) and treated plastic (TP). The aim was achieved through the following objectives:

i. To characterise and determine the optimum mix design of TCR and TP;

ii. To evaluate the mechanical performance of HMA incorporating TCR and TP as additives;

iii. To determine the optimum mixing ratio of combined TCR-TP and to evaluate its performance.

## 1.4 Scope of the Work

In this study, several standards have been used as a reference in conducting the laboratory test such as Jabatan Kerja Raya (JKR) specification, American Association of State Highway and Transportation Officials (AASHTO), American Society for Testing and Materials (ASTM), and British Standard (BS). For materials, Bitumen 60-70 PEN sourced from Kemaman Bitumen Company (KBC), Terengganu, and 14 mm nominal maximum aggregate size (AC14) from Hanson Quarry Kulai were used. TCR and TP additives with a size passing 0.425 mm sieve were supplied by Ahn Vertex company.

Both additives were characterised in a School of Chemical Engineering and University Laboratory Management Centre (UPMU), Universiti Teknologi Malaysia, Johor, which includes density, thermogravimetric analysis (TGA), field-emission scanning electron microscope (FE-SEM), and energy dispersive x-ray (EDX) test. Marshall test was conducted to determine the optimum percentage of TCR and TP mixtures. The properties and performances of two modified mixtures were compared regarding the results of the indirect tension resilient modulus, unconfined dynamic creep, double wheel tracker, tensile strength ratio, retained Marshall stability, water immersion, boiling water, and chemical immersion. Based on the findings, the combination of TCR and TP was done and the best mix design was selected by evaluation of mixture's performance using grid analysis. All the performance tests were carried out at Highway and Transportation Laboratory, Universiti Teknologi Malaysia, Johor. Furthermore, the surface morphology of the optimum mix design using a scanning electron microscope (SEM) was conducted at UPMU, Universiti Teknologi Malaysia, Johor.

## 1.5 Significance of Work

This study significantly contributes to alternative modification of conventional mixture that reduces pavement distress issues using dry process and sustainable materials. There have been numerous studies reporting that the use of crumb rubber and plastic from recycled materials as additives could enhance the performance of the mixture. However, in the dry process, the crumb rubber mixture exhibits moisture sensitivity and reduce tensile strength. Meanwhile, plastic mixture is prone to fatigue cracking at low temperature. These issues led to the inconsistence performance of the mixture and caused many researchers preferred to use the wet process compared to the dry process. Furthermore, several treatment processes were found to activate the surface texture of crumb rubber and plastic additives, which may increase the interaction between additives and binder and aggregate during dry mixing. Consequently, it is significant to combine the treated crumb rubber and treated plastic (TCR-TP) in the mixture to improve the conventional mixture performance, especially in moisture damage, tensile strength, and fatigue cracking at low temperature. As a result, the combination of crumb rubber and plastic may reduce maintenance activity and increase road pavement service life. The findings also may contribute to promote the application of the dry process, which is simpler and easier to apply in plants, thus encouraging road agencies to modify mixtures. Therefore, the outcome of this research not only significantly improves the engineering properties of mixtures, but could also provide a promising sustainable construction method that reduces waste disposal and environmental problems.

## 1.6 Thesis Outline

This study comprises five chapters as follows:

Chapter 1 introduces the comprehensive study and comprises the study background, problem statement, study objectives, study scope and study significance.

Chapter 2 comprehensively discusses the issues of pavement distress in the conventional mixture, mixing the methods, the properties of crumb rubber and plastic, and previous studies that utilized crumb rubber and plastic in mixture, including their mix design and performance based on mechanical tests.

Chapter 3 presents the preparation of samples and procedures for measuring the performance of mixture incorporating two different polymer additives, TCR and TP.

Chapter 4 reveals the optimum mixture design for TCR and TP mixtures, including their charaterisation. The effect of physical tests for a TCR-TP combination is also reviewed and discussed in detail.

Chapter 5 concludes the findings obtained from this study. Recommendations are also provided for potential future studies.

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# LIST OF PUBLICATIONS

## Indexed Journal

1. **Kamarudin, S. N. N.,** Hainin, M. R., Warid, M. N. M., Satar, M. K. I. M., & Jaya, R. P. (2021). The Usage of Treated Plastic as Additive to Improve the Asphalt Mixture's Performance by Using Dry Mix Method. In *Key Engineering Materials* (Vol. 879, pp. 126-135). https://www.scientific.net/KEM.879.126 **(Indexed by SCOPUS)**
2. **Kamarudin, S. N. N.**, Hainin, M. R., Warid, M. N. M., Satar, M. K. I. M., & Hassan, N. A. (2021, May). Performance of Asphalt Mixture Incorporating Activated Crumb Rubber as Additive. In IOP Conference Series: Materials Science and Engineering (Vol. 1144, No. 1, p. 012081). https://iopscience.iop.org/article/10.1088/1757-899X/1144/1/012081/meta **(Indexed by Web of Science)**
3. **Kamarudin, S. N. N.,** Hainin, M. R., Warid, M. N. M., Satar, M. K. I. M. and Raman, N. A. A. Effects of Moisture Damage Sensitivity of Asphalt Mixtures incorporating Treated Plastic as Additive. In Conference 12th International Conference on Road and Airfield Pavement Technology 2021 (ICPT 2021), 14 – 16 July 2021, University of Moratuwa, Sri Lanka. **(Indexed by SCOPUS) - Accepted**