BEHAVIOUR OF RUBBERIZED ASPHALT MIXTURE SUBJECTED TO THERMAL LOADING

DLER HASSAN HUSSEIN

A project report submitted in partial fulfilment of the
requirements for the award of degree of
Master of Engineering (Civil – Transportation and Highway)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JANUARY 2015

To my beloved ***Father*** *and* ***Mother***
who support me spiritually throughout my life

To ***DIMAN****,*
my amazing wife,
whose sacrificial care for me and our daughters
made it possible for me to complete this work

To my daughters,
ZHWAN *and* ***YARAN***
who are indeed a treasure from Allah

ACKNOWLEDGEMENT

In the Name of Allah, the Most Gracious, the Most Merciful

Praise and glory be to Almighty Allah for his blessings and giving me the health and power to complete this work.

Foremost, I would like to express my special appreciation and thanks for the continuous support of my supervisor Dr. Norhidayah Abdul Hassan. There are no proper words to convey my deep gratitude and respect for the useful comments, remarks and engagement through the learning process of this master project. Her patience, motivation, eagerness, and knowledge have inspired me to become an independent and helped me realize the power of critical reasoning. I am very fortunate to have met such a good supervisor in UTM. Really, this project would never have been completed (as we wish) without her assistance and support. I still remember her advice, is to produce a piece of work, that not only to fulfil the grade but something that I can be proud of.

A special thanks to my parents and my father and mother in-law, your prayers for me was what sustained me thus far. I am extremely grateful to my lovely wife and my daughters for their patient and continued support and encouragement throughout the study period. I would also like to thank my brothers and sisters and in-laws for their unconditional trust and prayers. Special thanks are also extended to the technicians of Transportation Laboratory in UTM, particularly (Mr Sahak) who afforded his precious time during the weekends to open the lab for me and tolerate until I finished my lab works.

Finally, I would express my gratitude to Kurdistan Regional Government for supporting me to have the opportunity to get higher degree in UTM-Malaysia.

ABSTRACT

This study investigated the behaviour of dry mixed rubberised asphalt mixture subjected to permanent deformation under high temperature variation. Crumb rubber, obtained from recycled scrap tyres was used as an aggregate replacement within the asphalt mixture as it could potentially provide greater elastic recovery to the mixture. The elements of natural and synthetic rubber within the scrap tyres have been identified to improve the thermal stability of the tyre compound and provide wider working temperature range. Therefore, to use the crumb rubber as a modifier in asphalt mixture could possibly improve the properties of asphalt mixture at various service temperatures and consequently, improve the resistance against permanent deformation. Additionally, this could provide an alternative in recycling the scrap tyres as non-decaying waste material. In this study, a mixture of Asphaltic Concrete of AC14 (dense graded with nominal maximum aggregate size 14 mm) was modified with 1, 2 and 3% of crumb rubber (coarse size, 5 mm) from the total weight of aggregate using dry process method. The properties of the rubberised mixtures were compared to the control mixture (with no rubber). Samples were prepared using Marshall Compactor and tested under Resilient Modulus at 25 and 40ºC to measure the material stiffness. In addition, Dynamic Creep Test was conducted to determine the permanent deformation at four temperature conditions; 25, 40, 50, and 60°C. The analysis was focused on the effect of adding crumb rubber in asphalt mixture in terms of accumulated permanent strain under the influence of temperature variation. Based on this study, it was observed that the susceptibility of asphalt mixture to high temperature was reduced by the crumb rubber modification.

ABSTRAK

Kajian ini telah dijalankan untuk mengenalpasti sifat campuran asfalt kering dengan campuran getah yang tertakluk kepada perubahan bentuk kekal dengan variasi suhu tinggi. Getah remah, 'Crumb Rubber' yang diperolehi daripada tayar sekerap yang dikitar semula telah digunakan sebagai pengganti agregat dalam campuran asfalt kerana ia boleh memberikan kebolehan elastik yang lebih tinggi kepada campuran. Unsur-unsur getah asli dan tiruan dalam tayar sekerap telah dikenal pasti dapat meningkatkan kestabilan terma dalam kompaun tayar dan menyediakan julat suhu kerja yang lebih luas. Oleh itu, penggunaan Getah Remah sebagai pengubahsuai dalam campuran asfalt boleh meningkatkan sifat-sifat campuran asfalt pada pelbagai julat suhu, justeru meningkatkan rintangan terhadap perubahan bentuk kekal. Tambahan lagi, penggunaan Getah Remah dalam kajian ini boleh memberikan alternatif dalam mengitar semula tayar sekerap yang sedia ada dari bahan buangan tidak mereput. Dalam kajian ini, campuran konkrit asfalt daripada AC14 (bergred tumpat dengan saiz nominal agregat maksimum 14 mm) telah diubah suai dengan 1, 2 dan 3% daripada Getah Remah (saiz kasar, 5 mm) dari jumlah berat agregat menggunakan kaedah proses kering. Sifat-sifat campuran Getah Remah dibandingkan dengan campuran kawalan (tanpa getah). Sampel telah disediakan dengan menggunakan Marshall Compactor dan diuji di bawah 'Resilient Modulus' pada suhu 25 dan 40ºC untuk mengukur kekukuhan bahan. Di samping itu, ujian 'Dinamik Creep' telah dijalankan untuk menentukan perubahan bentuk kekal pada empat keadaan suhu; 25, 40, 50, dan 60°C. Analisis ini telah memberi tumpuan kepada kesan penambahan Getah Remah dalam campuran asfalt dari aspek ketegangan tetap terkumpul 'permanent strain' hasil daripada pengaruh perubahan suhu. Berdasarkan kajian ini, telah didapati bahawa pengaruh suhu yang tinggi kepada campuran asphalt telah dikurangkan oleh pengubahsuaian Getah Remah tersebut.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

AASHTO	-	American Association of State Highway and Transportation
AC	-	Asphaltic Concrete
ASTM	-	American Society of Testing and Materials
BS	-	British Standards
CRM	-	Crumb Rubber Modifier
E_n	-	Creep modulus
F	-	Flow
G_{mb}	-	Bulk specific gravity of compacted mix
G_{mm}	-	Theoretical maximum density
Gse	-	Effective specific gravity of total aggregate
HMA	-	Hot Mix Asphalt
JKR	-	Jabatan Kerja Raya
LVDT	-	Linear Variable Differential Transformer
Mr	-	Resilient Modulus
OBC	-	Optimum Bitumen Content
RAM	-	Rubberized Asphalt Mixture
S	-	Stability
SSD	-	Saturated Surface Dry
TMD	-	Theoretical Maximum Density
UTM	-	Universal Testing Machine
VFB	-	Voids Filled with Bitumen
VMA	-	Voids in Mineral Aggregate
VTM	-	Void in Total Mix
ε	-	Accumulated strain
σ	-	Compressive axial stress

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Asphalt mixtures are complex heterogeneous materials consists of bitumen, aggregate and air voids. The interactions between these components resist the loads from the traffic to underneath layers and their properties determine the ability of the road layers to withstand the loads and prevent the failure (Abdul Hassan and Rosli, 2012). At high temperatures, the bitumen tends to flow easily, and behaves like a viscous liquid. This could lead to the loss of internal friction between the aggregate particles, consequently make the repeated loading be supported by the asphalt binder rather than the aggregate structure, resulting in the permanent deformation in asphalt mixtures (Huang *et al.*, 2012). On the other hand, asphalt mixture according to their components, is a temperature sensitive material, where the properties close to elastic material at a lower temperature and close to viscous material at a higher temperature. Its viscoelastic property has a close relationship to rutting, cracking, fatigue behaviour, and other distresses of asphalt pavement (Peilong Li *et al.*, 2013). Therefore, it is very important to find out ways to delay the asphalt pavement deterioration experienced by the conventional asphalt mixture and increase pavement service life.

Various researchers reported that using additives such as different type of polymers and fibres to modify asphalt mixture could be a solution to delay deterioration of asphalt pavement (Moghaddam *et al.*, 2011). The addition of Crumb Rubber Modifier (CRM) as polymer additives in asphalt mixtures has increased significantly in past years around the world, especially in the USA. Several of the roads have been reported to be in good condition after several years in service in comparison to conventional mixtures (Wong and Wong, 2007). Previous studies have demonstrated that CRM binders produce pavements with good mechanical behaviour. They offer improved resistance to rutting, better resistance to low temperature cracking, reduced fatigue cracking and temperature susceptibility, decreased traffic noise and maintenance costs, and prolonged pavement life. These pavements also save energy and natural resources by making use of waste products. Because of these advantages, CRM asphalt mixtures are increasingly used as a green material in the highway pavement construction industry in many countries (Rodríguez *et al.*, 2014).

Crumb rubber modified materials are mainly applied via two techniques in asphalt pavement. One is the wet process, in which the crumb rubber is used as a modifier in bitumen, and the other is the dry process, in which the ground crumb rubber is directly mixed with aggregate prior to mixing it with bitumen. Although, the wet process has been used widely for its excellent performance in comparison to dry process, still the last has own distinct advantages as it can be added directly to the aggregate, that means the process is simpler and the amount of crumb rubber recycled is greater than those used in wet process. In this study, the properties of the rubberized asphalt mixture using dry process under permanent deformation mode were investigated under the influence of high temperature. Different percentages of CRM modified asphalt mixture were evaluated and compared with the conventional asphalt mixture.

1.2 Problem Statement

Allocating design period and service quality for any highway construction project are essentially rely on the asphalt mixture component that consist of bitumen, aggregate and air voids. Unfortunately, with the steady increase in the traffic intensity and high axle load with the significant variation in daily and seasonal temperature asphalt mixtures a typical visco-elastic material damaged at different environmental condition particularly at high temperature. This is because; under this condition the viscosity of the asphalt binder will be very low and thus reduce the internal friction between the aggregate particles, leading to the permanent deformation.

The phenomenon of permanent deformation in asphalt pavements has a major impact on the pavement performance throughout its life. It will not only reduce the service life, but it may also affect the vehicle handling manoeuvres, which can be hazardous to the road users. Therefore, it is a demand for improving the properties of the asphalt mixture by modifying the conventional asphalt mixtures to enhance the mixture properties. One of the modification methods is to introduce recycled material such as crumb rubber (obtained from scrap tires) as aggregate replacement within the mixture using dry process. Previous research has established that adding CRM could improve asphalt mixture resistant against permanent deformation and fatigue cracks (Hamed, 2010; Peilong Li *et al.*, 2013; Moghaddam *et al.*, 2011).

In addition, by modifying asphalt mixture with CRM using dry process could result of better performance at both high and low temperatures (Cao, 2007). Therefore, this study was carried out to investigate the effect of CRM on the asphalt mixture characteristics in term of its resistance against permanent deformation under temperature variation. Moreover, the rubber composition within the tires consists of natural and synthetic rubber where these materials are identified to improve the thermal stability of the tire compound, making it ideal for anti-vibration applications and use in large tires where excessive heat build-up could be disastrous. For example the natural rubber has a working temperature range of approximately -50^{o}C to 100^{o}C.

Additionally, the properties of the compound also could provide greater elastic recovery and excellent physical strength as well as resilience and high resistance to tearing and abrasion.

1.3 Aim and Objectives of Study

The aim of this study is to investigate the mechanical properties of dry mixed rubberized asphalt mixture under the temperature variation. The objectives are as follows:

i) To determine the effect of different percentages of CRM on resilient modulus of asphalt mixture.

ii) To determine the performance of rubberized asphalt mixture under permanent deformation with the influence of temperature variation.

1.4 Scope of Study

In this study four mixture types were prepared namely control mixture (Asphalt mixture with nominal maximum aggregate size, NMAS 14 mm-AC14 without rubber) and rubberized mixture with 1, 2 and 3% of crumb rubber (single size of 5 mm) from the total weight of aggregate. AC 14 is a dense graded mixture type according to JKR/SPJ/2008-S4. Marshall Mix design was used for fabricating the compacted samples and determining the optimum bitumen content. Resilient Modulus test was conducted at 25 and 40ºC, to measure the material stiffness. In addition, the samples were tested under various temperature conditions to evaluate the permanent deformation under high temperature using Dynamic Creep Test. The samples were tested at four temperature conditions; 25, 40, 50, and 60°C. This range of temperatures was intended to simulate a full hot season cycle of outdoor temperature variations a pavement would experience. It should be noted that the temperature variation in an asphalt pavement is significantly higher than the air temperature. Therefore, the range of testing temperatures presented here reflects the pavement temperatures, not the encompassing aboveground temperature.

1.5 Significance to Knowledge

Noticeable differences in the temperature degree in many countries influence the asphalt mixture performance, causing a lot of distresses in the pavement. Permanent deformation is one of the main distresses which normally occur in hot climate area as a result of the repeated heavy axle load. The resistance of asphalt mixtures against permanent deformation change with the influence of the temperature fluctuation due to the asphalt temperature’s susceptibility where it tends to flow at high temperatures. As a result, each year millions of dollars are invested for the construction and maintenance of roads. Therefore, to use an elastomer polymer such as crumb rubber is expected to improve the stability of the asphalt mixture at high and low temperature service. This is because some valuable components within the crumb rubber might well contribute to the improvement of bitumen properties as well as asphalt mixture. Additionally, this could provide an alternative in recycling the scrap tires as non-decaying waste material. Previous studies conducted on the asphalt mixture modified with crumb rubber, particularly using wet process have proved that the rubber could reduce the temperature susceptibility of the mixture and increase thermal cracking resistance (Rodríguez *et al.*, 2014). However, not much information can be found on the performance of dry mixed rubberized asphalt mixture under the temperature variances. Therefore, this study is very important in getting some data related to the temperature influence upon the permanent deformation mode of dry mixed rubberized asphalt mixture.

REFERENCES

Abdul Hassan, N. (2012). *Microstructural Characterisation of Rubber Modified Asphalt Mixture.* (Doctor of Philosophy), University of Nottingham.

Abdul Hassan, N., & Rosli, H. M. (2012). Application of X-ray Computed Tomography for Air Voids and Damage Characterisation in Asphalt Mixtures. *JURUTERA*, 20-23.

Ahari, A. S., Forough, S. A., Khodaii, A., & Nejad, F. M. (2013). Modeling the Primary and Secondary Regions of Creep Curves for SBS-Modified Asphalt Mixtures under Dry and Wet Conditions. *Journal of Materials in Civil Engineering, 26*(5), 904-911.

Aloysius, T., & Napitupulu, R. (2013). *Verification of Resilient Modulus Prediction of Asphalt Mixtures.* Paper presented at the Proceedings of the Eastern Asia Society for Transportation Studies.

American Society for Testing and Materials (2005). Standard Test Method for Penetration of Bituminous Materials, ASTM D 5. Philadelphia, USA.

American Society for Testing and Materials (2014). Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus), ASTM D 36. West Conshohocken, PA.

American Society for Testing and Materials (2003). Standard Test Method for Specific Gravity and Density of Semi-Solid Bituminous Materials (Pycnometer Method), ASTM D 70. West Conshohocken, PA.

American Society for Testing and Materials (2006). Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates, ASTM C 136. West Conshohocken, PA.

American Society for Testing and Materials (2000). Standard Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures, ASTM D 2041. West Conshohocken, PA.

American Society for Testing and Materials (1995). Standard Test Method for Indirect Tension test for Resilient Modulus of Bituminous Mixtures, ASTM D 4123. West Conshohocken, PA.

Arshadi, A. (2013). *Importance of Asphalt Binder Properties on Rut Resistance of Asphalt Mixture.* (Master of Science), University of Wisconsin-Madison.

Bai, F., Yang, X., & Zeng, G. (2014). Creep and recovery behavior characterization of asphalt mixture in compression. *Construction and building materials, 54,* 504-511.

Bennert, T., Maher, A., & Smith, J. (2004). Evaluation of crumb rubber in hot mix asphalt.

British Standards Institution (2000). Tests for mechanical and physical properties of aggregates, Determination of particle density and water absorption, BS EN 1097-6. BSI, London.

British Standards Institution (2012). Bituminous mixtures: Test methods for hot mix asphalt- Part 34: Marshall test. BS EN 12697-34. BSI, London.

British Standards Institution (2005). Bituminous mixtures: Test methods for hot mix asphalt- Part 25: Cyclic compression test. BS EN 12697-25. BSI, London.

British Standards Institution (2012). Bituminous mixtures: Test methods for hot mix asphalt- Part 26: Stiffness. BS EN 12697-26. BSI, London.

British Standards Institution (2002). Bituminous mixtures: Test methods for hot mix asphalt- Part 29: Determination of the dimensions of a bituminous specimen. BS EN 12697-29. BSI, London.

Cao, W. (2007). Study on properties of recycled tire rubber modified asphalt mixtures using dry process. *Construction and building materials, 21*(5), 1011-1015.

Chen, M., Wan, L., & Lin, J. (2012). Effect of Phase-Change Materials on Thermal and Mechanical Properties of Asphalt Mixtures. *Journal of Testing and Evaluation, 40*(5), 746-753.

Chesner, W., Collins, R., & MacKay, M. (1997). User Guidelines for Waste and By-product Materials in Pavement Construction, US Department of Transportation, Federal Highway Administration, Publication No.

Chesner, W. H., Collins, R. J., & MacKay, M. (1998). User guidelines for waste and by-product materials in pavement construction.

Fadiel, A., Al Rifaie, F., Abu-Lebdeh, T., & Fini, E. (2014). Use of crumb rubber to improve thermal efficiency of cement-based materials. *American Journal of Engineering and Applied Sciences, 7*(1), 1-11.

Garba, R. (2002). *Permanent deformation properties of asphalt concrete mixtures.* Norwegian University of Science and Technology.

Ghaly, A. M. (2003). A Mechanistic analysis of static and repeated loading effects on rubberized asphalt. *International Journal of Pavement Engineering, 4*(4), 209-219.

Golalipour, A. (2011). *Modification of multiple stress creep and recovery test procedure and usage in specification.* University of Wisconsin.

Gu, X., Dong, Q., & Yuan, Q. (2014). Development of an Innovative Uniaxial Compression Test to Evaluate Permanent Deformation of Asphalt Mixtures. *Journal of Materials in Civil Engineering*.

Hamed, F. K. M. (2010). *Evaluation of Fatigue Resistance for Modified Asphalt Concrete Mixtures Based on Dissipated Energy Concept.* TU Darmstadt.

Huang, X., Xu, T., Zhao, Y., & Li, Z. (2012). Investigation into High-Temperature Stability of Asphalt Pavement. *Journal of Testing and Evaluation, 40*(7), 1-6.

Ibrahim, M. R., Katman, H. Y., Karim, M. R., Koting, S., & Mashaan, N. S. (2013). A Review on the Effect of Crumb Rubber Addition to the Rheology of Crumb Rubber Modified Bitumen. *Advances in Materials Science and Engineering, 2013*.

Jabatan Kerja Raya (JKR) (2008). Standard Specifications for Road Works, Section4: flexible Pavement, JKR/SPJ/2008-S4. KualaLumpur, Malaysia.

Kalantar, Z. N., Karim, M. R., & Mahrez, A. (2012). A review of using waste and virgin polymer in pavement. *Construction and building materials, 33*, 55-62.

Kalofotias, A., Mavridou, S., & Oikonomou, N. (2011). laboratory results of rubberized asphalt mixtures made by the dry process.

Li, P., Ding, Z., & Zhang, Z. (2013). Effect of Temperature and Frequency on Visco-Elastic Dynamic Response of Asphalt Mixture. *Journal of Testing & Evaluation, 41*(4), 1-8.

Li, P., Jiang, K., & Li, H. (2012). High-Temperature Stability of Asphalt Mixture with the Influence of Styrene Butadiene Styrene. *Procedia-Social and Behavioral Sciences, 43,* 842-848.

Lo Presti, D. (2013). Recycled tyre rubber modified bitumens for road asphalt mixtures: a literature review. *Construction and building materials, 49*, 863-881.

Lu, Y., & Wright, P. J. (2000). Temperature related visco-elastoplastic properties of asphalt mixtures. *Journal of transportation engineering, 126*(1), 58-65.

Mashaan, N. S., Ali, A. H., Karim, M. R., & Abdelaziz, M. (2014). A Review on Using Crumb Rubber in Reinforcement of Asphalt Pavement. *The Scientific World Journal, 2014*.

Mashaan, N. S., & Karim, M. R. (2013). Evaluation of Permanent Deformation of CRM-Reinforced SMA and Its Correlation with Dynamic Stiffness and Dynamic Creep. *The Scientific World Journal, 2013*.

McNally, T. (2011). *Polymer modified bitumen: properties and characterisation*: Elsevier.

Moghadas , N. F., Azarhoosh, A., & Hamedi, G. H. (2014). Effect of high density polyethylene on the fatigue and rutting performance of hot mix asphalt–a laboratory study. *Road Materials and Pavement Design*(ahead-of-print), 1-11.

Moghaddam, T. B., Karim, M. R., & Abdelaziz, M. (2011). A review on fatigue and rutting performance of asphalt mixes. *Scientific Research and Essays, 6*(4), 670-682.

Rahman, M. (2004). *Characterisation of dry process crumb rubber modified asphalt mixtures.* University of Nottingham.

Rodríguez, A. A. M., Gallego, J., Pérez, I., Bonati, A., & Giuliani, F. (2014). High and low temperature properties of crumb rubber modified binders containing warm mix asphalt additives. *Construction and building materials, 53*, 460-466.

Shu, X., & Huang, B. (2013). Recycling of waste tire rubber in asphalt and Portland cement concrete: an overview. *Construction and building materials*.

Sousa, J. B., Craus, J., & Monismith, C. L. (1991). Summary report on permanent deformation in asphalt concrete.

Sun, L., Zhu, H., & Zhu, Y. (2012). Two-Stage Viscoelastic-Viscoplastic Damage Constitutive Model of Asphalt Mixtures. *Journal of Materials in Civil Engineering, 25*(8), 958-971.

Wang, J. C., & Zeng, X. (2006). Influence of temperature and pressure on the dynamic properties of rubber-modified asphalt concrete. *Journal of Materials in Civil Engineering, 18*(1), 125-131.

Way, G. B., Kaloush, K. E., & Biligiri, K. P. (2011). Asphalt-rubber standard practice guide.

Wong, C. C., & Wong, W.-g. (2007). Effect of crumb rubber modifiers on high temperature susceptibility of wearing course mixtures. *Construction and building materials, 21*(8), 1741-1745.

Xu, T., & Huang, X. (2012). Investigation into causes of in-place rutting in asphalt pavement. *Construction and building materials, 28*(1), 525-530.

Yu, M., Wu, G., Zhou, J., & Easa, S. (2014). Proposed compaction procedure for dry process crumb rubber modified asphalt mixtures using air void content and expansion ratio. *Journal of Testing and Evaluation, 42*(2), 1–11.