ABSTRACT

With the exponential growth in the number of automobiles in Malaysia in recent years, the problem generated by waste tyres has also increased. Therefore, incorporating waste tyres as an additive in road pavement might be an option to overcome the increase in the number of waste tyres as well as address some of the pavement problems, such as rutting deformation.

Crumb rubber modified binder is acknowledged to provide better rutting resistance. Many research works have been implemented on the effects of chemical additives to further increase the performance of crumb rubber modified binders. Recent studies have shown that the properties of crumb rubber modified binders can be improved by adding crosslinking agents, such as trans-polyoctenamer (TOR) for which the main function is to activate the rubber-bitumen interaction and improve crosslinking.

This study was conducted to determine a method to improve the rutting resistance of SMA 20 bituminous mixtures. Accordingly, different percentages of crumb rubber were added to bitumen using different blending methods (continuous blend and terminal blend) in order to produce different concentrations of crumb rubber modified binder. In addition, a crosslinking agent, namely, trans-polyoctenamer (TOR), was introduced in the crumb rubber modified binder with the intention of further improving the binder properties and minimizing the rutting problem.

In order to analyse the performance of the binders and mixtures as well as to evaluate the relationship of the rutting characteristics between them, a series of binder tests and bituminous mixture tests were performed. In the final analysis, the author found that the binder tests were not adequate to evaluate the rutting characteristics of bituminous mixtures. For instance, in the case of the crumb rubber modified binder prepared using
the terminal blend method, most of the binder tests show that the terminal blend binder displays the best performance; however, in respect of the bituminous mixtures it became worse.

To further study the creep behaviour (rutting characteristics) of bituminous mixtures, the dynamic creep test was performed using the universal testing machine (UTM) at different temperatures and stress levels. Finally, the creep behaviour of the specimens was estimated using the Zhou three-stage creep model. The results show that crumb rubber and TOR significantly affected the rutting parameters, especially at high stress levels and temperatures. Moreover, based on the Zhou model, it was concluded that resistance to permanent deformation (rutting resistance) was improved by the application of crumb rubber and TOR.

In addition, multiple linear regression (stepwise method) was used for statistical analysis for which the main objective was to develop an equation (regression model) that could be used for predicting the rutting of the mixtures for all factors engaged. A secondary purpose was to use regression analysis as a means of explaining the causal relationship among the factors (significant level).
ABSTRAK

Dengan pertumbuhan yang pesat dalam bilangan kenderaan di Malaysia pada tahun-tahun kebelakangan ini, masalah yang dihasilkan oleh tayar sisa juga telah meningkat. Oleh itu, dengan tayar terpakai sebagai bahan tambahan dalam turapan jalan raya mungkin menjadi satu pilihan untuk mengatasi peningkatan dalam jumlah tayar sisa serta menyelesaikan masalah jalan raya, seperti aluran ubah bentuk.

Crumb getah diubahsuai pengikat diakui untuk menyediakan rintangan aluran yang lebih baik. Banyak kerja-kerja penyelidikan telah dilaksanakan pada kesan bahan tambahan kimia untuk meningkatkan lagi prestasi remah getah pengikat diubah suai. Kajian terbaru menunjukkan bahawa sifat-sifat remah getah diubahsuai pengikat boleh diperbaiki dengan menambah ejen silang, seperti trans-polyoctenamer (TOR) yang mana fungsi utama adalah untuk mengaktifkan interaksi getah - bitumen dan meningkatkan silang.

Kajian ini dijalankan untuk menentukan kaedah untuk memperbaiki rintangan aluran SMA 20 campuran bitumen. Oleh itu, peratusan yang berbeza getah remah telah ditambah kepada bitumen menggunakan kaedah pengadunan yang berbeza (gabungan berterusan dan gabungan terminal) untuk menghasilkan kepekatan yang berbeza remah getah pengikat diubah suai. Di samping itu, ejen silang, iaitu trans-polyoctenamer (TOR), telah diperkenalkan pada remah getah pengikat diubah suai dengan niat untuk meningkatkan lagi sifat-sifat pengikat dan meminimumkan masalah aluran.

Dalam usaha untuk menganalisis prestasi pengikat dan campuran dan juga untuk menilai hubungan ciri-ciri aluran antara mereka, satu siri ujian pengikat dan ujian aggregate campuran bitumen telah dijalankan. Dalam analisis terakhir, penulis mendapati bahawa ujian pengikat tidak mencukupi untuk menilai ciri-ciri aluran.
campuran bitumen. Sebagai contoh, dalam kes getah remah pengikat diubahsuai disediakan dengan menggunakan kaedah gabungan terminal, kebanyakan ujian pengikat menunjukkan bahawa gabungan pengikat terminal memaparkan prestasi yang terbaik; walau bagaimanapun, berkenaan dengan campuran bitumen ia menjadi lebih teruk.

Mengkaji lagi kelakuan rayapan (aluran ciri-ciri) campuran bitumen, ujian rayapan dinamik dilakukan dengan menggunakan mesin ujian universal (UTM) pada suhu yang berbeza dan tahap tekanan berbeza. Akhir sekali, tingkah laku rayapan daripada spesimen dianggarkan menggunakan Zhou tiga peringkat model rayapan. Hasil kajian menunjukkan bahawa serbuk getah dan TOR ketara dipengaruhi parameter aluran, terutama pada tahap tekanan dan suhu yang tinggi. Selain itu, berdasarkan model Zhou, ia telah membuat kesimpulan bahawa rintangan kepada ubah bentuk kekal (rintangan aluran) telah bertambah baik dengan penggunaan getah remah dan TOR.

Di samping itu, regresi linear (kaedah langkah demi langkah) telah digunakan untuk analisis statistik yang mana objektif utama adalah untuk membangunkan (model regresi) persamaan yang boleh digunakan untuk meramalkan aluran dari campuran untuk semua faktor-faktor yang terlibat. Analisis regresi juga digunakan sebagai satu cara untuk menjelaskan hubungan sebab akibat antara faktor (tahap penting).
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Not to forget, my deepest appreciations to my beloved husband for his precious assistance, guidance and encouragement especially during the stressful moment of my study. Lastly, I offer my regards to my parents and parents in law for their endless support, love and prayers.
DEDICATION

This thesis is especially dedicated to:

My husband, Mohd Rasdan bin Ibrahim

My parents, Hj. Katman bin Madikon and Hjh. Buninah binti Kusor

My parents in law, Hj. Ibrahim bin Haron and Hjh Fathilah binti Othman
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<td>APA</td>
<td>Asphalt Pavement Analyzer</td>
</tr>
<tr>
<td>AS</td>
<td>Australian Standard</td>
</tr>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
</tr>
<tr>
<td>CR</td>
<td>Crumb Rubber</td>
</tr>
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<td>CRMB</td>
<td>Crumb Rubber Modified Binder</td>
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<td>CRMB-TOR</td>
<td>Crumb Rubber Modified Binder Reinforced with TOR</td>
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<td>CRMM</td>
<td>Crumb Rubber Modified Mixture</td>
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<tr>
<td>CRMM-TOR</td>
<td>Crumb Rubber Modified Mixture Reinforced with TOR</td>
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<tr>
<td>ELT</td>
<td>End of life tyres</td>
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<tr>
<td>ETRMA</td>
<td>European Tyre and Rubber Manufacturers’ Association</td>
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<tr>
<td>FHWA</td>
<td>The Federal Highway Administration</td>
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<td>HMA</td>
<td>Hot Mix Asphalt</td>
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<tr>
<td>ID</td>
<td>Identification name</td>
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<td>ITSM</td>
<td>Indirect Tensile Stiffness Modulus</td>
</tr>
<tr>
<td>JATMA</td>
<td>Japan Automobile Tyre Manufacturers Association</td>
</tr>
<tr>
<td>$J_{nr}$</td>
<td>Non-Recoverable Compliance</td>
</tr>
<tr>
<td>JKR</td>
<td>Jabatan Kerja Raya (Public Works Department)</td>
</tr>
<tr>
<td>MPa</td>
<td>Mega Pascal</td>
</tr>
<tr>
<td>MQ</td>
<td>Marshall Quotient</td>
</tr>
<tr>
<td>N/A</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>OBC</td>
<td>Optimum Binder Content</td>
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<td>OPC</td>
<td>Ordinary Portland cement</td>
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<td>PWD</td>
<td>Public Works Department</td>
</tr>
<tr>
<td>%R</td>
<td>% Recovery</td>
</tr>
<tr>
<td>$R^2$</td>
<td>Reliability value</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
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</tr>
<tr>
<td>REAM</td>
<td>Road Engineering Association of Malaysia</td>
</tr>
<tr>
<td>RPM</td>
<td>Revolutions per Minute</td>
</tr>
<tr>
<td>RMA</td>
<td>Rubber Manufacturers Association</td>
</tr>
<tr>
<td>s</td>
<td>Second</td>
</tr>
<tr>
<td>SBR</td>
<td>Styrene Butadiene Rubber</td>
</tr>
<tr>
<td>SMA</td>
<td>Stone Mastic Asphalt</td>
</tr>
<tr>
<td>SMA 20</td>
<td>Stone Mastic Asphalt with aggregate nominal size 20mm</td>
</tr>
<tr>
<td>SPSS</td>
<td>Statistical Package for the Social Sciences</td>
</tr>
<tr>
<td>TOR</td>
<td>Trans-polyoctenamer</td>
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<tr>
<td>TRL</td>
<td>Transport Research Laboratory</td>
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<tr>
<td>UMATTA</td>
<td>Universal Material Testing Apparatus</td>
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<tr>
<td>VFB</td>
<td>Voids Filled with Bitumen</td>
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<tr>
<td>VIM</td>
<td>Voids in Mix</td>
</tr>
<tr>
<td>VMA</td>
<td>Voids in Mineral Aggregate</td>
</tr>
<tr>
<td>WBCSD</td>
<td>World Business Council for Sustainable Development</td>
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