EFFECTS OF NEWLY DEVELOPED CELLULOSE OIL PALM FIBER IN THE FATIGUE FAILURE OF STONE MASTIC ASPHALT

By

RATNASAMY MUNIANDY

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy
September 2004

DEDICATION

“One’s aspirations become a reality at the expense of the beloved one’s sacrifice and tolerance”. This work is passionately dedicated to my wife Mina and daughter Vimisha who have undergone much endurance and patience throughout the course of my study.

“ A friend in need is a friend indeed’. This research work is also dedicated to Ir. Salihuddin Hassim, a good friend of mine who had relentlessly pushed me to achieve my goals.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

EFFECTS OF NEWLY DEVELOPED CELLULOSE OIL PALM FIBER IN THE FATIGUE FAILURE OF STONE MASTIC ASPHALT

By

RATNASAMY MUNIANDY

September 2004

Chairman : Associate Professor Bujang Kim Huat, PhD., P.E.

Faculty : Engineering

Fatigue or tensile cracking along wheel paths of vehicles are predominant on Malaysian roads as compared with other forms of distress. This is primarily due to accelerated loading from trucks, which is causing the authorities millions of ringgit on road maintenance alone. This situation is further aggravated with the traditional use of soft 80-100 penetration binders, which are poor in shear strength. At the same time, the use of additives such as Ethylene Vinyl Acetate (EVA) has proved costly. With the rising cost of asphalt in Malaysia, construction and rehabilitation of asphalt road pavements are expected to constrain the road agencies' budget in the coming years. The objectives of this study were to research the rheological properties of newly developed cellulose oil palm fibers and their potential in resisting fatigue failure of Stone Mastic Asphalt (SMA).

The research was undertaken in two parts. The first part of the study was carried out at UPM on SMA with granite aggregates. The selection of

aggregate and asphalt for the study were done based on typical SMA mix requirements. Utmost importance was given to the use of the newly developed cellulose oil palm fiber in SMA. Out of the six types of cellulose fibers obtained through various types of pulping procedures, the Chemical Refined(Chem-R) Cellulose Fiber gave the best performance in terms of drain-down and rheological properties such as complex shear modulus. As such Chem-R cellulose fiber was selected and used throughout the study in proportions of 0.0%, 0.2%, 0.4%, 0.6%,0.8%,1.0% in 100mm cylindrical SMA14 mix design and fatigue and IDT tests.

SMA specimens, prepared with the above cellulose fiber proportions were tested to simulated loading and temperature conditions in accordance with the American Standard for Testing and Materials (ASTM) and Association of American State Highway and Transportation Officials (AASHTO) Standards. The various proportions of cellulose oil palm fiber tested in 100 mm cylindrical specimens showed remarkable improvement in terms of fatigue life, stiffness and modulus. All of the SMA14 specimen properties increased as the fatigue life increased to a maximum value that corresponds to about 0.6% fiber. Remarkably, at 0.6% optimum fiber content, the initial strain decreased while the stiffness modulus increased, as compared with SMA14 specimens without fibers.

The diameteral fatigue, and beam flexure tests have become popular in the Super Pave and AASHTO Tests. Along with that, new approaches in the fatigue analysis such as Dissipated Energy Ratio(DER), and Stiffness have also become very useful in the analysis of asphalt beams. Tests carried out on SMA9.5 beam specimens with the same cellulose fiber proportions as in SMA14, displayed similar trends in the fatigue performance of cellulose fibers regardless of the aggregate and gradation types. Maximum performance curves for fatigue life, stiffness and DER for the SMA9.5 beams were established. The fatigue life of beam specimens showed a maximum value between 0.6 and 0.8% of fiber contents, and the trend was similar for other parameters such as stiffness and DER. The results indicated that use of cellulose oil palm fibers greatly reduced the stiffness of the SMA9.5 and increased the number of load cycles to failure. These special characteristics of the fibers are expected to extend the life span of SMA pavement in the field. In addition, DER value was found to be the lowest for 0.6% cellulose oil palm fibers indicating a decreased loss of energy through dissipation. The more energy is retained and stored the longer life of the SMA pavements.

Another important aspect observed in this study was the resistance of cellulose oil palm fibers to fatigue failure of SMA mixes. Several 150mm IDT samples were tested to determine the maximum indirect tensile stress, crack initiation, and propagation. The specimens tested in accordance with AASHTO TP-9 standard showed an increase in indirect tensile stress at 0.6% fiber proportions before taking a down turn. This seems to be promising for more new research in the area since previous research by others showed that gap graded mixes such as SMA displayed poor tensile strength.

Two new approaches were undertaken to study the resistance of cellulose fibers against fatigue life of SMA. The first crack tensile stress and the maximum tensile stress values were used to quantify the fatigue resistance of the newly developed cellulose oil palm fibers. The fiber fatigue resistance quantifying approach is termed as **Sustenance Ratio (SR)**. SR in this newly developed approach is defined as the ability of cellulose fibers to carry the maximum applied load to the first crack load divided by the time taken or total number cycles to failure. The unit of measure can be kN/sec or kN/cycles. Using this newfound analogy, the SR of various fiber percentages in SMA9.5 cylindrical specimens were determined. It was observed that the SR decreased to the lowest point at 0.6% fiber content, indicating a higher fatigue resistance. It was observed that the lower the SR the higher the fatigue resistance of fibers. In summary, it has been shown that the addition of Cellulose Oil Palm Fiber (COPF) up to 0.6% provides the maximum fatigue resistance to SMA which can be measured in terms of SR for various temperatures and load configuration.

Another concept that was developed in this study was the **Crack Meander (ξ)** concept analogous to that of a river meander. Theoretically the lower the resistance encountered along the path of crack propagation, the more linear the line of crack becomes. The crack initiation and propagation within the 40mm gauged stress zone, was captured using a SLR camera, and the crack pattern was digitized. It was observed that the crack started to meander as the fiber proportions in the mix increased. A maximum meander was observed at a fiber content of 0.6%. The crack propagation within the stress zone appeared to be pinned by fiber reinforcements thus causing the line of crack to meander and propagate through weaker matrix.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KESAN GENTIAN PENGHASILAN BARU SELULOS KELAPA SAWIT DALAM KEGAGALAN LESU ASFALT MAMAH BATU

Oleh

RATNASAMY MUNIANDY

September 2004

Pengerusi : Profesor Madya Bujang Kim Huat, PhD., P.E.

Fakulti : Kejuruteraan

Keretakan lesu atau pun tegangan di sepanjang laluan tayar merupakan satu mod kegagalan utama di Malaysia dibandingkan dengan mod-mod kegagalan yang lain. Ini adalah disebabkan peningkatan beban kenderan berat yang amat tinggi. Pihak berkuasa terpaksa menanggung kerugian kos penyelengaraan bernilai berjuta-juta ringgit. Namun, penggunaan asfalt penusukan 80-100 yang lembut telah memburukkan lagi keadaan. Asfalt penusukan 80-100 adalah lemah dalam kekuatan tegangan. Peggunaan bahan tambah seperti Ethylene Vinyl Acetate (EVA) dalam campuran asfalt telah meningkatkan kos asfalt. Agensi-agensi berkaitan jalan raya menghadapi kekurangan peruntukan pembinaan dan pemulihan jalan raya akibat daripada kenaikan harga asfalt. Objektif-objektif kajian ini adalah untuk mengkaji ciri-ciri reologi gentian penemuan baru gentian kelapa sawit dan potensinya dalam rintangan kegagalan lesu Asfalt Mamah Batu (SMA).

Kajian ini telah dilakukan dalam dua peringkat. Kajian peringkat pertama dijalankan di UPM terhadap Asfalt Mamah Batu (SMA) dengan menggunakan batuan granit. Pemilihan agregat dan asfalt dilakukan berdasarkan piawaian SMA. Dalam kajian ini keutamaan diberi kepada penggunaan gentian kelapa sawit baru di dalam campuran asfalt SMA14. Daripada enam jenis gentian kelapa sawit yang dihasilkan melalui pelbagai proses, gentian kelapa sawit ‘Chemical Refined” (Chem-R) memberi prestasi yang lebih tinggi dari segi ciri-ciri saliran asfalt ke bawah (drain-down) dan ciri-ciri reologi seperti modulus ricih kompleks. Oleh yang demikian gentian kelapa sawit Chem-R telah dipilih untuk kajian ini. Specimen SMA14 berukuran 100mm telah disediakan dengan campuran gentian sebanyak 0.0%, 0.2%, 0.4%, 0.6%, 0.8%, dan 1.0%

Kesemua specimen-specimen SMA yang mempunyai campuran gentian kelapa sawit telah diuji dalam keadaan beban dan suhu simulasi mengikut piawaian “American Standard for Testing and Materials (ASTM) dan Association of American State Highway and Transportation Officials (AASHTO). Kesemua specimen-specimen yang mempunyai pelbagai peratusan gentian kelap sawit yang berbeza menunjukan peningkatan prestasi yang ketara dari segi jangkahayat lesu, kekukuhan dan modulus keanjalan. Kesemua ciri-ciri specimen meningkatkan lagi prestasi SMA14 terutama jangka hayat lesu, dimana nilai maksima yang dicapai pada 0.6 peratus gentian kelapa sawit. Pada 0.6% gentian, terikan awal berkurangan manakala modulus kekukuhan meningkat apabila dibanding dengan specimen SMA14 tanpa sebarang gentian kelapa sawit.

Ujian lesu diametral dan ujian alur asfalt telah diterima pakai dalam kaedah Superpave dan AASHTO. Pendekatan baru dalam analisis kelusuan sperti 'Dissipated Energy Ratio' (DER) dan kekukuhan alur juga sangat berguna untuk tujuan analisis rasuk asfalt. Ujian-ujian yang dijalankan keatas specimen-specimen rasuk SMA9.5 yang mempunyai kandungan campuran gentian kelapa sawit yang sama dengan SMA14 menunjukkan corak yang sama dari segi prestasi kelesuan gentian kelapa sawit tanpa mengira kesan gradasi dan agregat. Corak yang sama juga dikenalpasti untuk unijian-ujian kekukuhan dan DER. Pengunaan gentian kelapa sawit mengurangkan kekukuhan SMA9.5 dan meningkatkan bilangan kitaran sehingga gagal. Ciri-ciri ini meningkatkan lagi akan jangka hayatnya jalan raya. Nilai DER dicatat paling rendah pada peratusan gentian 0.6% menunjukkan pengurangan kehilangan tenaga melalui proses pelepasan. Lebih banayak tenaga yang disimpan menunjukkan jangka hayat asfalt SMA yang berlebihan.

Satu lagi aspek yang ditemui idalam kajian ini alah rintangan gentian kelapa sawit dalam kegagalan lesu campuran SMA. Beberapa sampel berukuran 150 mm specimen IDT telah diuji untuk menentukan kekuatan tegangan maksima, permulaan dan pergerakan keretakkan. Specimen-specimen yang diuji mengikut piawaian AASHTO TP-9, menunjukan kekuatan tegangan yang maksima pada 0.6% gentian kelapa sawit. Kajian seterusnya perlu dijalankan kerana kajian sebelum ini menunjukkan campuran asfalt 'gap-graded' seperti SMA adalah dalam kekuatan tegangan. Keretakan tegangan berlaku setelah specimen mencapai tegasan tegangan maksima. Sekali lagi campuran 0.6% gentian kelapa sawit menunjukkan nilai tegangan maksima.

Dalam kajian ini, satu lagi kaedah baru dihasilkan yang boleh mengira rintangan lesu gentian kelapa sawit dalam campuran SMA. Kemampuan gentian kelapa sawit untuk memikul beban daripada maksima ke retakan pertama diagihi dengan masa purata yang diambil didefinasikan sebagai 'Sustenance Ratio'(SR). Dengan menggunakan kaedah baru ini, SR gentian kelapa sawit dalam campuran SMA9.5 dapat ditentukan. SR mencapai tahap yang paling rendah pada campuran 0.6% gentian kelapa sawit. Ini menunjukkan kerintangan lesu kelapa sawit yang tinggi. Lebih rendah nilai SR menandakan gentian kelapa sawit mempunyai nilai ke kelesuan yang lebih tinggi. Secara ringkas, kajian menunjukkan bahawa rintangan kelesuan akan meningkat sekiranya kandungan gentian kelapa sawit ditambah ke tahap campuran peratusan 0.6.

'Crack Meander' adalah satu lagi Konsep yang beranalogikan konsep 'Crack meander' dapat dihasilkan menurusi kajian ini. Secara teori, semakin kurang rintangan pada pergerakakn retakan, semakin lurus garisan retak menjadi. Permulaan dan pergerakan keretakan dalam zon tegangan 40mm, digambarkan dengan menggunakan kamera SLR. Corak-corak keretakan direkodkan secara digital. Corak 'crack meander' SMA menunjukkan bahawa ciri rintangan lesu memuncak pada 0.6 % gentian kelapa sawit.

Pergerakan keretakan dalam zon ketegangan seolah-olah telah dihentikan oleh tetulang gentian kelapa sawit menyebabkan keretakan tadi bergerak kearah matriks yang lebih lemah.

ACKNOWLEDGEMENTS

A famous philosopher once said “I sit astride life like a bad rider on a horse. I only owe it to the horse's good nature that I am not thrown off at this very moment”. Every individual, aspiring to learn from the learned experts, find themselves in bad shapes having to undergo rigorous and trying times before any achievements can be grasped. I am no exception to this situation and philosophy. Like the good horse with a bad rider, I had this great and wonderful opportunity in receiving relentless assistance and guidance from many dedicated experts and individuals without whom I may not have come this far in my life.

I would to take this opportunity to thank my supervisor Associate Professor Dr. Ir. Bujang Kim Huat for his valuable guidance and advise in many areas of the research that are related to geotechnical aspects of fatigue and permanent deformations. His advice and support have been very useful in the implementation of my research and finishing up the report.

I would also like to thank, first of all my main supervisor at South Dakota State University, USA, Professor Dr. Ali A. Selim for guiding and assisting me all the way through my major chunk of research. There was not a day that went by without him checking and monitoring my research progress as well as my rather unstable state of health. In the course of the difficult and unbearable path of research work, his kind and timely philosophical preaching gave me tremendous courage to continue to plough the wilderness of research looking for an outcome. My heartfelt, sincere thanks and salute to Professor Dr. Ali A. Selim for making my dream come true.

My sincere thanks also go to Dr. Rosely Abd Malik who had been my research supervisor at Universiti Putra Malaysia for two semesters. I have learned to be courageous with every turning point during the course of my research work. Thanks to the many morale boosting stories (the marble story) and the research guidance from Dr. Rosely Abd Malik. It is also appropriate here to thank Dr. Meor Othman, one of the co supervisors of my dissertation, whom I consider the foremost expert in asphalt materials in Malaysia. Mere thanking may not be enough to appreciate his thoughts and comments and the regular late-night email counseling on my dissertation. Dr. Meor Othman has become a big part of my work and my appreciation goes out to him for all the support he has rendered to me.

Learning is an on going process. This is what I have learned from Professor Dr. Vernon R. Schaefer who is one of the supervisory committee. I would like to thank him for the never-ending discussions and comments on my research work. A lot of fruitful ideas and guidance from him made my work even more meaningful. Above all, my sincere thanks to Professor Schaefer, who provided a stipend for my stay in Brookings while being the head of department of civil and environmental engineering at South Dakota State University. I cannot thank him enough for rendering such great assistance in both my research work and other matters.

I would also like to thank Professor Dr. Gary Anderson and Dr. Nicolai, of the Agricultural Engineering Department for assisting me a great deal on the instrumentation and data acquisition needed for the fatigue testing of SMA specimens. Also not forgotten is Professor Dr. Robert Lacher of the Statistics Department, SDSU who was one of the committee for my qualifying examination. The laboratory work needed was way too much of fabrication and improvision of the equipment and testing devices. Countless hours of assistance was provided by the CEE, SDSU technician, Mr. James Anderson without whom I may not have seen the end of the tunnel in my laboratory testing. I would like to thank Mr. Anderson from the bottom of my heart for making the impossible possible. I wish I could continue working with him who has such a great personality and dedication. Before I run out memory, I would like to thank Professors Dr. Delvin Deboer and Professor Dr. Nadim Wehbe for assisting me with my fiber dispersion study and the beam static energy equation respectively. My sincere gratitude and thanks goes to the National Center for Asphalt Technology (NCAT) especially Professor Dr. Ray Brown, Brian Prowell, and Chris for allowing and assisting me with the IPC asphalt beam fatigue testing at their laboratory in Auburn, Alabama. The South Dakota Department of Transportation's cooperation and assistance in allowing the Dynamic Shear Rheometer tests to be carried is also appreciated very much.

Last but not the least, I would like to thank my Civil Engineering Department and Faculty especially Associate Professor Dr. Salleh Jafar, Professor Dr. Radin Umar for their support and my good friends and colleagues Ir. Salihudin

Hassim and Associate Professor Dr. Husaini Omar who have given me all the friendly and moral support throughout my dissertation work. Also not forgotten are our department of civil Engineering, UPM secretaries Kak Badar and Lisa for their kind support. Before I forget my sincere thanks to our CEE, SDSU secretary Ms. Diane Marsh and Ms. Ann Monnents of Great Plains, for rendering their kind support and assistance whenever I needed. Again, my sincere thanks to all for making this happen.

Ratnasamy Muniandy

I certify that an Examination Committee has met on 1st September 2004 to conduct the final examination of Ratnasamy Muniandy on his Doctor of Philosophy thesis entitled "Experimental Studies on the Effects of Cellulose Oil Palm Fiber in the Fatigue Failure of Stone Mastic Asphalt" in accordance with Universiti Peratnian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher degree) Regulations 1981. The committee recommends that the candidate to be awarded the relevant degree. Members of the Examination Committee are as follows:

Husaini Omar, Ph.D
Associate Professor
Faculty of Engineering, Universiti putra Malaysia
(Chairman)

Mohd. Razali Abdul Kadir, Ph.D
Associate Professor
Faculty of Engineering, Unversiti Putra Malaysia
(Internal Examiner)

Wong Shaw Voon, PhD
Associate Professor
Faculty of Engineering, Universiti Putra Malaysia
(Internal Examiner)

Abd El Halim Omar Abd El Halim
Professor
Faculty of Engineering, University of Carleton,
Ontario, Canada

GUALM RUSUL RAHMAT ALI, Ph.D.
Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia
Date:

This thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfillment of the requirements for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

Bujang Kim Huat, Ph.D
Associate Professor
Faculty of Engineering, Universiti Putra Malaysia

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

RATNASAMY MUNIANDY

Date:

TABLE OF CONTENTS