Covering a wide range of topics, **Advances in Civil Engineering and Building Materials IV** presents the latest developments in:

- Structural Engineering
- Road & Bridge Engineering
- Geotechnical Engineering
- Architecture & Urban Planning
- Transportation Engineering
- Hydraulic Engineering
- Engineering Management
- Computational Mechanics
- Construction Technology
- Building Materials
- Environmental Engineering
- Computer Simulation
- CAD/CAE

Emphasis was put on basic methodologies, scientific development and engineering applications. **Advances in Civil Engineering and Building Materials IV** will be useful to professionals, academics, and Ph.D. students interested in the above-mentioned fields.

CRC Press
Taylor & Francis Group
an informa business
www.crcpress.com

6000 Broken Sound Parkway, NW
Suite 300, Boca Raton, FL 33487
Schipholweg 107C
2316 XC Leiden, NL
2 Park Square, Milton Park
Abingdon, Oxon OX14 4RN, UK

ISBN 978-1-138-00088-9
an informa business

Editors
Chang
Al Bahar
Husain
Zhao

Advances in
Civil Engineering and
Building Materials IV

CRC

Advances in Civil Engineering and Building Materials IV

Editors: Shuenn-Yih Chang, Suad Khalid Al Bahar,
Adel Abdulmajeed M. Husain & Jingying Zhao

CRC Press
Taylor & Francis Group
A BALKEMA BOOK

SELECTED AND PEER REVIEWED PAPERS FROM THE 2014 4TH INTERNATIONAL
CONFERENCE ON CIVIL ENGINEERING AND BUILDING MATERIALS (CEBM 2014),
15–16 NOVEMBER 2014, HONG KONG

Advances in Civil Engineering and Building Materials IV

Editors

Shuenn-Yih Chang
Department of Civil Engineering, National Taipei University of Technology, Taiwan

Suad Khalid Al Bahar
Kuwait Institute Scientific Research, Safat, Kuwait

Adel Abdulmajeed M. Husain
*Kuwait Institute Scientific Research, Energy and Building Research Center (EBRC),
Safat, Kuwait*

Jingying Zhao
International Science and Engineering Research Center, Wanchai, Hong Kong

CRC Press
Taylor & Francis Group
Boca Raton London New York Leiden

CRC Press is an imprint of the
Taylor & Francis Group, an informa business
A BALKEMA BOOK

CRC Press/Balkema is an imprint of the Taylor & Francis Group, an informa business

Typeset by MPS Limited, Chennai, India
Printed and Bound by CTPS Digiprints, Hong Kong

Published by: CRC Press/Balkema
P.O. Box 11320, 2301 EH Leiden, The Netherlands
e-mail: Pub.NL@taylorandfrancis.com
www.crcpress.com – www.taylorandfrancis.com

ISBN: 978-1-138-00088-9 (Hardback)
ISBN: 978-1-315-69049-0 (Ebook PDF)

Advances in Civil Engineering and Building Materials IV – Chang et al (eds)
© 2015 Taylor & Francis Group, London, ISBN: 978-1-138-00088-9

Table of contents

Architecture

Bridge engineering

Building materials performance analysis

Building materials preparation

Coastal engineering

Computer simulation and CAD/CAE

Construction technology

Detection of building materials

Engineering management

Geotechnical engineering

Hydraulic engineering

Others

Road engineering

Structural engineering

Transportation engineering

Urban planning

Advances in Civil Engineering and Building Materials IV – Chang et al (eds)
© 2015 Taylor & Francis Group, London, ISBN: 978-1-138-00088-9

Preface

Following the great progress made in civil engineering and building materials, the 2014 4th International Conference on Civil Engineering and Building Materials (CEBM 2014) aimed at providing a forum for presentation and discussion of state-of-the-art development in Structural Engineering, Road & Bridge Engineering, Geotechnical Engineering, Architecture & Urban Planning, Transportation Engineering, Hydraulic Engineering, Engineering Management, Computational Mechanics, Construction Technology, Building Materials, Environmental Engineering, Computer Simulation & CAD/CAE. Emphasis was given to basic methodologies, scientific development and engineering applications.

This conference is co-sponsored by Asia Civil Engineering Association, the International Association for Scientific and High Technology and International Science and Engineering Research Center. The purpose of CEBM 2014 is to bring together researchers and practitioners from academia, industry, and government to exchange their research ideas and results in the areas of the conference. In addition, the participants of the conference will have a chance to hear from renowned keynote speakers Prof. XIAO-YAN LI from University of Hong Kong.

We would like to thank all the participants and the authors for their contributions. We would also like to gratefully acknowledge the production supervisor Janjaap Blom, Léon Bijnsdorp, Lukas Goosen, who enthusiastically support the conference. In particular, we appreciate the full heart support of all the reviewers and staff members of the conference. We hope that CEBM 2014 will be successful and enjoyable to all participants and look forward to seeing all of you next year at the CEBM 2015.

November, 2014

Prof. Shuenn-Yih Chang
Dr. Suad Khalid Al Bahar
Dr. Adel Abdulmajeed M. Husain
Dr. Jingying Zhao

Advances in Civil Engineering and Building Materials IV – Chang et al (eds)
© 2015 Taylor & Francis Group, London, ISBN: 978-1-138-00088-9

Sponsors and Committees

GENERAL CHAIR

David Packer, *International Science and Engineering Research Center, Hong Kong*

SCIENTIFIC COMMITTEE CHAIR

Konstantinos Giannakos, *Fellow of ASCE, University of Thessaly, Greece*
Suad Al-Bahar, *Kuwait Institute for Scientific Research, Kuwait*

INTERNATIONAL COMMITTEE & SCIENTIFIC COMMITTEE

Ali Rahman, *Jundi-Shapur University Technology, Iran*
Anuchit Uchaipichat, *Vongchavalitkul University, Thailand*
Ata El-kareim Shoeib Soliman, *Faculty of Engineering El-Mataria, Egypt*
Badreddine Sbartai, *Université de Skikda, Algeria*
David S. Hurwitz, *Oregon State University, USA*
Du Jia-Chong, *Tungnan University, Taiwan*
Fu-Jen Wang, *National Chin-Yi University of Technology, Taiwan*
Hosein Rahnema, *Yasuj University, Iran*
Jian Yang, *University of Birmingham, UK*
Jianping Han, *Lanzhou University of Technology, China*
Jianqing Bu, *Shijiazhuang Tiedao University, China*
Jia-Ruey Chang, *MingHsin University of Science & Technology, Taiwan*
Konstantinos Giannakos, *University of Thessaly, Greece*
Lan Wang, *Inner Mongolia University of Technology, China*
Malagavelli Venu, *BITS, Pilani, India*
Manjeet Singh Hora, *Director, MANIT Bhopal, India*
Mehmet Serkan Kirgiz, *Hacettepe University, Turkey*
Moghadas Nejad, *Amirkabir University of Technology, Iran*
Mohammadreza Vafaei, *Imenrah Consulting Engineers Co., Iran*
Mohammadreza Yadollahi, *Universiti Teknologi Malaysia, Malaysia*
Mubiao Su, *Shijiazhuang Tiedao University, China*
Niyazi Ugur Kockal, *Akdeniz University, Turkey*
Ruey Syan Shih, *Tumgnan University, Taiwan*
Shengcai Li, *Huaqiao University, China*
Sina Kazemian, *SCG Consultant Company, Selangor, Malaysia*
TaeSoo Kim, *Hanbat National University, Korea*
Zakiah Ahmad, *Coordinator of Quality Unit, Malaysia*
Zhixin Yan, *Lanzhou University, China*

TECHNICAL COMMITTEE CHAIR

Chang, Shuenn-yih, *National Taipei University of Technology, Taiwan*
Suad Al-Bahar, *Kuwait Institute for Scientific Research, Kuwait*

TECHNICAL COMMITTEE

Deng-Hu Jing, *Southeast University, China*
Dong Yongxiang, *Beijing Institute of Technology, China*

Jiachun Wang, *Xia men University of Technology, China*
Jianrong Yang, *Kunming University of Science and Technology, China*
Jingying Zhao, *International Association for Scientific and High Technology, Hong Kong*
Kuixing Liu, *Tianjin University, China*
Li Liping, *Shandong University, China*
Liangbin Tan, *Kunming University of Science and Technology, China*
Lu Qun, *Tianjin Institute of Urban Construction, China*
Ming Zhang, *Henan Institute of Engineering, China*
Patrick Tiong Liq Yee, *Universiti Teknologi Malaysia, Malaysia*
Tianbo Peng, *Tongji University, China*
Xujie Lu, *Jianghan University, China*

PUBLICATION CHAIRS

Jingying Zhao, *International Association for Scientific and High Technology*

CO-SPONSORED BY

Asia Civil Engineering Association
International Association for Scientific and High Technology
International Science and Engineering Research Center

Advances in Civil Engineering and Building Materials IV – Chang et al (eds)
© 2015 Taylor & Francis Group, London, ISBN: 978-1-138-00088-9

The effect of granular BRA modifier binder on the stiffness modulus of modified asphalt

Muhammad Karami & Hamid Nikraz
Department of Civil Engineering, Curtin University, Perth, Western Australia, Australia

ABSTRACT: This study is aimed to evaluate the effect of using a granular Buton Rock Asphalt (BRA) modifier binder for improving the stiffness modulus performance of asphalt mixtures. The stiffness moduli of BRA modified asphalt mixtures and unmodified asphalt mixtures (as control mixtures) for a dense grading of 10 mm were determined using an Indirect Tensile Stiffness Modulus (ITSM) test at five different temperatures (5, 15, 25, 40, and 60°C), three different rise times (40, 60, and 80 ms), and three pulse repetition periods (1000, 2000, and 3000 ms). Results from this study indicated that stiffness moduli for BRA modified asphalt mixtures were higher than that for control mixtures at any test temperature, rise time, and pulse repetition period. The change in temperature is the biggest influence on changing the stiffness modulus compared to the change in rise time and the pulse repetition period for both asphalt mixtures.

Keywords: Buton Rock Asphalt (BRA), asphalt mixtures, Indirect Tensile Stiffness Modulus (ITSM)

1 INTRODUCTION

The need to increase the capability of asphalt mixtures to withstand increasingly heavy loads as well as to withstand the effect of climate is very important in order to prevent the rapid deterioration of asphalt mixtures. Therefore, the use of modified asphalt mixtures in road structures with the aim to improve the performance and service life of road surfaces is greatly needed.

Asphalt mixtures are formed by bitumen and aggregate. In a certain conditions, such as high temperature and low loading times, bitumen behaves as a viscous material, whereas at low temperature and high loading times, bitumen behaves as an elastic solid (Yilmaz & Celoglu, 2013). Asphalt mixtures behave like bitumen because the main function of the bitumen in the mixtures is as a binder, where the properties of bitumen have a direct and significant effect on the properties of asphalt mixtures. As a result, at a typical traffic speed and temperature, asphalt mixtures almost behave as an elastic material, where the deformation under loading conditions is considered recoverable (Hartman et al., 2001, Ahmedzade & Sengoz, 2009, Mokhtari & Nejad, 2012). Since the binder characteristic is among the factors that affect the elastic stiffness of an asphalt mixture (Tayfur et al., 2007), a stiffness modulus is considered as an important performance characteristic of asphalt mixtures. A stiffness modulus is used as a measure on resistance to bending and the capability to spread the applied load for asphalt mixtures (Hartman et al. 2001).

In order to improve the stiffness modulus of asphalt mixtures, this research considered the use of a granular BRA modifier binder. The form of this modifier binder is granular (pellets), and is composed of two parts, natural binder and fine mineral, which are known together as mastic asphalt. It is well known that mastic asphalt has a favourable influence on the performance of asphalt mixtures (Wang et al, 2011, Silva et al., 2003). Limited study reported about using BRA modifier binder products for improving stiffness modulus and other performances of asphalt mixtures. Affandi (2012) reported that the stiffness modulus is increased and the temperature sensitivity of asphalt mixtures is improved by using BRA modifier binder semi-extraction. Other BRA modifier binder products, for example, filler, were studied and resulted in an increase in the resilient modulus and rutting potential (Subagio et al., 2003), and also in the fatigue performance of asphalt mixtures (Subagio et al., 2005).

The objective of this study is to perform a laboratory investigation on unmodified and BRA modified asphalt mixtures to identify their effect on the stiffness modulus performance.

2 MATERIALS AND METHODS

2.1 *Asphalt binder*

A type of asphalt cement, C-170, from a regional supplier in Western Australia was used as the base

Table 1. Properties of base binder.

Properties	Test Method	Value
Density, kg/L	ASTM D-1298	1.03
Flash point, °C	ASTM D-93	>250
Viscosity at 60°C, Pa.S	ASTM D-445	170
Viscosity at 135°C, Pa.S	ASTM D-445	0.35

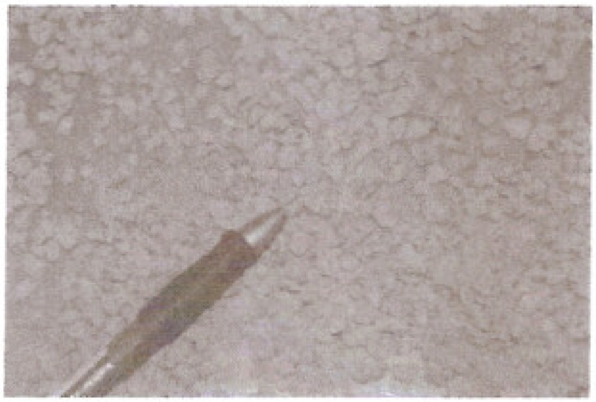

Figure 1. The form of granular BRA modifier binder.

Table 2. Particle size distribution of BRA mineral.

Sieve size (mm)	2.36	1.18	0.60	0.30	0.15	0.075
Passing (%)	100	97	92	81	61	36

asphalt binder for control asphalt mixtures; it is classified according to the Australian Standard AS-2008. The properties of the base asphalt binder are listed in Table 1. In this study, BRA modified asphalt mixtures were made by replacing 20% of the base asphalt binder (by weight of total asphalt binder) with 20% of the natural binder, containing the granular BRA modifier binder, with the purpose of improving the stiffness modulus of asphalt mixtures. The form of BRA modifier binder used in this study was granular (pellets) with a size of 7 to 10 mm in diameter, as shown in Figure 1. Three samples of granular BRA modifier binder were extracted in accordance with Standard WA730.1-2011. These test results showed that the granular BRA modifier binder was composed of 70% mineral and 30% binder by total weight. Table 2 shows the particle size distribution for BRA mineral. Based on a size of less than 4.75 mm, the mineral is considered as fine aggregate and the granular BRA modifier binder can be concluded as mastic binder based on a mineral size of less than 2 mm (Silva et al., 2003).

2.2 *Aggregate*

The aggregate gradation of dense graded, as shown in Table 3, was used for the control and the BRA modified asphalt mixtures. The gradation had a maximum aggregate size of 9.5 mm in accordance with Specification 504 used in Australia. One sourced of crushed granite was used for all of the asphalt mixtures. In this study, the aggregate gradation for BRA modified asphalt mixtures below 2.36 mm was adjusted to accommodate the mineral content in the granular BRA modifier binder. The weight of the crushed aggregate was reduced by the BRA mineral in order to minimize the variance of aggregate gradation.

Table 3. Aggregate gradation used in this study.

	Dense grading 10-mm, Passing (%)				
		BRA modified**			
Sieve size (mm)	Control* Crushed aggregate	Crushed aggregate	BRA mineral	Final	Lower-upper limit***, Passing (%)
13.20	100	100		100	100
9.50	97.5	97.5		97.5	95–100
6.70	83.0	83.0		83.0	78–88
4.75	68.0	68.0		68.0	63–73
2.36	44.0	44.0	100	44.0	40–48
1.18	28.5	28.6	99.9	28.5	25–32
0.60	21.0	21.2	99.8	21.0	18–24
0.30	14.5	15.0	99.5	14.5	12–17
0.15	10.0	11.0	99.0	10.0	8–12
0.075	4.0	5.7	98.3	4.0	3–5
(%)	100	97.4	2.6	100	

*Control asphalt mixtures;
**BRA modified asphalt mixtures;
***Limit values in accordance with Specification 504

2.3 *Mix design and specimen preparation*

The Marshall Mix design method was used for determining the optimum binder content for the control asphalt mixtures in accordance with specification 504. Three specimens of 101 mm diameter and 63.5 mm height were produced with compacting energy of seventy-five blows applied to each side. The binder range region was 5.0% to 6.0% with 0.5% increment. The optimum binder content was determined as 5.4% by weight of the mixtures. In this study, the BRA modified asphalt mixtures used the same binder content as the control asphalt mixtures in order to maintain consistency for comparison purposes.

The BRA modified asphalt mixtures were fabricated as follows: 1.5% of hydrated lime (by weight of the total aggregates) was included in blended aggregates and mixed manually (Specification 504). The blended aggregates were then heated in a controlled temperature oven at 160°C for at least 12 hours. The base asphalt binder and the granular BRA modifier binder altogether were put in a bowl and then heated in another oven at 150 ± 5 for 30 min to 1 hour, with frequent manual stirring in order to blend and incorporate the two binders as the BRA modified asphalt binder. The blended aggregates were then put in the same bowl and mixed with the BRA modified asphalt binder for

1.5 minutes at a mixing temperature of 150°C. The mixing temperature for the control and the BRA modified asphalt mixtures were 140°C and 150°C, based on viscosity testing results.

3 INDIRECT TENSILE STIFFNESS MODULUS TEST

The resilient modulus tests were conducted in accordance with the test procedures Australian Standard AS2891.13.1-1995, to evaluate elastic properties in the form of stress-strain measurement. In this study, the Universal Testing Machine (UTM25) was used for the test to determine resilient modulus asphalt mixture in accordance with AS2891.13.1-1995. A gyratory compactor was used to fabricate specimens of 100 ± 2 mm in diameter and between 35 and 70 mm in height, following AS2891.2.2-1995. A number of gyrations were applied to achieve target air voids of 5 ± 0.5%. The compactions were performed at a gyratory angle of 2° and vertical loading stress of 240 kPa. Fifteen specimens were prepared for the control asphalt mixtures, and fifteen specimens were also prepared for the BRA modified asphalt mixtures (three specimens for each level of temperature).

The specimens were placed in the temperature-controlled cabinet at the required test temperature, and the temperature in the specimen was allowed to reach equilibrium before the testing was performed. The load pulse was applied vertically in the vertical diameter of a cylindrical specimen through a curved loading strip. Two Linier Variable Differential Transformers (LVDTs) were attached at the mid thickness at each end of the horizontal diameter to measure horizontal deformation. Initially, the test specimens were conditioned through the application of five load pulses with the specified rise time to the peak load at the specified pulse repetition period, and then the calculation of the modulus was done based on the average of a further five load pulses.

Specimens were conducted with control and BRA modified asphalt mixtures at five different temperature (5, 15, 25, 40, and 60°C), three different rise time (40, 60, and 80 ms), and three different pulse repetition period (1000, 2000, and 3000 ms). During testing, recovered horizontal strain were set to 50 $\mu\varepsilon$. The rise time is the time used for the applied load to increase from 10% to 90% while the pulse repetition period is a distance between 10% applied load in one pulse and 10% applied load in the next pulse. For simulating the volume and speed of traffic, a pulse repetition period of 1000 and 3000 ms was chosen for high and low trafficked volume roads respectively; for vehicle speeds, a rise time of 40 and 80 ms was chosen for high and low speeds respectively (Tayfur et al., 2007).

The average values of the stiffness modulus that were conducted to correlate the three identical specimens using power regression are shown in Table 4. Equations are obtained, where y is the average of the modulus in MPa and x is the rise time in mili-seconds (ms). The coefficient of correlation (R^2) was used to verify the accuracy of the equation.

Table 4. Variation of experimental parameters.

Temp. (°C)	Asphalt mixtures	Pulse rep. period (ms)	Equation	R^2
5	Control	1000	$y = 27692.309x^{-0.155}$	0.898
	Control	2000	$y = 25220.375x^{-0.128}$	0.840
	Control	3000	$y = 22982.688x^{-0.092}$	0.697
	BRA Modified	1000	$y = 34567.427x^{-0.128}$	0.832
	BRA Modified	2000	$y = 31427.543x^{-0.099}$	0.865
	BRA Modified	3000	$y = 30358.117x^{-0.080}$	0.912
15	Control	1000	$y = 21281.490x^{-0.219}$	0.713
	Control	2000	$y = 21235.835x^{-0.230}$	0.729
	Control	3000	$y = 21746.324x^{-0.239}$	0.763
	BRA Modified	1000	$y = 25320.082x^{-0.178}$	0.828
	BRA Modified	2000	$y = 24982.692x^{-0.180}$	0.809
	BRA Modified	3000	$y = 25721.289x^{-0.186}$	0.812
25	Control	1000	$y = 17773.527x^{-0.405}$	0.817
	Control	2000	$y = 13897.884x^{-0.375}$	0.780
	Control	3000	$y = 14391.167x^{-0.393}$	0.788
	BRA Modified	1000	$y = 19080.082x^{-0.288}$	0.929
	BRA Modified	2000	$y = 19812.853x^{-0.316}$	0.914
	BRA Modified	3000	$y = 20146.454x^{-0.328}$	0.853
40	Control	1000	$y = 4152.254x^{-0.508}$	0.939
	Control	2000	$y = 2577.166x^{-0.412}$	0.787
	Control	3000	$y = 2286.208x^{-0.389}$	0.749
	BRA Modified	1000	$y = 6898.153x^{-0.438}$	0.924
	BRA Modified	2000	$y = 5559.128x^{-0.411}$	0.963
	BRA Modified	3000	$y = 5271.487x^{-0.405}$	0.954
60	Control	1000	$y = 348.243x^{-0.221}$	0.585
	Control	2000	$y = 370.539x^{-0.249}$	0.550
	Control	3000	$y = 415.445x^{-0.290}$	0.648
	BRA Modified	1000	$y = 824.259x^{-0.258}$	0.817
	BRA Modified	2000	$y = 726.250x^{-0.237}$	0.762
	BRA Modified	3000	$y = 677.955x^{-0.233}$	0.878

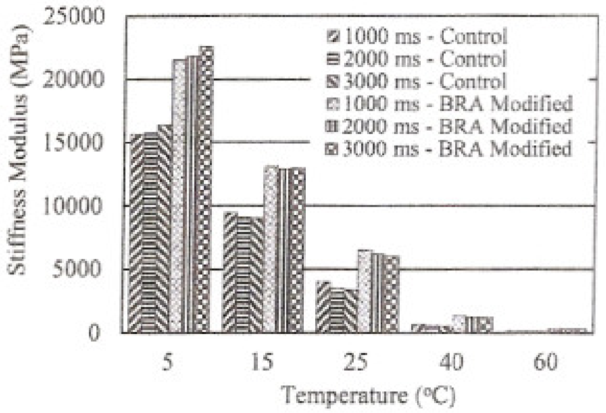

Figure 2. ITSM values for asphalt mixtures at a rise time of 40 ms.

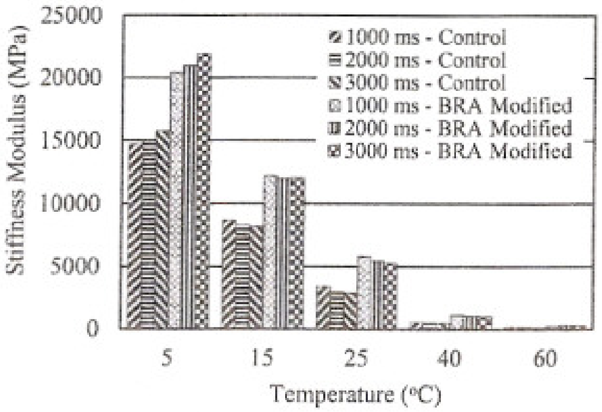

Figure 3. ITSM values for asphalt mixtures at a rise time of 60 ms.

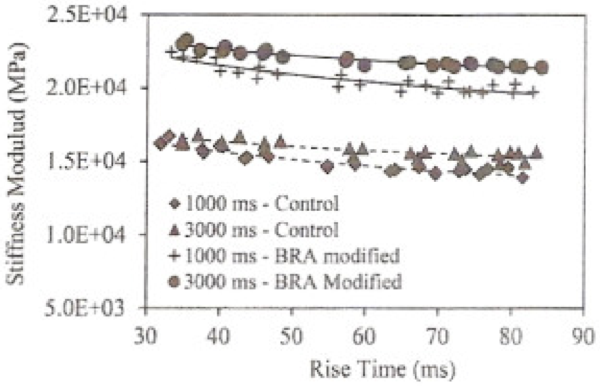

Figure 5. ITSM values for asphalt mixtures at test temperature of 5°C.

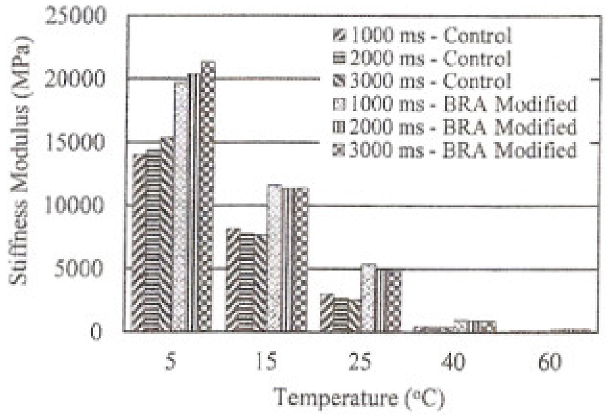

Figure 4. ITSM values for asphalt mixtures at a rise time of 80 ms.

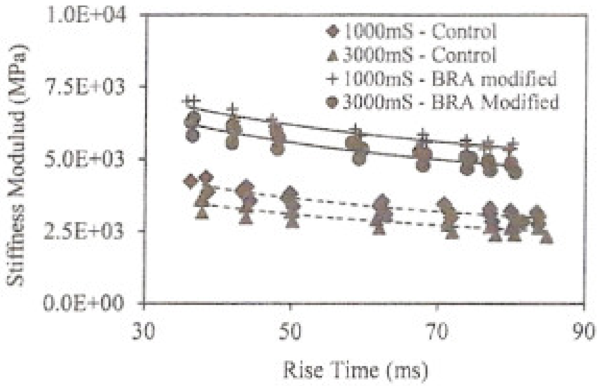

Figure 6. ITSM values for asphalt mixtures at a test temperature of 25°C.

Figures 2 to 4 present ITSM values for mixtures at any level of temperature, rise time and pulse repetition period. The ITSM results for control and BRA modified asphalt mixtures decreased with increasing temperature at all levels of rise time and pulse repetition periods. The ITSM values in BRA modified asphalt mixtures increased and was significantly higher at all levels of temperature, rise time and pulse repetition periods compared to control mixtures.

The ratio of the ITSM values from the BRA modified and the control asphalt mixtures was increased when the temperature increased. At the same rise time and pulse repetition period, the ITSM values of BRA modified were between 38% and 126% higher than that of the control asphalt mixtures.

It can be seen that the ITSM values for both mixtures were affected most by temperature. The ITSM values were decreased as much as 85% and 82% for control and BRA modified asphalt mixtures respectively in between two adjacent test temperatures. At the same rise time and repetition period, the decrease in the value of ITSM for control asphalt mixtures was between 2% and 3% higher than that of BRA modified asphalt mixtures, except for the change in temperature from 40°C to 60°C.

Pulse repetition period also affected the ITSM values. Figure 5 shows that at 5°C, control and BRA modified asphalt mixtures with pulse repetition period of 3000-ms had ITSM values higher than that of asphalt mixtures with pulse repetition period of 1000 ms. ITSM values for both asphalt mixtures at the same level of rise time increased up to 9.4% with increasing pulse repetition period from 1000 to 3000 ms. In contrast, at other test temperatures, the ITSM values for both asphalt mixtures with pulse repetition period of 3000 ms were lower than that of asphalt mixtures with pulse repetition period of 1000 ms. The ITSM values for both asphalt mixtures decreased up to 15.4% with increasing pulse repetition period from 1000 to 3000 ms, as presented in Figure 6.

The ITSM results for control and BRA modified asphalt mixtures decreased with increasing rise time at any level of test temperature and pulse repetition period. The change in rise time from 40 to 80-ms decreased ITSM values up to 29.7% and 26.2% for control and BRA modified asphalt mixtures respectively. The decrease in ITSM values due to the increase in rise time for BRA modified was lower than that for control asphalt mixtures at any test temperature and the same pulse repetition period.

4 CONCLUSIONS

Based on the testing result, the substitution of 20% of a base asphalt binder with a natural binder, containing a granular BRA modifier binder, resulted in an increase in ITSM values for the BRA modified asphalt mixtures, indicating that the cracking resistance for BRA modified mixtures increased.

The ITSM values for the control and BRA modified asphalt mixtures were affected by any level of temperature, rise time and pulse repetition period. However, the ITSM values for both asphalt mixtures were most affected by the temperature. The increase in temperature resulted in a decrease of the ITSM values for both mixtures. The ITSM results for BRA modified were higher than for control asphalt mixtures at any testing level temperature. A higher of test temperature resulted in an increase in the ratio of ITSM values of BRA modified and control asphalt mixtures increased.

The pulse repetition period also affected the ITSM results for control and BRA modified asphalt mixtures. However, the change in the ITSM values due to a change in the pulse repetition period is different for any given temperature. The increase in the pulse repetition period from 1000 ms (high trafficked volume roads) to 3000 ms (low trafficked volume roads), resulted in increase of the ITSM values for both the control and the BRA modified asphalt mixtures at a test temperature of 5°C, while at any other test temperature, the value decreased. Moreover, the increase in the rise time from 40 ms (high speed) to 80 ms (low speed) resulted in decreased ITSM values for both the control and the BRA modified asphalt mixtures at any level of test temperature and pulse repetition period.

ACKNOWLEDGEMENTS

The first author is grateful for financial support from the Directorate of Higher Education (DIKTI) – Indonesian Ministry of Education within the scholarship programme, and for the support received in undertaking this research from the University of Lampung, Indonesia. The authors acknowledge Mr. Arief Santoso of Olah Bumi Mandiri Pty Ltd. for supplying the granular BRA modifier binder for this project. Acknowledgement must also be made of the Curtin Geomechanics and Pavement Laboratory for providing laboratory equipment, aggregate and bitumen materials during the research.

REFERENCES

Affandi F. 2012. The performance of bituminous mixes using Indonesia natural asphalt. *25th ARRB Conference*, Perth, Australia: 1–12.

Ahmedzade P. & Sengoz B. 2009. Evaluation of steel slag coarse aggregate in hot mix asphalt concrete. *Journal of Hazardous Materials* 165: 300–305.

Hartman A.M, Gilchrist M.D. & Walsh G. 2001. Effect of mixture compaction on indirect tensile stiffness and fatigue. *Journal of Transportation Engineering* (127) 5: 370–378.

Main Roads Western Australia (MRWA) standards. 2010. Specification 504 Asphalt Wearing Course: 1–45.

Main Roads Western Australia (MRWA) standards. 2011. WA 730.1-2011: Bitumen Content and Particle Size Distribution of Asphalt and Stabilised Soil-Centrifuge Method: 1–4.

Mokhtari A & Nejad F.M. 2012. Mechanistic approach for fiber and polymer modified SMA mixtures. *Journal of Construction and Building Materials* 36: 381–390.

Silva H, Pais J, Pereira P. & Picardo-Santos L. 2003. Evaluation of the bond between mastic and coarse aggregates. *3rd International Symposium on Maintenance and Rehabilitation of Pavement and Technological Control, Guimaras, Portugal*: 465–474.

Standards Australia. 2008. AS 2008-Residual Bitumen for Pavements.

Standard Australia. 1995. AS 2891.2.2-1995: Method of Sampling and Testing Asphalt-Sample Preparation-Compaction of Asphalt Test Specimens Using a Gyratory Compactor: 1–8.

Standard Australia. 1995. AS 2891.13.1-1995: Methods of sampling and testing asphalt-Method 13.1: Determination of resilient modulus of asphalt-Indirect tensile method: 1–8.

Subagio B.S, Siswosoebrotho B.I. & Karsaman R.H. 2003. Development of laboratory performance of Indonesian rock asphalt (Asbuton) in hot rolled asphalt mix. *Proceedings of the Eastern Asia Society for Transportation Studies* 4: 436–449.

Subagio B.S, Karsaman R.H, Adwang J. & Fahmi I. 2005. Fatigue performance of HRA (hot rolled asphalt) and superpave mixes using Indonesian rock asphalt (asbuton) as fine aggregates and filler. *Journal of the Eastern Asia Society for Transportation Studies* 6: 1207–1216.

Tayfur S, Ozen H. & Aksoy A. 2007. Investigation of rutting performance of asphalt mixtures containing polymer modifiers. *Journal of Construction and Building Materials* 21: 328–337.

Wang H, Al-Qadi I.L, Faheem A.F, Bahia H.U, Yang S.H. & Reinke G.H. 2011. Effect of mineral filler characteristicson asphalt mastic and mixture rutting potential. *In Transportation Research Record: Journal of the Transportation Research Board* 2208: 33–39.

Yilmaz, M. & Celoglu, M.E. 2013. Effects of SBS and different natural asphalts on the properties of bituminous binders and mixtures. *Journal of construction and Building Materials* 44: 533–540.