THE EFFECT OF BITUMEN RHEOLOGY TO THE PERMANENT DEFORMATION OF AN ASPHALT CONCRETE MIXTURE

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This work is dedicated to
my beloved husband, ROHMEN HJ. TASARIB,
Also to my kids, ALIF RAHIMI and ADHAM RAFIQI,
For the love, patience, understanding and invaluable support……………

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ABSTRACT

Bitumen which functions as a binder in asphalt concrete mixture is also a visco-elastic and thermoplastic material. The characteristics are also influence by the temperature. It is because in hot condition or at high temperature, bitumen acts like a viscous liquid. In cold climate or at low temperature, bitumen behaves like an elastic solid. Even though bitumen is an elastic solid at low temperatures, it may become too brittle and crack when excessively loaded. However, the characteristic of an asphalt concrete are influenced by the rheology of bitumen which having two important properties; resistance to permanent deformation and fatigue. In this study, the most important thing to measure is the rheology of two different types of bitumen. The measurement was done using the Dynamic Shear Rheometer to obtain the visco-elastic properties of bitumen. The bitumen was then used in preparing an asphalt concrete mixture in order to test the rutting or permanent deformation using the Static Creep test. An analysis was done to verify the correlation between the rheology of two different types of bitumen and the rate of permanent deformation of the asphalt concrete mixture. Results obtained showed that both bitumens having a different rheology. Moreover, rutting parameter, $G^*/\sin \delta$ could predict the different of creep performance. However, bitumen with identical value of $G^*/\sin \delta$ at a different temperature would not necessarily produce mixture with the same creep compliance under the related temperature. Therefore, for further study it is recommended to focus on the load effect to the creep compliance.

ABSTRAK

Bitumen yang berfungsi sebagai bahan pengikat di dalam campuran konkrit asfalt juga merupakan suatu bahan yang *visco-elastic* dan *thermoplastic*. Sifat-sifatnya juga banyak dipengaruhi oleh suhu. Ini kerana dalam keadaan suhu yang tinggi atau cuaca panas, bitumen bertindak seperti cecair yang likat. Pada cuaca yang sejuk atau pada suhu yang rendah pula, bitumen akan menjadi bahan anjal yang padat. Walaupun bitumen adalah merupakan bahan anjal yang padat pada suhu rendah, ia boleh menjadi terlalu rapuh dan retak apabila dikenakan beban yang banyak atau melampau. Walau bagaimanapun, ciri-ciri campuran konkrit asfalt lebih dipengaruhi oleh reologi (sifat perubahan bentuk bahan akibat tegasan) bitumen yang mana mempunyai dua ciri penting iaitu ketahanan terhadap perubahan bentuk yang kekal akibat kesan roda atau tayar kenderaan dan ciri lesunya. Di dalam projek ini, perkara penting yang diukur adalah reologi daripada dua jenis bitumen yang berbeza. Pengukuran dilakukan menggunakan peralatan *Dynamic Shear Rheometer* untuk mendapatkan ciri-ciri anjal dan likat bitumen terbabit. Selanjutnya, bitumen tersebut digunapakai untuk membuat sampel campuran konkrit asfalt untuk menguji ciri-ciri ketahanannya terhadap perubahan bentuk yang kekal menggunakan ujikaji *Static Creep*. Suatu analisis telah dibuat untuk menjelaskan hubungkait antara reologi bitumen dan ciri-ciri perubahan bentuk yang kekal campuran konkrit asfalt tersebut. Keputusan daripada ujikaji yang telah dibuat menunjukkan bahawa kedua-dua jenis bitumen mempunyai reologi yang berbeza. Seterusnya, parameter lekukan turapan , $G^*/\sin\delta$ dapat menggambarkan perubahan dalam *creep performance.* Walau bagaimanpun, bitumen yang mempunyai nilai $G^*/\sin\delta$ yang sama pada suhu yang berbeza belum tentu dapat menghasilkan campuran konkrit dengan nilai *creep performance* yang sama. Maka, untuk kajian yang akan datang adalah dicadangkan agar kajian kesan daripada beban terhadap *creep performance* dapat dilakukan.

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LIST OF ABBREVIATIONS AND SYMBOLS

δ	-	phase angle of asphalt binder
G*	-	complex shear modulus of asphalt binder
ε_f	-	failure strain
ΔL	-	change in length
σ	-	stress
S_{mix}	-	mix stiffness
S_{bit}	-	bitumen stiffness
ASTM	-	American Standard for Testing Material
BTDC	-	Bitumen Test Data Chart
DMA	-	Dynamic Mechanical Analysis
DSR	-	Dynamic Shear Rheometer
HMA	-	Hot Mix Asphalt
OBC	-	Optimum Bitumen Content
PI	-	Penetration Index
RMB	-	Rubber Modified Binder
RTFO	-	Rolling Thin Film Oven
SHRP	-	Strategic Highway Research Program

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CHAPTER I

INTRODUCTION

1.1 Introduction

Pavement design is essentially a structural evaluation process, ensuring that the traffic loads are so distributed that the stresses and strains developed at all levels in the pavement and the subgrade are within the capabilities of the materials at those levels. The objective of pavement design is to produce an engineering structure that will distribute traffic loads efficiently, whilst minimizing the whole-life cost of the pavement, i.e both initial construction and maintenance costs. It involves the selection of materials for the different layers and the calculation of the required thickness. The load-carrying capacity of a pavement is a function of both the thickness of the material and its stiffness.

The mechanical properties of the materials comprising the layers in a pavement are important for designing the structure. Climatic conditions influence the performance of the whole pavement. Moisture affects the subgrade, sub-base or unbound base and the temperature affects the bitumen-bound materials; therefore it is essential that design methods take account of climatic conditions.

It is generally accepted that a well-designed, well-constructed, modern trunk road pavement should at least meet the following basic performing criteria:

a. The finished carriageway should have good skid resistance and provide the motorist with a comfortable and safe ride,
b. The pavement should be able to carry its design traffic without excessive deformation
c. Its component layers should not crack as a result of the stresses and strains imposed on them by heavy commercial vehicles or climatic conditions
d. A pavement's foundation (including its subbase and any capping layer that might be required to protect the subgrade) should have enough load-spreading capability for it to provide a satisfactory platform for construction vehicles whilst the road is being built.

Bituminous pavement is one of the most popular method used in the construction of new road pavements. This is because some advantages claimed for bituminous pavements generally include the following, when compared with concrete pavements (O'Flaherty, 1967):

a. In new major roads, bituminous surfacings generally provide a better riding quality when opened to traffic, especially if the transverse joints in the concrete slab are closely spaced and not well formed.
b. Bituminous surfacings are traditionally considered to be quieter and are preferred for use in locales where noise is deemed a problem. (However, a low noise concrete paving has now been developed that gives a much quieter ride)
c. Bituminous pavements can be opened to traffic as soon as compaction is completed and the surfacings have cooled to the ambient temperature, whereas concrete ones formed from conventional mixes cannot be opened until they have gained sufficient strength. (However, it should be noted that 'fast-track' process has now been developed which uses rapid-hardening cement in association with high-temperature curing to allow concrete pavements to be opened to traffic within 12 hours of their construction).

Increased traffic factors such as heavier loads, higher traffic volume and higher tire pressure demand higher performance pavements. Truck loading is increasing worldwide, resulting in more permanent deformation of asphalt concrete pavements. It is therefore necessary to ensure pavements can withstand this loading without rutting, which requires improvements to mix design and analyses. The effects of different tyre types were found to have significant effect on the development of rutting.

A higher performance pavement requires bitumen that is less susceptible to high temperature rutting or low temperature cracking and has excellent bonding to stone aggregates. The chemical composition of the bitumen has a significant effect on its visco-elastic properties and hence on its performance as road paving materials in asphalt concrete mixture.

With increasing traffic loadings and more demanding performance requirements, the need to be able to predict long-term behavior is essential. Performance on the road depends on many factors including the design, application and the quality of the individual components. The most important pavement materials are bitumen and tar, cement and lime, soil and rock, gravel and slag aggregates. Although bitumen is, in terms of its volume, a relatively minor component of a bituminous mix, it has a crucial role acting as a durable binder and conferring visco-elastic properties to the mix. Satisfactory performance of bitumen on the road can be ensured if four properties are controlled. Those properties are rheology, cohesion, adhesion and durability.

Highway engineers recognized that improved durability would be achieved using dense, impermeable mixes. The gradual increase in the use of BS 594 rolled asphalt for trunk roads and the development of dense bitumen macadam, which first appeared in the 1961 edition of BS 1621, reflected this awareness. Since the mid sixties both the volume and axle weight of vehicles on the roads in the United Kingdom have increased dramatically, and in the early seventies it was realized that recipe mixes, which had hitherto given long and satisfactory performance, were deforming under the increasing numbers of heavier vehicles.

Therefore, bituminous mixes have to fulfill a wide range of requirements for today's traffic, in particular the ability to:

1. resist permanent deformation
2. resist fatigue cracking
3. be workable during laying, enabling the material to be satisfactorily compacted with the available equipment
4. be impermeable, to protect the lower layers of the road from water
5. be durable, resisting abrasion by traffic and the effects of air and water
6. contribute to the strength of the pavement structure
7. be easily maintained and most importantly, must be cost-efective.

In addition to the above, wearing course materials must also fulfill the following tyre/pavement interaction requirements:

1. provide a skid-resistant surface under all weather conditions
2. have an acceptable level of rolling resistance
3. provide a surface which under trafficking, produces an acceptable
4. provide a surface of acceptable riding quality

In 1987, Congress established the Strategic Highway Research Program (SHRP) to sponsor several coordinated research projects that were directed at improving the performance and durability of roads in United States. From October 1987 through March 1993, a $50 million Strategic Highway Research Program (SHRP) project was conducted to develop new ways to specify, test and design asphalt paving materials. The results of this research effort are collectively referred to as 'Superpave' (Kennedy et. al., 1994). The percentages of hot-mix asphalt projects designed using the Superpave system over the past four paving seasons are shown in Figure 1.1 below. From 1996 to 1999, the percent of projects designed using the Superpave system increased from one percent (1%) to 41 percent (41%).

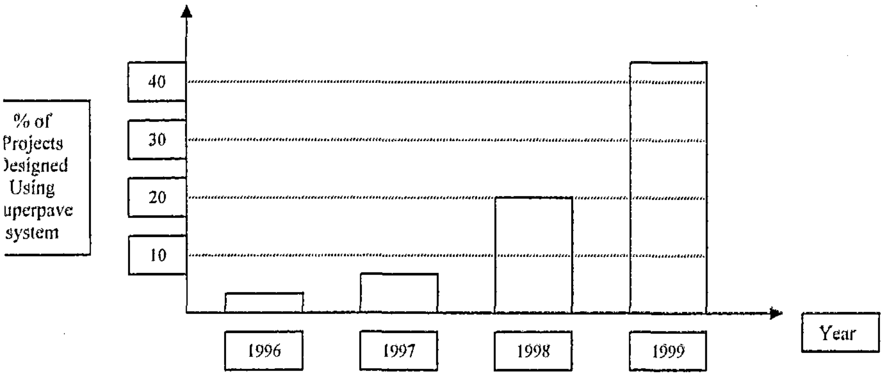

Figure 1.1 Propotion of Hot-Mix Asphalt Project Designed using the Superpave System (Dunn, 1999)

Though the use of Superpave mix design procedures are becoming more and more common, it has always been felt that there was a need for a strength test to validate the volumetric mix design procedure. A good strength tests mould serve to calm the fears of concerned agencies and contractors. The static creep test is one such test that could be used to validate the Superpave volumetric mix design procedures.

1.2 Statement of Problem

The performance of bitumen-bound mixes in practice is significantly influenced by the rheological (or mechanical) properties and to a lesser extent the chemical constitution of the bitumen. The latter is particularly important at the road surface because the constitution of the bitumen influences the rate of oxidation of thereby how rapidly the bitumen is eroded by traffic. These factors are, in turn, influenced by changes due to the effect of air, temperature and water on the bitumen. There are, of course, many factors influencing behavior, including the nature of the aggregate, mix composition, bitumen content (ie bitumen film thickness), degree of compaction, etc, all of which influence long term durability.

Using the Static Creep test method, it will explain the performance of an asphalt concrete mix design specimen through the creep behavior response to the stress. Furthermore, the result obtain from the Static Creep test will show the relationship between deformation and time.

1.3 Objectives of Study

This study aims to investigate the effect of bitumen rheology on the rate of permanent deformation of an asphalt concrete mixture. Specifically this study aims to:-

a. Determine and compare the rheology of two different types of bitumen in terms of visco-elastic properties of the bitumen
b. Measure the rate of permanent deformation of an asphalt concrete mixture using two different types of bitumen
c. Verify the relationship between the rheology of two different types of bitumen and the rate of permanent deformation of an asphalt concrete mixture.

1.4 Scope of Study

This study is to investigate and cover the effect of bitumen rheology compared to the permanent deformation of an asphalt concrete mixture. The scope of study is more to:

a. Conditioning the characteristic of bitumen using Penetration test, Softening Point test and Viscosity test
b. Simulate binder aging (hardening) characteristic using Rolling Thin Film Oven test

REFERENCES

1. Asphalt Institute, "Performance Graded Asphalt Binder Specification and Testing". Superpave Series No. 1 (SP-1), USA.

2. Asphalt Institute, (1996): "Superpave Mix Design". Superpave Series No. 2 (SP-2), USA.

3. Goodrich, J.L, (1991): "Asphaltic Binder Rheology, Asphalt Concrete Rheology and Asphalt Concrete Mix Properties". Asphalt Paving Technology, Journal of the Association of Asphalt Paving Technologists, Volume 60, Seattle, Washington. 80 – 120.

4. Schramm, G., (1994): "A Practical Approach to Rheology and Rheometry". HAAKE Rheometers, Federal Republic of Germany.

5. Brennan, M.J. and O'Flaherty, C.A, (2002): "Materials Used in Road Pavements". Highways: The Location, Design, Construction and Maintenance of Pavements. Fourth Edition, Butterworth Heinemann, India. 118 – 159.

6. Johanson, L. S., (1998): "Bitumen Ageing and Hydrated Lime". Kungliga Tekniska Hogskolan, Sweden. (PhD Doctoral Thesis). 131 pg.

7. Smith, R., and James, B., (2001): "Low Temperature and Dynamic Fatigue Toughening Mechanism in Asphalt Mastics and Mixtures". Queen's University at Kingston, Canada.

8. Butcher, M. J, (1994): "Test Procedures, Mix Design and Specification Requirements to Counter Deformation and Rutting of Asphalt in Heavily Trafficked Situations". 9th AAPA International Asphalt Conference. Conference Proceedings, Volume Two, Conrad Jupiters, Surfers Paradise, Queensland Australia.

9. Kinder, D.F, (1986): "A Study of Both The Visco-elastic and Permanent Deformation Properties of A New South Wales Asphalt". 13th ARRB – 5th REAAA Combined Conference: Materials

10. Harvey, J. and Monismith, C.L, (1992): "Effects of Laboratory Asphalt Concrete Specimen Preparation Variables on Fatigue and Permanent Deformation Test Results Using Strategic Highway Research Program A-003A Proposed Testing Equipment". Transportation Research Record No. 1417, (1993): Materials and Construction: Asphalt Concrete Mixture. Transportation Research Board, National Research Council.

11. Little, D.N., Button, J.W., Youseff, H., (1986): "Development of Criteria To Evaluate Uniaxial Creep Data and Asphalt Concrete Permanent Deformation Potential". Transportation Research Record No. 1417, (1993): Materials and Construction: Asphalt Concrete Mixture. Transportation Research Board, National Research Council.

12. Whiteoak, D. (1990): "Shell Bitumen Handbook". Shell Bitumen UK, London.

13. Robert, M. A, Khandal, P. S., Brown, T. W. and Kennedy, M. S., (1996): "Hot Mix Asphalt Materials Mixture Design and Construction". 2nd ed. Lanham, Maryland: NAPA Education Foundation.

14. Mohd Rehan Karim, Meor Othman Hamzah dan Asri Hassan, (1991): "Pengenalan Pembinaan Jalanraya Berbitumen". Edisi 1, Dewan Bahasa dan Pustaka, Kementerian Pendidikan Malaysia, Ampang, Selangor.

15. Tayebali, A.A, Goodrich, J.L, Sousa, J.B and Monismith, C.L, (1991): "Relationship Between Modified Asphalt Binders Rheology and Binder-Aggregate Mixture Permanent Deformation Response". Asphalt Paving Technology, Journal of the Association of Asphalt Paving Technologists, Volume 60. Seattle, Washington. 121 – 159

16. Australian Provisional Guide, Revision No. 1, (1998): "Selection and Design of Asphalt Mixes". APRG Report No. 18, Austroads in partnership with ARRB Transport Research, Australian Asphalt Pavement Association (AAPA), Vermont South, Australia.

17. Weng, O. T., (1999): "Development and Use of Static Creep Test to Evaluate Rut Resistance of Superpave Mixes". University of Texas at Austin, (phD thesis).

18. Brown, E.R, Kandhal, P.S. and Zhang, J., (2001): "Performance Testing For Hot-Mix Asphalt". National Center for Asphalt Technology (NCAT) Report 01 – 05, Auburn University, Alabama.

19. Kuo, C.Y., (2002): "Correlating Permanent Deformation Characteristics of Hot Mix Asphalt in Aggregate Geometric Irregularities". Journal of Testing and Evaluation, Volume 30, Issue 2 (March 2002).

20. Zhang, J., Cooley Jr., L.A. and Kandhal, P.S., (2002): "Comparison of Fundamental and Simulative Test Methods for Evaluating Permanent Deformation of Hot-Mix Asphalt". National Center for Asphalt Technology (NCAT) Report 02-07, Auburn University, Alabama.

21. Mang, T., Ruth, B. and Roque, R., (2001): "Development of Relationship between SHRP Asphalt Test Parameters and Structural Mixtures of Mechanistic Analysis and Rehabilitation Design of Flexible Pavement". The University of Florida.

22. Anderson, D.A., Christensen, D.W. and Bahia, H., (1991): "Physical Properties of Asphalt Cement and The Development of Performance-Related Specifications". Asphalt Paving Technology, Journal of the Association of Asphalt Paving Technologists, Volume 60. Seattle, Washington. 437 - 475

23. O'Carroll, K. T. and Josephine, B., (2000): "Factors Affecting Bitumen Recovery From Oil Sand". University of Ottawa, Canada. 116 pg.

24. Asphalt Institute, (1989): "The Asphalt Handbook : Manual Series No. 4". (MS-4), 1989 Edition.

25. Kett, I. P., (1989): "Asphalt Materials and Mix Design Manual". California State University, Los Angeles, California. Noyes Publications, Westwood, New Jersey, U.S.A

26. Huang, H.Y., (2004): "Pavement Analysis and Design". University of Kentucky, Pearson, Prentice Hall.

27. Asphalt Institute, (2003): "Construction of Hot-Mix Asphalt Pavements". Manual Series No. 22, Second Edition. Research Park Prive, Lexington.

28. David, C., (1977): "The Design and Performance of Road Pavements". Department of Transport, Transport and Road Research Laboratory, HMSO, London.

29. AASHTO, (1986): "Guide for Design of Pavemenr Structure: 1986". American Association of State Highway and Transportation Officials, Washington D.C.

30. Abd El Halim, A.O., (1990): "Field and Laboratory Evaluation of a New Compaction Technique". Civil Engineering Department, Carleton University, Ottawa, Canada.

31. Svec, O.J., (1990): "Field and Laboratory Evaluation of a New Compaction Technique". Institute for Research in Construction, National Research Council, Ottawa, Canada.

32. IKRAM, (1994): "Interim Guide To Evaluation and Rehabilitation of Flexible Road Pavements". IKRAM Cawangan Jalan, IKRAM Series (Pavement) ISP-2.

33. Manke, P.G., (1970): "Asphalt Mix Design Procedures". A Laboratory Manual for CIVEN 5653. Technical Publication No. 17. Stillwater: Oklahoma State University.

34. Standards Australia, (1995): "Determination of the Permanent Compressive Strain Characteristics of Asphalt – Dynamic Creep Test". Method 12.1. AS 2891.12.1 (Standards Association of Australia)

35. Oliver, J.W.H., Alderson , A.J, Treadrea, P.F. and Karim, M.R., (1995): "Results of the Laboratory Program Associated with the ALF Deformation Trial". APRG Report No. 12 (ARR 272) (ARRB TR: Vermont South, Vic.)

36. AUSTROADS, (1992): "Pavement Design – A Guide To the Structural Design of Road Pavements". AUSTROADS AP 17/92 (ARRB TR: Vermont South, Vic)

37. Sousa, J.B., Craus, C. and Monismith, C.L., (1991): "A Summary Report on Permanent Deformation in Asphalt Concrete". SHRP-A/IR-91-104 (National Research Council)

38. Nievelt, G. and Thamfald, H., (1987): "Evaluation of the Resistance to Deformation of Different Road Structures and Asphalt Mixtures Determined by the Pavement-Rutting Tester". Symposium: Effect of Mix Properties on Structural Design, Pennsylvania.

39. O'Flaherty, C. A., (1967): "Highway: The Location, Design, Construction and Maintenance of Pavements". Fourth Edition (2002), Butterworth-Heineman, New Delhi, India. 225 – 242

40. Gordon, F. H., Navneet, G. and May, D., (2004): "Permanent Deformations During Traffic Tests on Flexible Pavement Test Facility". Journal of Transportation Engineering, American Society of Civil Engineering (ASCE). Pp. 147 - 169