PERFORMANCE OF MICRO SURFACING ON EXPRESSWAY

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ABSTRACT

Micro surfacing is developed from slurry seal technique. It is a mixture of polymer modified bitumen emulsion with 9.5 mm chipping, quarry dust, cement, additive and water. The emulsion used in micro surfacing is CQS-1h and added with natural latex as its polymer modifier. This study was carried out to evaluate the performance of micro surfacing applied on expressway. In 2008, a number of preventive maintenance projects in North South Expressway used micro surfacing especially in the northern region. This study involved particular sections of expressways located at km 58.60 to km 59.60 south bound and km 84.60 to km 85.60 south bound from Bukit Kayu Hitam. The construction was completed on 7th January 2009. The performance of micro surfacing in this specific expressway sections was monitored for one year. The Portable Pendulum Tester was used to evaluate skid resistance performance while the texture depth of micro surfacing was measured using Sand Patch Test. The surface irregularities data was collected using a 3 m rolling straight edge while the rutting measurement was based on 3 m static straight edge. The measurement was carried out after 4, 6, 9 and 12 months period of operations starting from April 2009 to January 2010. The result shows that the skid resistance, texture depth, surface irregularities and rut depth for micro surfacing comply with the specification requirements after one year of operation. The pendulum test value obtained is greater than 46 with a texture depth of 0.50 mm. The average number of surface irregularities is below 4.0 mm while the rut depth average value is less than 5.0 mm.

ABSTRAK

Micro surfacing merupakan satu teknik penyelenggaraan jalan yang diubahsuai daripada teknik *Slurry Seal*. Ia merupakan campuran bitumen emulsi terubahsuai polimer bersama batu baur bersaiz 9.5 mm, habuk kuari, simen, bahan tambahan dan air. Emulsi yang digunakan di dalam *Micro Surfacing* adalah CQS-1h yang telah ditambah getah asli untuk menjadikan ianya sebagai polimer. Kajian ini telah mengkaji prestasi *Micro Surfacing* di lebuhraya. Pada tahun 2008, banyak projek penyelenggaraan yang berkonsepkan pencegahan menggunakan teknologi *Micro Surfacing* dilaksanakan di Lebuhraya Utara Selatan terutama di bahagian utara. Kajian ini melibatkan beberapa seksyen iaitu di km 58.60 ke km 59.60 arah selatan dan km 84.60 ke km 85.60 arah selatan dari Bukit Kayu Hitam. Pembinaan ini telah disiapkan pada 7 Januari 2009. Prestasi *Micro Surfacing* di kawasan tersebut dipantau selama setahun. Alat ujian pendulum digunakan untuk mengkaji prestasi rintangan gelinciran dan kedalaman tekstur diukur menggunakan kaedah ujian tampalan pasir. Data kekasaran permukaan diperolehi dari pengukur 3 m pinggir lurus bergerak dan aluran diukur menggunakan pengukur 3 m pinggir lurus statik. Pengukuran ini dilaksanakan selepas 4, 6, 9 dan 12 bulan beroperasi, bermula pada April 2009 sehingga Januari 2010. Keputusan ujian mendapati rintangan kegelinciran, kedalaman tekstur, kekasaran permukaan dan kedalaman aluran mematuhi kehendak spesifikasi selepas setahun beroperasi. Nilai ujian pendulum lebih daripada 46 dan kedalaman tekstur melebihi 0.50 mm. Purata tahap kekasaran permukaan kurang daripada 4.0 mm dan purata kedalaman aluran kurang daripada 5.0 mm.

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LIST OF ABBREVIATION

PWD	-	Publics Works Department
USA	-	United States of America
IKRAM	-	Institut Kerja Raya Malaysia
HMA	-	Hot Mix Asphalt
ACW	-	Asphaltic Concrete Wearing
L	-	Low
M	-	Medium
H	-	High
ADT	-	Annual Daily Traffic
ADCV	-	Annual Daily Commercial Vehicle
SO	-	Superintendent Officer
BPN	-	British Pendulum Number
TRRL	-	Transport and Expressway Research Laboratory
IRI	-	International Roughness Index
ISSA	-	International Slurry Surfacing Association
MB	-	Methylene Blue
MT	-	Mixing Time
ST	-	Setting Time
WTAT	-	Wet Track Abrasion Test
PTV	-	Pendulum Test Value
RHS	-	Right Hand Side
COL	-	Centre of Lane
LHS	-	Left Hand Side
GTN	-	Grip Tester Number
SRV	-	Skid Resistance Value

TD	-	Texture Depth
FI	-	Flakiness Index
ACV	-	Aggregate Crushing Value
AIV	-	Aggregate Impact Value
LAAV	-	Los Angeles Abrasion Value
AC	-	Asphaltic Concrete

CHAPTER 1

INTRODUCTION

1.1 Introduction

Road plays an important role in the communication system of mankind. Rutting, corrugation, cracks, surface deformation, surface defects and pothole were the common problems found in Malaysian roads. All these deformation will lead to an uncomfortable riding quality to the road user. To ensure that the road is always in a good condition, a substantial amount of money has been spent for the purpose of maintenance.

Over the years, The Malaysian Government through the Public Works Department (PWD) has spent huge amount of money to ensure the roads are in good operating condition. In year 1998, about RM 139 million was allocated for the maintenance of the Federal Roads. The allocated fund was very much below than what was required (RM 369 million) to maintain the Federal Roads (Abdul Hamid et. al., 2005). PWD Malaysia had spent more than RM 500 millions every year since 2004 to 2010 (Hamzah, 2010). PWD Malaysia had allocated RM 900 million for the maintenance of 13, 000 kilometers of road throughout the country (Bernama, 2010). The current high maintenance cost is because of deteriorated roads which require rehabilitation works. Severe road deterioration which require major rehabilitation

works, will lead to a high cost of maintenance. Therefore, prevention is the best solution to this problem.

Road pavement structures consist of layers of material constructed between the surface of the road and the ground. Its main purpose is to support traffic loading and each layer has its own specific role in resisting the loading so that the forces exerted by the traffic will not exceed the capabilities of the materials at the respective layers. A failure from each layer will influence another layer to fail.

From the perspective of the road user, the attention will normally focus on the road surface. The road user is ignorant of what lies below the road. The contractor would at least expect the road surface to have a safe and smooth riding quality.

For the road to perform functionally and structurally, a durable, water proof, skid resistance and dust-free surfaces are required. This is necessary in order to provide the road user with an acceptable level of service and to protect the structural layers of the road from abrasive forces of traction from traffic and from the effect of the environment.

Roads should be maintained and upgraded with new types of maintenance treatments. Micro surfacing is a one of the preventive maintenance methods in Malaysia which can solve the problem of surface deformation and defect. Micro surfacing is a high performance, safe and cost effective maintenance technique.

1.2 Background of Problem

Almost all roads in our country used flexible pavements. The main problems that always occurred on the flexible pavements are surface deformation and surface defects. It is important that the flexible pavements meet the requirements of pavement performance goals. Once the construction of the pavement work is completed, it is most essential to implement pavement preventive maintenance that

emphasizes keeping roads in good condition through early application of maintenance treatment.

Several problems of the flexible pavement surface include rutting, low skid resistance and surface irregularity. A lot of studies have been carried out on examining the performance of conventional asphalt concrete pavement, yet only a few studies had been conducted for micro surfacing. The main reason is that the application of micro surfacing is still new in Malaysia.

Micro surfacing is defined as a modified version of slurry seal (PWD Malaysia, 2008) and was introduced in Canada in the early 1990s. Micro surfacing is used to restore the pavement surface characteristics and to preserve pavement surfacing. This surfacing mixture can be designed to correct rutting, improve skid resistance, seal surface cracks, and protect pavement surfacing against hardening and improve surface texturing. Hixon (1993) recommends that micro surfacing is used for filling ruts, re-establishing transverse profile of an asphalt roadway, restoring pavement friction characteristic and filling wide depression and alligator cracks. For that reason, Malaysia has been using micro surfacing since 2008. In Malaysia, micro surfacing has been used to improve skid resistance and to prolong a pavement's life span. Since micro surfacing is a new type of surface pavement in Malaysia, this study was carried out to examine the performance of micro surfacing under Malaysian condition.

Micro surfacing has been proven to be effective in filling ruts, reducing the amount of original rate of rutting by 40 percent, and in substantially increasing the friction characteristic of the pavement for 9 years (Hixon, 1993). In a study by Bradbury and Kazmierowaski (1994), it has been shown that after three years of operation, the roughness of micro surfacing is still within the smooth range, with no apparent loss of frictional properties and no signs of instability.

The purpose of any quality management program is not only to ensure that the product meets the contract requirements but also to ensure that the product is constructed in a manner that permits it to perform as designed. In U.S. and Canada,

the common microsurfacing distresses are crack reflection, streaking, ravelling, delamination, bleeding, badly constructed joint and corrugation (Gransberg, 2010). Since micro surfacing is new in Malaysia, this study is important to evaluate the problem and performance of micro surfacing in Malaysia.

1.3 Objectives of Study

This study will determine the performance and effectiveness of type III micro surfacing in Malaysian Expressway at south bound northern area. To achieve the aim, the following objectives are identified:-

1. To determine the required proportions of aggregate chippings and quarry dust for the micro surfacing mix
2. To design a micro surfacing mix that complies with the specification requirements
3. To determine the optimum mixing time for the micro surfacing mix
4. To evaluate the one year field performance of the micro surfacing mix in terms of skid resistance, texture depth, rut depth and surface irregularities.

1.4 Scope of Study

This study is limited for the scope below:-

1. Study on a single layer micro surfacing on expressway.
2. The duration of the study is only for one year.
3. Focused on the performance of micro surfacing surface in term of rut depth, skid resistance, texture depth and surface irregularities.

1.5 Significance of Study

Common problems that arised in flexible pavement are rutting, low skid resistance and surface irregularity. To solve the problem, re-profiling and restoration work or improving the skid resistance are required. In some cases, it is sufficient enough to resurface the existing pavement. However, in certain cases, the existing pavement is required to be milled first before laying the pavement with a new wearing course. This conventional method is costly compared to a new method such as a chip seal, slurry seal or micro surfacing. Micro surfacing is the best option compared to chip seal and slurry seal due to the limitations of chip seal and slurry seal. Chip seal cannot solve the rutting problem and slurry seal would take a longer time to cure and to reopen the road to traffic. Micro surfacing can be used to restore or improve skid resistance properties of existing surfacing. It can also be used to solve rutting and surface irregularity problems by re-profiling the existing pavement.

Micro surfacing is recommended as a preventive maintenance. Micro surfacing is used not to provide structural improvement for the roadway but rather to repair pavements with surfacial distresses such as coarse aggregate loss and ravelling or to improve surface frictional resistance. (Hein et al., 1994)

This study discussed the performance of micro surfacing in Malaysia in terms of skid resistance value, texture depth, surface irregularity and rut depth. The result would be useful in identifying the suitability of micro surfacing obtained for Malaysian conditions. The findings can be used as a guide and reference for any micro surfacing modification and application in the future.

REFERENCES

Abdul Hamid Isa, Dadang Mohamed Ma'some and Law Tiek Hwa (2005). Pavement Performance Model for Federal Roads. *Proceedings of the Eastern Asia Society for Transportation Studies.* 428-440.

Arafat Suleiman Yero (2008). *The Determination of The Texture Depth, Skidding Resistance and Roughness Index of Various Bituminous Surfaces.* Universiti Teknologi Malaysia: Master Degree Thesis.

Asian Development Bank (2003). *Road Funds and Road Maintenance an Asian Perspective.* Manila. Asian Development Bank.

Bakhtiar Affandy Othman (2008). *A Study of Skid Resistance and Surface Roughness on Surface Dressing Road – Jalan Kg. Parit Bulat, Muar.* Universiti Teknologi Malaysia: Bachelor Degree Thesis.

Bernama (2010, August 23). RM 900 Million for Road Maintenance. *Malay Mail.* Retrieved August 23, 2010, from http://www.mmail.com.my

Bina Masyhur Sdn. Bhd., (2010) *Micro Surfacing : Simplest Way To Get Safer Road.* [Brochure. 2011]. Ayer Keroh, Melaka

Bina Masyhur Sdn. Bhd., (2010) *Micro Surfacing.* from (http://www.binamasyhur.com.my)

Bradbury,A. and Kazmierowski,T.J (1994). *Implementation of Micro-Surfacing Warranty Specification in Ontario.* Downsview, Ontario.: Ministry of Transportation, Ontario.

Croney, D. and Croney, P. (1997). *Design and Performance of Road Pavements.* 3rd edition. New York : Mc Graw-Hill.

Ducasse, K., Distin, T. and Osborne, L. (2004). The Use of Microsurfacing as a Cost Effective Remedial Action for Surface Rutting. *Proceeding of the 8th Conference on Asphalt Pavements for Shouthern Africa (CAPSA '04).* September 12-16. Sun City, South Africa.

Gransberg, D. and James, D.M.B (2005). *Chip Seal Best Practices.* Washington D.C.: Transportation Research Board.

Gransberg, D. (2010). *Microsurfacing.* Washington D.C.: Transportation Research Board.

Hamzah Hashim (2010). Management of Road Safety by Public Works Department of Malaysia – Mumdane Routine or Significant Challenge? *Proceeding of the 24th ARRB Conference 2010.* October 13. Melbourne, Australia.

Hein, D.K., Emery, J.J., D'Ippolito,.D. and Moonah, S. (1994). Design, Construction and Performance of Micro-Surfacing for Urban Pavements. *Proceeding of 72nd Annual Meeting of the Tranportation Research Board.* January 9-13. Washington, D.C.

Hicks, R.G., Seeds, S.B. and Peshkin, D.G. (2000). *Selecting a Preventive Maintenance Treatment for Flexible Pavements.* Washington D.C.

Hixon, C.D. and Ooten, D.A. (1993). Nine Years of Microsurfacing in Oklahama. *Proceeding of the 72nd Annual Meeting Transportation Research Board.* January 10-14. Washington D.C.

IKRAM (1992). *Interim Guide to Evaluation and Rehabilitation of Flexible Road Pavements.* Kuala Lumpur.

International Slurry Surfacing Association. *Micro-Surfacing Pavement Resurfacing.* Washington D.C.: ISSA.

International Slurry Surfacing Association (2005). *Recommended Performance Guidelines for Micro-Surfacing A 143 (Revised) May 2005.* Annapolis, MD: ISSA.

Jones, C.R., Tan Fah Mee and Hasbur Rabiain Bin Ismail (1990). Early Performance of Slurry Seals Used for Paved Road Maintenance in Malaysia. *Proceedings of the Sixth Conference of REAAA.* March 4-10. Kuala Lumpur: REAAA

Jones, C.R., Tan Fah Mee and Ford, W.G. (1992). Performance of Slurry Seals Used in Paved Road Maintenance in Malaysia. *Proceedings of IRF/ARF Asia Pasific Regional Road Conference.* March 22-27. Brisbane.

Joseph, E.S and Shah, S.C. (2002). *Evaluation of Louisiana's Maintenance Chip Seal and Micro-Surfacing Program.* Louisiana Department of Transportation and Development Louisiana Transportation Research Center.

Kirk, J.V. Slurry Seal: A Long-Lasting Maintenance Treatment. *ISSA Report.* 2004. 2004 #1: 16.

Kwang, H.J., Morosiuk, G. and Embi, J. (1992). An Assessment of the Skid Resistance and Macrotexture of Bituminous Road Surfacing in Malaysia. *Proceedings of the Seventh REAAA Conference.* June 22-26. Singapore.

Mohd Khairul Idham Mohd Satar (2008). *Relationships of Skid Resistance Value, Texture Depth and Surface Roughness of Aspahltic Concrete Pavement – A Case Study*. Universiti Teknologi Malaysia: Bachelor Degree Thesis.

Mohd. Sabri Hasim (1994). Performance of Slurry Seals in Routine Maintenance and Pavement Rehabilitation. *Proceedings of the International Workshop on HDM-4.* November 28 – December 1. Kuala Lumpur: IKRAM.

Peltier, W.P. (2008). Slurry Seal and Micro Surfacing for Pavement Preservation. *Proceedings of the 2008 Michigan Seminar on Maintenance of Asphalt Pavement.* January 8-9. Mount Pleasant, Michigan.

Peshkin, D.G., Hoerner, T.E. and Zimmerman, K.A. (2004). *Optimal Timing of Pavement Preventive Maintenance Treatment Application.* Washington D.C.: Transportation Research Board.

PWD Malaysia (2008). *Standard Specification for Road Works.* Kuala Lumpur. JKR/SPJ/2008 – S4.

Safry Kamal Ahmad (2008). *Data Collection Strategies in Malaysia.* Kuala Lumpur: Road Facility Maintenance Branch, Public Works Department Malaysia.

TRRL (1969). *Instruction for Using the Portable Skid Resistance Tester.* Road Note 27, Transport and Road Research Laboratory.

Z. Suffian, H.R. Smith and W.G. Ford (1996). The Benefits of Using Chip Seals in Malaysia. *Proceedings of the Second Malaysian Road Conference.* June 10-13. Kuala Lumpur: JKR Malaysia.

Zulakmal Sufian (2005). Performance of Microsurfacing. *Proceedings of the Malaysian Road Conference.* 2005. Kuala Lumpur: JKR Malaysia.