A Comparitive Study on Noise Reduction Ability of Rubberized Pavement with Conventional Pavement.

by

Lee Chung Tak

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

(Miss Koh Moi Ing)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
December 2006

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

LEE CHUNG TAK

ABSTRACT

In the recent years, number of vehicles and roads are increasing exponentially. Noise pollution has been a concern among the publics and currently there is an up rise regarding the health and mental issues that might result from it. Thus the result, various development solutions such as softer tires, noise dampening barriers and new quiet pavement materials has been introduced. One of the new pavements introduced is rubberized pavement. Based on various researches around the world, rubberized pavement has the potential of reducing noise generated from tire-pavement contact. To date, a few rubberized pavement roads have been constructed in the country. However, the performance is yet to be evaluated. Therefore, this study was proposed to evaluate the noise reduction ability of rubberized pavement in Malaysia. This study will be carried out by performing test run on both rubberized and conventional pavements. Two field test methods have been proposed namely pass-by method and cruising method. Eventually, the result of the study shows that rubberized pavement produced relatively lower noise level as compared to conventional pavement. However, the reductions in noise level were not significant to the hearing of the human.

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1.0 INTRODUCTION

1.1 Background of Study

According to Europe's Environment Assessment (EEA), 60% of urban European population are exposed to critical traffic noise levels over 55dB(A). Noise pollution is the major stress factor of inhabitant in western European countries. Over a quarter of a century noise pollution was not taken into account as a major pollution. Even after 50 years, rolling tire noise did not drop. Interaction of rolling tire with pavement noise are the major dominant source of traffic noise pollution (refer to Figure 1-1).

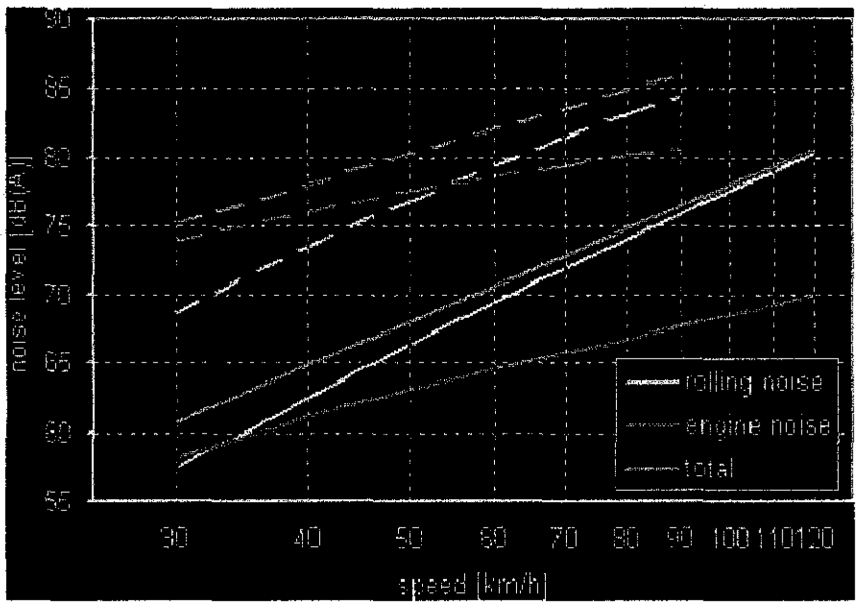


Figure 1-1 Statistic Comparison Graph between Rubberized Pavement and Conventional Pavement taken from EEA.

In Malaysia, rubberized pavement is not widely used. The pavement is considerably new where high cost and strict control on production and paving operation is crucial in producing the finishing pavement. Currently, Sultan Abdul Aziz Road in Putrajaya is the major road which is currently identified as a rubberized pavement. The rubberized pavement mix was developed by Petronas and the product is named **Bituminous-R.** Bituminous-R (rubberized pavement) is also been constructed on locations within the country. However, most of these roads are not assessable by public users.

1.2 Problem Statement

In recent years, many studies and researches have concluded that rubberized pavement is capable of reducing the rolling noise from the vehicle tires. Rubberized pavements are widely used in urban residential areas of United States and in Europe due to its ability in noise reduction. Presently in Malaysia, there are only a few locally designed rubberized pavements because of its high cost and new technology involved. However little study is conducted to evaluate its noise reduction effectiveness, therefore a study using rubberized pavement with site test is proposed for this purpose to further evaluate the feasibility of noise reduction measure.

1.3 Objective and scope of study

This research study will study on the effectiveness of the rubberized pavement in reducing noise as compared with conventional asphalt pavement. The study is to confirm whether the application of rubberized pavement will also provide a noise reduction benefit as showcased by foreign studies. The major task required to complete the research are as follow;

1. To measure the noise emitted from a conventional pavement when a reference car travels along the pavement.
2. To measure the noise emitted from a rubberized pavement when a reference car travels along the pavement.
3. To experiment various type of vehicle on both rubberized pavement and conventional pavement.
4. To evaluate both measurements and conclude the effectiveness of the rubberized pavement in reducing traffic noise.

2.0 LITERATURE REVIEW

2.1 Introductions

Different types of pavement will produce different level of noise characteristics. Generally the differences in noise characteristics are due to the difference in pavement properties and mixes. Before study the noise reduction ability of rubberized pavement, it is important to understand the effects of noise, the concept of rubberized pavement and the application of rubberized asphalt in Malaysia. A detail discussion on noise level is discussed on the following section.

2.2 Vehicle noise studies

Studies have indicated that a moving vehicle generated substantial noise as compared to idle vehicle. Noises are from mechanical parts of the vehicle ranging from engine compartment to the tires and exhaust. List of known mechanical parts are the engine block, air intake, exhausts, vehicle body structure and transmission gears. Vehicle body structures aren't the main noise generator, but are the main contributor of transferring mechanical vibrations from the vehicle and emit it out to the surrounding.

Vehicles which had a long history of operating life will generate more noise as compared to new vehicles. This is because most mechanical parts are worn off and less lubricated. Thus these vehicles may jeopardize the final results of the noise measurement on the pavement. The idle noise level of the vehicle may be measured; however the operating noise level when the vehicle is cruising may vary due to different operating noise level of the vehicle. Different cars have different aerodynamic designs and they all yield at different noise level. In addition, new vehicle exterior on the front and the back of the vehicles are comprise of plastic and fiber components. These components provide weight reduction and noise reduction ability of the vehicle.

European commission noise homologation has been an essential experimental method used by most manufacturers to determine the noise level of a vehicle. Significant test on European Commission noise homologation method is that the results are considered valid when the consecutive results obtained are within 2db from each other.

2.3 Tire noise studies

Tire manufacturer has formulated a formula on calculating tonal tire noise. Tonal tires are generally conventional tires. The formula of tonal tires is acknowledged as general benchmark to compare with new designs of tires in terms of noise reduction, grip and tire efficiency. The tonal tires noise level can be calculated with the following formulas and the provided pavement conditions.

$$L_A = C + \log_{10}(V^n)\ \mathrm{dB}$$

L_A = sound pressure at 7.5m dBA due solely to tire noise
V = vehicle coasting speed (Km h^{-1})

Rib tire on wet road	C = 47,	n = 1.7
Smooth tire on wet road	C = 23,	n = 2.7
Smooth tire on dry road	C = 10,	n = 3.4
Regular tire on dry road	C = 18,	n = 3.0

2.4 Effect of Noise

The noise intensity is measured in decibel unit. The decibel scale is in logarithmic; each 10 decibel increase represents a ten fold increase in noise intensity. Human perception of loudness also conforms to logarithmic scale; a 10 decibel increase is perceived as roughly a doubling of loudness. Thus 30 decibel is 10 times more intense than 20 decibel and sounds 4 times louder; 80 decibels is 1 million times more intense than 20 and sounds 64 times louder. However distance diminishes the effective decibel level reaching the ear. Thus, moderate auto traffic at a distance of 30 m rates about 50 decibels. To a driver with a car window open or a pedestrian on the sidewalk, the same traffic rates about 70 decibels; that is, it sounds 4 times louder. At a distance of 600m, the noise of a jet takeoff reaches about 110 decibels approximately the same as in an automobile horn from 1 m distance.

Considering an individual subjected to 45 decibels of noise, the individual will suffer a restless sleep. At 120 decibels the ear registers pain, but hearing damage begins at a much lower level, about 85 decibels. The duration of the exposure is also affecting the level of damage. Apart from hearing loss, such noise can cause lack of sleep, irritability, heartburn, indigestion, ulcer, high blood pressure, and possibly heart disease. One burst of noise, as from a passing truck, is known to alter endocrine, neurological, and cardiovascular functions in many individuals; prolonged or frequent exposure to such noise tends to make the physiological disturbances chronic. In addition, noise-induced stress creates severe tension in daily living and contributes to mental illness.

However, noise is recognized as a controllable pollutant that due to abatement technology. In the united states, the Noise Control Act of 1972 empowered the Environment Protection Agency to determine the limits of noise requirement to protect public health and welfare; to set noise emission standards for major sources of noise in the environment, including transportation equipment and facilities, construction equipment and electrical machinery; and to recommend regulations for controlling aircraft noise and sonic booms. Also in the 1970s, the Occupation Safety and Health Administration began to try to reduce workplace noise. However funding for these efforts and similar local efforts was severely cut in the early 1980s, and enforcement became negligible. In Malaysia, similar regulation have been carried out but not enforced.

2.5 Rubberized Pavement

Generally rubberized pavement is produced by incorporating rubber particle as an additive into asphalt mixture in flexible pavement construction. Such addition will gradually improve the performance of the pavement compared to fine aggregates substitution. The process of incorporating rubber into asphalt mixture produces two types of mixtures: "Rubber Modified Asphalt Mixtures" and "Rubber Asphalt Mixture" where processes are recognized as Dry Process and Wet Process. Figure 2-1 depicts the whole illustration.

For Dry process, the asphalt pavement is mixed with scrap tires as a portion of the fine aggregate. The process can be used for hot mix asphalt paving in dense graded, open graded or gap graded mixtures. In the dry process the crumb rubber is used as a substitute for a small portion of fine aggregate which is usually 1 to 3 percents by weight of the total aggregate mix. Rubber particles are blended with the aggregate prior to the addition of asphalt cement and will produce a material which is referred as Rubber Modified Asphalt Mixture. The rubber particle size is graded and the gradation commonly used in rubberized asphalt pavement is between 2.0mm and 5.0mm.

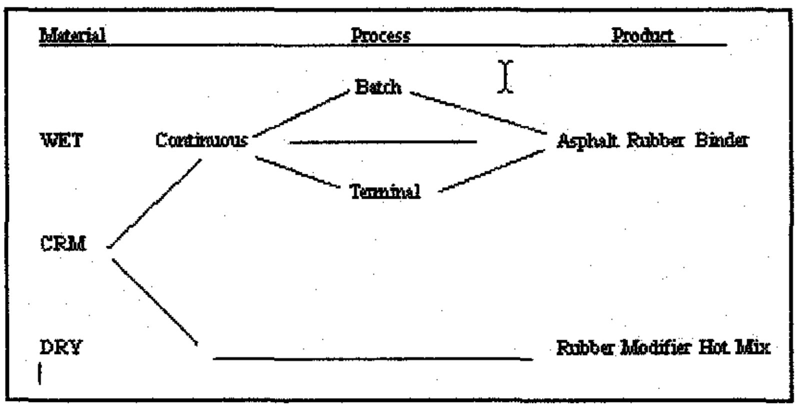


Figure 2-1 Process of mixing Rubberized Pavement

The Dry process procedure consists of substituting small portion of fine aggregate. Wet process requires large portion of rubber to incorporate into mixes. Rubber for wet process needs to be dispersed and melted in liquid asphalt at high temperature for several hours before mixing with asphalt. The dry process requires low cost cutting of rubber and consist of large quantity of rubber particle sizes compared to wet process. The preparation of wet process equipment requires a relatively high temperature to melt the standard small size of rubber particle to facilitate digestion. High binder content is required for wet process because rubber asphalt is more viscous than conventional asphalt binder. The Wet Process of rubber asphalt is known to have a better long-term deformation resistance as compared to Dry Process.

2.6 Application of rubberized pavement in Malaysia

As mentioned previously, in Malaysia Rubberized pavement is not widely used. The high cost and strict control for production and operation sets back the practicality usage of such pavement in Malaysia. With cost as a major concern in highway and pavement construction, it is crucial to promote better awareness on other benefits which rubberized pavement can offer, for instance, reduction in traffic noise level. Thus, this research has been carried out on the rubberized pavement to document the reduction of noise level as per claimed by other foreign researches. One of the pavement constructed using rubberized pavement is identified as the Sultan Abdul Aziz Road in Putrajaya. Sultan Abdul Aziz is a dense bituminous pavement. The 9km protocol road encircles the Putrajaya government precincts. The road was constructed by Putrajaya Holding Sdn Bhd, a construction company which responsible for most of the Putrajaya's construction. Materials and mixes were supervised and produced by Petronas Research & Scientific Services Sdn Bhd (PRSS), a Subsidiary of Petronas whom conducted research on rubberized pavement. The operational period for the pavement since it was open for public usage is about five years. To date, there were only minor maintenance conducted on the pavement as the durability and reliability of the pavement is relatively high.

The rubberized pavement supplied to construct the finishing level of Sultan Abdul Aziz pavement was named **Bituminas PREMIUM-R.** The material is used as a wearing course substitution to the Asphalt Concrete Wearing Course (ACWC) which was produced by incorporating crumb rubber mixture into plain bitumen in specific proportions. The Bituminous PREMIUM-R pavement is designed by Petronas Research & Scientific Services Sdn Bhd (PRSS). The product is locally produced and has been scientifically proven to be unique upon application on road construction. The characterization of crumb rubber mixture is carried out to ensure consistency in the quality of Bituminas PREMIUM-R produced. The addition of rubber into bitumen enhances the strength and visco-elasticity characteristic of bitumen thus improves the performance and durability of pavement. Bituminas PREMIUM-R is suitable for use in both dense and porous mix roads.

2.7 Noise reduction characteristics of Rubberized pavement

Rubberized pavement had undergone extensive research to scientifically prove the effectiveness in noise reduction. Based on researches carried out from various researchers for respective countries, tests were conducted and compared with conventional pavement with same age, reference vehicle and speed. Table 2-1 shows the result of each country's findings.

Table 2-1

Countries Used/Using Rubberized Asphalt and Resulting Noise Reduction

Country	Year	Reported Noise level Reduction
Belgium	1981	8-10 dB (65-85%)
Canada	1991	Shown noise reduction
England	1998	Project not completed
France	1984	2-3dB/3-5dB (50-75%)
Germany	1980	3dB (50%)
Austria	1988	3+ dB
Netherlands	1988	2.5dB

Source: Sacramento Country Department of Environmental Review and Assessment Rubberized pavement noise reduction results from various countries

From the Table 2-1, the results indicate a reduction of 2-10 db noise level. The 2-5 dB reduction theoretically isn't significant to the human's hearing ability. The above test was carried out with pavement samples of the similar service life, similar reference vehicle and similar speed.

Table 2-2

States Using Rubberized Asphalt and Resulting Noise Reduction

State	Counties & Cities	Year	Noise Level Reduction
Arizona	Phoenix, AZ	1990	10dB (88%)
	Tucson, AZ	1989	6.7dBs (78%)
California	Sacramento County	1993	7.7 - 5.1 dB
	Orange County	1992	3-5 dB on Open Graded asphalt
	Los Angeles County	1991	3-7 dB
	San Diego County	1998	Project in process
Texas	San Antonio	1992	Data not Provided
Oregon	Corvallis	1994	Data not Provided

* Table is not comprehensive. Studies may have taken place in other states.

Source: Sacramento Country Department of Environmental Review and Assessment Rubberized pavement noise reduction results in United States

Table 2-2 shows noise comparison between rubberized pavement and conventional pavement in the states. Studies showed 3-10 dB in noise reduction.

Table 2-3

Roadway	Pavement Type	Duration of Time Elapsed After Paving	Change in Noise Levels, dB Leq
Alta Arden Expressway	Rubberized Asphalt	1 month	-6 dB
		16 months	-5 dB
		6 years	-5 dB
Antelope Road	Rubberized Asphalt	6 months	-4 dB
		5 years	-3 dB
Bond Road	Conventional Asphalt	1 month	- 2 dB
		4 years	0 dB

Source: Sacramento Country Department of Environmental Review and Assessment Rubberized pavement noise reduction deterioration after a time duration

However, it is believed noise reduction ability for rubberized pavement deteriorates after duration of time and the deterioration is permanent. This was proven by the finding reported by Sacramento Country Department of Environment. The results display in Table 2-3 shows that noise reduction ability of rubberized pavement reduced by 1 dB for pavement age up to 5-6 years.

According to PRSS report, porous mix rubberized pavement has a better noise reduction as compared to dense mix rubberized pavement. The study was done by researcher from Universiti Kebangsaan Malaysia, UKM on a porous mix rubberized pavement constructed around Nilai-Bangi Highway. The research uses the method of measuring vehicle noise passing by a designated location. Distance between the passing by vehicle and the noise level meter is approximately 3m. A constant 90km/h speed is moderated on the reference vehicle when passing by the noise level meter. Engine is cut off from operating before passing by the noise level meter. From the test conducted, there is a slight reduction in noise as compared to the conventional asphalt dense pavement. Porous Rubberized pavement yields a 86.2 dB - 87.4 dB noise while conventional dense bituminous pavement yields 89.1 dB - 92.1dB. Difference in noise reduction is approximately 1.7dB to 5.9dB.

2.8 Conclusion

Malaysia is undergoing a vast boom of development. Each year the number of residents is increasing. The high population and high transportation demands induce a need for better transportation design. Vehicle and road has been the essential tools in transportation in Malaysia and it will be a need for every household to travel around. As the numbers of roads and vehicle increases by time, noise pollution will increase and eventually becomes a serious health concern among the local residents. A vehicle on a conventional pavement generated an average of 89.1 db-92.1db noise level. This is a concern as the noise level exceeds human hearing acceptance threshold of 85 decibel, thus resulting hearing damage.

Studies have incurred that rubberized pavement can dampen traffic noise from tires up to 10 db. The figure may indicate a small difference, however as the development are getting close to the highway facilities, these noise reduction would be significant to both residents and the road users. Even though the noise reduction ability for rubberized pavement deteriorates as it aged. The deterioration would not completely fail its ability in reducing traffic noise.

Although a study on local rubberized pavement was conducted to evaluate the noise reduction ability. There is still room for research in this area as the research methodology would greatly affect the accuracy of the result. Therefore a new methodology is proposed in this study to further verify rubberized pavement ability in reducing traffic noise.

3.0 METHODOLOGY

3.1 Introduction

The chapter briefly describes the flow of the research to be conducted. The main priority in completing the research is by obtaining more literature review and conducting experiments in verifying the research hypothesis. The flow can be summarized by the Figure 3-1. The figure shows the Flow Chart of procedure taken for the research.

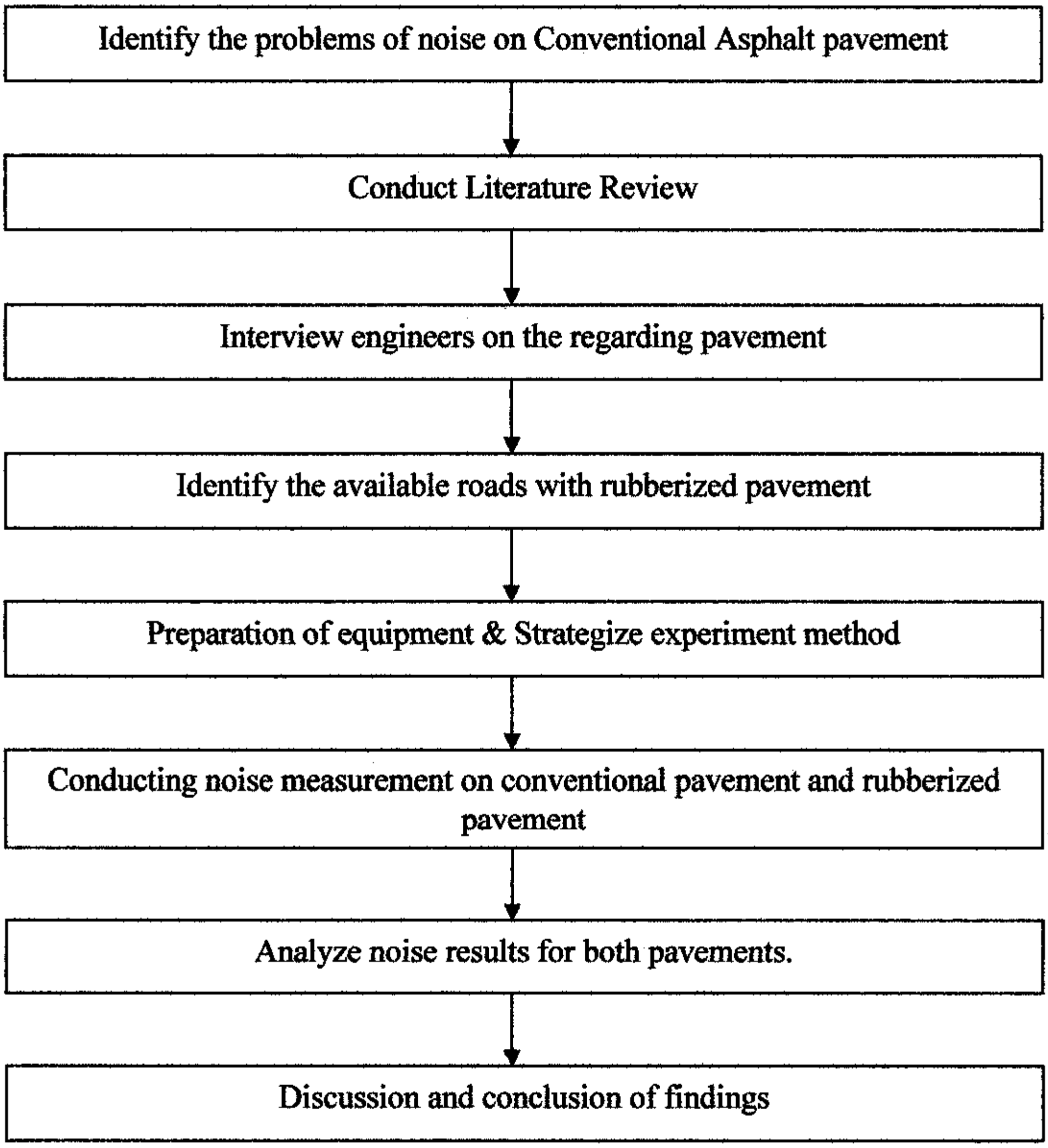


Figure 3-1: Flow Chart of research

3.2 Identify the noise problem on conventional pavement

For the research to comply with the objective, initially, the problem of existing noise on conventional pavement has to be identified. The conventional pavement exerts a loud noise when vehicles travel along the pavement. Noise level may source from engine noise, mechanical noise and noise emitted from tires coming contact with conventional pavement. Our main problem is to reduce tire contact noise as both engine noise and mechanical noise can be reduced by mechanics. Thus there is a need to improve the road pavement that which will result a quieter pavement.

There had been some researchers' claims on the rubberized pavement in recent years about its ability in reducing the noise as compared to conventional pavement. Therefore this research is aim to verify the findings and further compare the noise reduction effectiveness of rubberized pavement in Malaysia.

3.3 Conduct literature review

The following step included the acquiring of information from various resources available regarding traffic noise on rubberized pavement. these information are crucial for research. This step is to assure that the research is following the right method in order to have a successful result.

Rubberized pavement has been identified as the essential pavement type in this research to study the noise reduction effectiveness of modified pavement. Findings obtained from different researches are taken as references, In this study, research on the method of attaining experimental data is also been refer.

3.4 Interview engineers regarding pavement in Malaysia

Various visits were done to acquire information from practicing engineers past based on their past experience in dealing with rubberized pavement. Visits arrangements have been conducted to organizations, newly Putrajaya Holding and Petronas Research Scientific and Services (PRSS).

The interview was conducted with Mr Hasnun Nizam from Putrajaya Holdings. Mr Hasnun is the Project Manager of Infrastructure for the company. Various information and verbal facts pertaining to the construction of rubberized pavement were given by Mr Hasnun. In addition, interview session was also conducted with Mr Loh Kong Min from PRSS. Mr Loh provided brochures of Bituminas PREMIUM-R from PRSS. Most of the information provided consists of methodology of noise test done and facts on Bituminas PREMIUM-R.

3.5 Identify roads constructed with rubberized pavement

Identification of rubberized pavement road in Malaysia is crucial for noise measurement. On the other hand, to prevent deviation due to pavement age, conventional pavement with the similar age and length characteristics is also identified. The Sultan Abdul Aziz road is identified as the rubberized pavement, while the highway heading towards Putrajaya at Gate-one is identified as conventional pavement. Both pavements have similar life span which can be safely assume that the noise reduction deterioration for both pavements is about the same.

3.6 Preparation of equipment

The equipment to be used for the research is sound level meter. Sound level meter used in this study is capable of measuring noise ranging from 40 dB to 100 dB. With the sensitivity 0.1±dB, the sound level meter is capable of obtaining the average sound data for a period of time and record the maximum noise for the environment. .

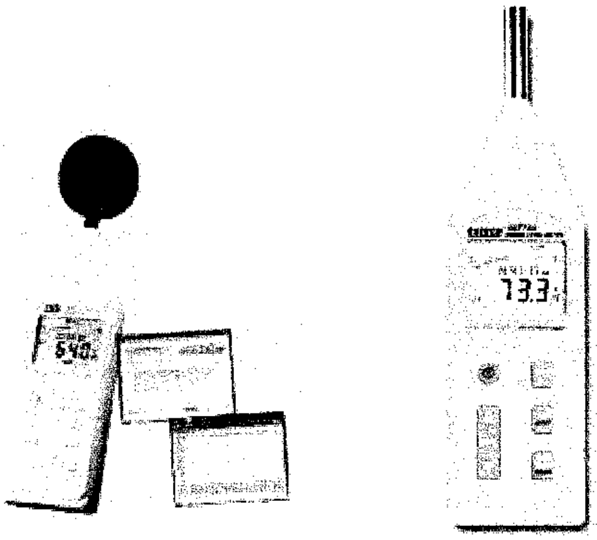


Figure 3-2: Noise Level Meter Apparatus.

3.7 Field experiment

Noise measurement for both type of pavement were conducted by using two different test method: pass-by method and cruising method.

3.7.1 Experiment Pass-by method 1.0

This experiment will measure the noise level of the passing vehicle on both types of pavements at a fixed location. For a better comparison, the test is conducted on both rubberized and conventional pavement.

Procedure

1. A location on the road is identified and the sound level meter is stationed at that location.
2. The sound level meter is attached to a tripod and the clearance from the passing by vehicle is approximately 3m.
3. The sound level meter is aimed perpendicular with the road. Maximum noise reading is recorded.
4. The reference vehicle is traveled at a constant speed of 80km/h when passing the location of the sound level meter.
5. Upon arrival on the sound level meter location, the car engine is turned off and the reference vehicle is left cruising along the pavement.
6. The noise is recorded and the test is repeated. Forty noise measurements are recorded for each type of pavement.
7. The experiment is repeated for each type of pavement.
8. The same reference vehicles and methodology is repeated on different pavement.

3.7.2 Cruising Method

In this method, the noise measurement is performed inside the test vehicle traveling at various constant speeds.

Procedure

1. The sound level meter is placed in the cabin of the test vehicle.
2. The test car travel at the conventional pavement at different constant speeds. The speeds are 40 km/h, 50 km/h, 60km/h, 70 km/h. 80km/h and 90 km/h.
3. Noise level of each speed is then recorded and analyzed. Twenty data measurement is recorded on each speed.
4. The test is repeated for rubberized pavement.

3.7.3 Experiment Pass-by Method 2.0

Experiment Pass-by Method 2.0 is the replica of previous Pass-By Method experiment. There have been some minor changes on the experiment Pass-By Method 2.0. The experiment will utilize the use of different vehicle. This experiment is to indicate noise reduction difference of rubberized pavement when subjected to different types of vehicle.

<u>Procedure</u>

1. A fixed location is been identified for rubberized pavement. The picked location must be safe for carrying out experiment and the location should be less interfered by external noise. The sound level meter is stationed on the particular location for noise level measurement.
2. The Sound level meter is attached to a tripod to provide an easy access and measurement reading. The clearance between the noise level meter and the designated reference vehicle passing by is approximately 3m away.
3. The Sound level meter sensor must be positioned to the road to obtain the maximum noise level measurement. The sound level meter is calibrated to record the maximum noise reading before the reference vehicle approaches.
4. Before arrival to the noise level meter, the reference vehicle should signal for preparation. The reference vehicle should cruise at slightly above 80 km/h.
5. Noise level meter is calibrated to record maximum noise level.
6. The car engine is turned off and the reference vehicle cruises at 80 km/h when passing the noise level meter.
7. Upon passing the noise level meter, the noise level meter record maximum noise level in decibel.
8. Maximum noise level was recorded.
9. The test was repeated forty times to obtain forty noise level measurements.
10. Similar test procedure was applied to the conventional pavement and ten noise level measurements were also recorded.

11. The previous procedure is repeated with a different reference vehicle.
12. All results are tabulated and shown on bar chart to indicate noise level difference between rubberized pavement and conventional pavement.

3.8 Comparison of experiment methods

The pass-by method has an advantage of measuring noise level emitted directly from the tires of vehicle. The disadvantages of the method are due to interference of external surrounding and nearby vehicle sounds during noise measurement. It is crucial to conduct the measurement where there is minimal noise interference. In addition, it is very time consuming because of the one-way road design where each round will only produce one noise data.

The cruising method is ideal where the noise level for the tire can be constantly monitored. However, the method may not yield the actual noise level from the tire as the sound level meter is insulated in the cabin of the vehicle. In addition, vehicles around the moving reference vehicle will result in a minor deflection of the result. Traffics are also another main concern as it will disrupt the reference vehicle from maintain a constant speed.

Similar to the previous Pass-By Method, Pass-By Method 2.0 shares the same similarity of advantages, disadvantages and constrains. The difference is on the application of various vehicles but restricts on a designated 80 km/h speed. The benefits of this revised experiment is where it is capable of indicating different vehicle dimension, chassis, tire compound used will yield different noise characteristics. In addition of noise level difference, the main objective of this experiment is to ensure that noise reduction capability do not differs much in difference of vehicle.

The Pass-by method, Pass-by Method 2.0 and Cruising method are compared and analyzed for methodology difference. Both experiment Pass-by Method and Pass-by Method 2.0 has been identified as an ideal method of analyzing the noise level for both conventional and rubberized pavement. Although the Pass-by Method 1.0 & 2.0 are considered tedious, time and cost consuming, it is capable of producing more accurate and persist result compared to the cruising method. The claim is supported with the facts where noise level meter installed in experiment cruising method is highly shielded by the vehicle's cabin insulating material. In addition, maintaining at constant speed may yield different result as there are different conditions on the road due to pavement defects. The pass-by method and Pass-by Method 2.0 can be further improved by conducting the experiment under controlled and quiet environment. The cruising method however might have trouble on controlling noise level as major noise generation contribution is from the vehicle's mechanical components. However, both experiments are still executed to identify the validity of the hypothesis.

3.9 Noise result analysis and discussion

Once the result of the experiment is obtained, analysis will be conducted to uncover the difference in noise level between the conventional pavement and rubberized pavement. Previous researches clarifies that rubberized pavement has the ability to reduce sound compared with conventional pavement. Our result will confirm the application effectiveness of rubberized pavement in noise reduction ability when it applies to Malaysian climate and vehicle traffic handling.

3.10 Conclusion

Finally the discussion and conclusion of the results will be made to determine whether the objectives of the research have been fulfilled. The conclusion will include the comparison between the rubberized pavements and conventional pavement in the aspect of noise. Rubberized pavement noise reduction effectiveness will also be noted

4.0 RESULT AND DISCUSSION

4.1 Introduction

The noise measurements for both rubberized pavement and conventional pavement were successfully conducted. Several experiments have been conducted to identify and verify the noise reduction capability of the rubberized pavement as compared to the conventional pavement.

The experiments conducted on the side are labeled as pass-by method 1.0, pass-by method 2.0 and cruising method. All test have successfully conducted. It is grateful that the experiments were started during the end of the first semester. The results obtained from the experiments will be reported and discussed in this chapter.

4.2 Preliminary field experiment

Prior to the actual experiment, a preliminary field experiment was conducted based on the three noise measurement methods, which are pass-by method 1.0, pass-by method 2.0 and cruising method. This is to test and select a more accurate method in this study.

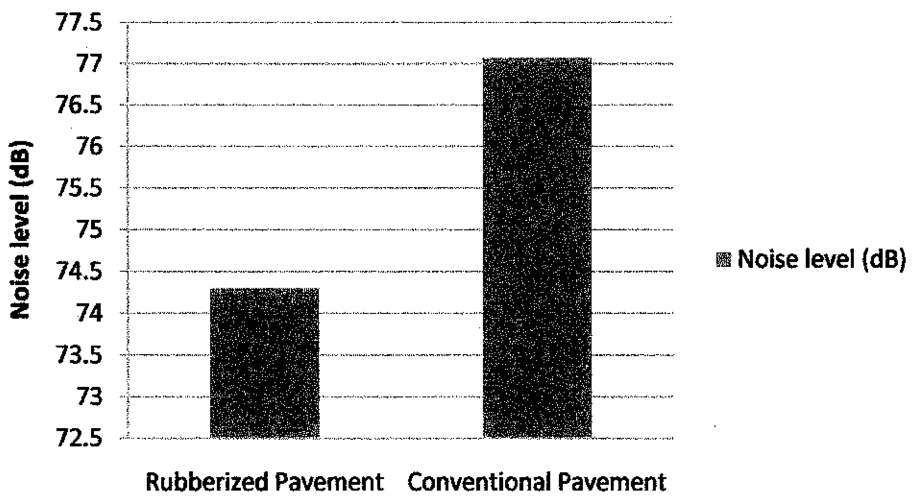
4.2.1 Pass by Method 1.0

This experiment measured the noise level of the passing vehicle on both types of pavements at a fixed location. Pass-by method has been performed on the pavement of 6 years old. Table 4-0 and Figure 4-0 indicate the noise level results for both conventional and rubberized pavements. From the result, average noise reduction is approximately **2.77 dB.**

Table 4-0: Noise level measured using Pass-by method 1.0

Data Number	Rubberized pavement Noise level (db)	Conventional Pavement noise level (db)
1	69.7	79.5
2	75.5	75.8
3	67.2	75.7
4	76.7	76.7
5	77.5	77.2
6	77.3	77.2
7	76.4	77.6
8	75.8	76.9
9	77.1	77.3
10	69.8	76.8
Average	**74.3**	**77.07**

Figure 4-0: Noise level measured using Pass-by method 1.0



4.2.2 Experiment Pass-by Method 2.0

Experiment Pass-by method shares the same experiment with different criteria and reference vehicle. Three type of reference vehicle were used to obtain noise level difference. The chosen three vehicles are Toyota Unser, Nissan Bluebird, Proton Waja. Toyota Unser is under the Multi purpose vehicle category, Nissan BlueBird under large corporate sedan category and Proton Waja under family sedan category. Each vehicle will have its significant noise level emission, but our main focus is on the noise level of the reference vehicle operation difference between the two pavements.

Figure 4-1 shows a comparison of noise between Rubberized pavement and conventional Pavement depict from Table 4-1. The results show indication of noise reduction. However, the noise level reduction is low or below the human perceivable hearing ability. The result is fairly average and the inaccurate results might due to similar interference suffered from the previous Pass-by experiment. This is because both share similarity in experiment procedure. As observed from the three vehicles, Toyota Unser shared the most quiet noise level. This is due to the soft compound tires used where it dampens the tire rolling noise with both pavements; result in much quieter noise as compared to both pavements. The Nissan Bluebird uses a worn off tire where large contact area of the tires will contribute to large noise level since the interaction between tires and road surface is at most. For Proton Waja, it is using a recycled hard compound tire. It is no surprise as it measured the highest among all three reference vehicle. In general hard compound tires generate the most noise as it is hard and unable to damp noise.

The noise reduction level result compared between the rubberized pavement and conventional pavement is very low. However, the result has a clear indication the rubberized pavement is capable of noise reduction as compared to conventional pavement. This means it has fulfill some of the objective of the studies.

Figure 4-1: Noise level measured using different reference vehicle

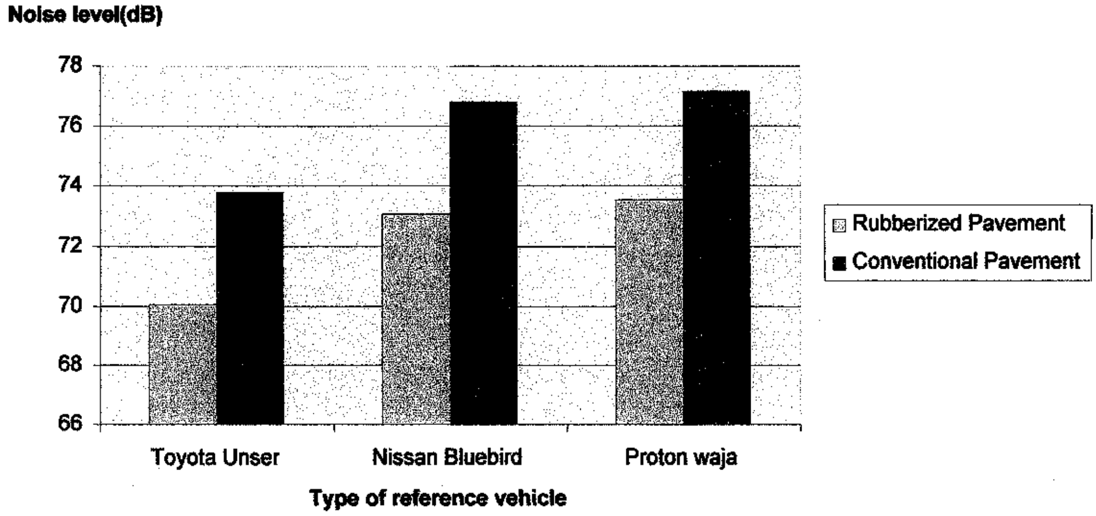


Table 4-1: Noise level for Experiment Pass-by Method 2.0

	Toyota Unser		Nissan Bluebird		Proton Waja	
Data Number	Rubberized Pavement	Conventional Pavement	Rubberized Pavement	Conventional Pavement	Rubberized Pavement	Conventional Pavement
1	70.4	75.1	73.3	77.2	74.5	76.5
2	69.8	76.2	73.7	77.6	73.8	77.4
3	69.6	75.3	73.4	75.8	72.3	77.6
4	70.1	73.7	74.2	75.7	72.6	76.7
5	70.0	75.4	72.5	76.7	73.9	77.0
6	68.5	74.9	74.5	77.2	72.9	76.9
7	70.2	72.2	74.1	76.8	73.2	77.5
8	70.8	74.6	71.3	79.5	74.1	77.2
9	70.6	73.9	72.9	75.8	72.7	76.4
10	70.8	74.5	72.8	75.7	73.9	77.3
11	70.4	72.0	73.2	75.7	74.2	77.7
12	68.5	71.8	73.3	76.7	73.8	77.5
13	69.5	72.6	73.5	77.2	73.1	77.4
14	70.1	72.4	72.1	76.8	74.2	77.6
15	70.6	74.0	73.9	75.8	74.4	77.3
16	70.4	72.5	73.5	75.7	73.5	76.8
17	70.4	73.9	71.4	76.7	72.8	77.4
18	70.3	73.4	72.4	77.2	74.2	77.5
19	69.6	73.3	74.4	76.8	73.1	76.9
20	69.4	72.2	72.2	79.5	74.3	76.9
21	68.7	72.5	72.8	75.8	73.2	76.7
22	70.7	74.1	73.7	75.7	74.1	77.2
23	70.8	73.1	72.5	76.8	73.5	77.5
24	70.5	74.2	72.5	77.2	74.0	76.7
25	70.2	73.8	74.8	77.6	73.5	77.6
26	69.4	73.1	72.1	79.5	72.4	77.4
27	69.7	74.2	72.9	75.8	74.2	76.8
28	70.3	74.4	73.3	75.7	73.7	77.4
29	70.5	73.5	72.2	76.8	72.9	77.1
30	70.6	75.1	72.5	75.8	74.2	76.9
31	70.1	74.9	74.1	75.7	73.2	76.5
32	70.4	75.1	73.1	76.7	72.5	76.8
33	69.6	74.0	72.0	77.2	73.1	77.7
34	70.1	72.5	71.8	75.7	74.2	76.8
35	69.8	73.9	72.6	76.7	74.3	77.2
36	70.4	73.4	72.4	77.2	72.7	77.3
37	70.8	73.3	74.0	77.6	74.5	76.6
38	68.9	72.2	72.5	76.9	73.6	77.8
39	70.5	72.5	73.9	77.3	72.7	77.4
40	70.0	75.0	73.4	76.8	73.6	77.0
Average	**70.055**	**73.7675**	**73.0425**	**76.765**	**73.54**	**77.1475**

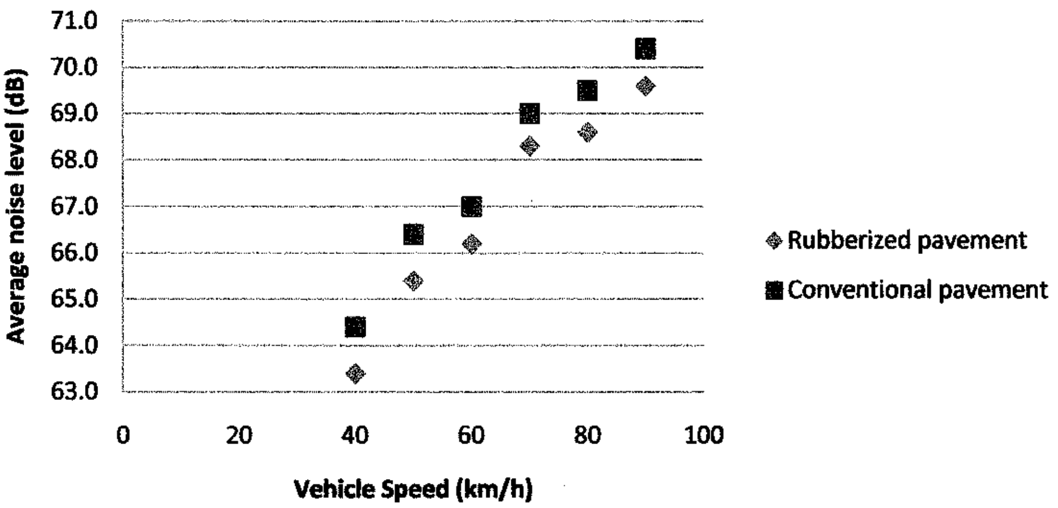
4.2.3 Experiment Cruising Method

This experiment is conducted on the reference vehicle moving at a constant speed. Similar road was conducted for experiment 2. Please refer the results of the experiment in Table 4-2 & Figure 4-2. Tables 4-2 indicate the noise level for both conventional and rubberized pavements conducted using experiment cruising method. Table 4-2 shows the noise level data are inconsistent. Deviation in noise level is suspected due to the factors discussed in section 3.8. Figure 4-2 shows the plots of average noise level versus speed for rubberized & conventional pavements. It was found that noise level increases linearly with speed. The figure also illustrates a lower noise level for rubberized pavement as compared with conventional pavement in all speeds.

Table 4-2: Noise level measured using cruising method

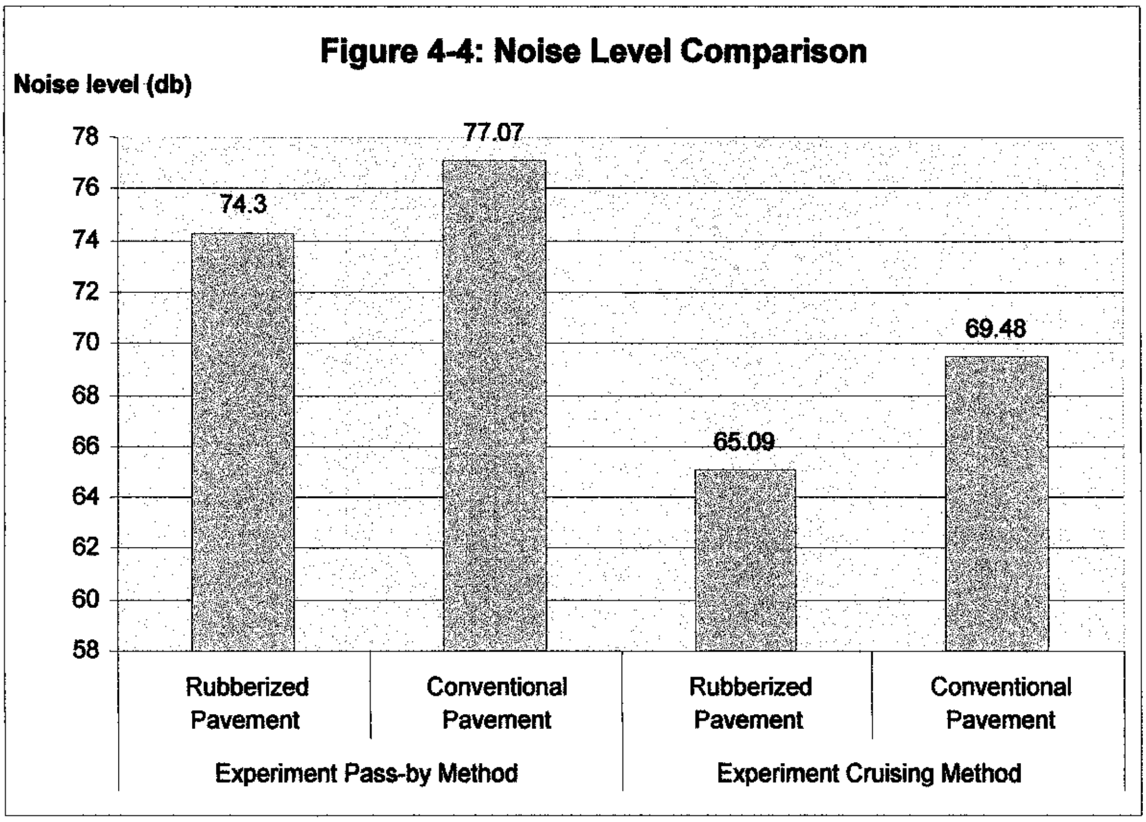
	Rubberized Pavement						Conventional Pavement					
Vehicle speed (km/h) / Data	40	50	60	70	80	90	40	50	60	70	80	90
1	63.5	67.2	64.7	69.5	67.5	68.9	64.2	68.4	65.6	70.1	68.5	70.3
2	61.2	66.4	64.8	66.7	68.3	68.4	63.1	67.5	66.1	67.3	69.3	68.8
3	65.2	64.7	67.5	68.6	66.9	69.3	64.8	65.0	68.4	69.3	67.9	70.5
4	64.7	64.8	64.8	68.9	69.9	68.9	63.6	66.3	66.0	69.5	70.9	69.3
5	62.6	66.2	65.9	67.5	70.3	70.5	63.8	67.4	66.8	67.9	71.3	71.2
6	61.6	65.6	66.1	69.1	66.9	69.7	62.8	66.8	66.8	69.7	69.1	70.1
7	62.8	64.6	68.6	68.3	69.8	70.9	64.2	65.8	68.5	69.3	70.8	71.4
8	64.5	65.3	64.8	67.5	67.4	69.6	65.7	66.4	65.7	68.1	68.4	72.2
9	63.7	67.8	65.7	69.8	66.9	68.2	64.5	67.8	66.8	70.7	67.9	68.6
10	64.8	65.4	65.6	68.9	69.9	70.8	66.3	66.6	66.5	69.3	70.9	71.2
11	63.2	66.6	64.7	66.5	67.6	70.2	63.8	67.8	64.6	67.1	68.6	70.6
12	65.2	63.5	68.6	68.7	68.3	70.6	66.4	64.7	68.9	69.3	66.3	71.5
13	61.8	65.4	65.7	67.4	69.8	68.7	63.2	66.8	67.2	68.0	70.8	69.1
14	62.4	63.4	68.6	69.5	69.5	69.3	63.6	64.6	69.2	70.7	70.8	69.7
15	63.5	67.2	64.9	68.5	66.9	70.5	64.7	67.0	66.4	68.2	67.9	71.9
16	61.4	66.9	64.7	67.6	67.4	70.1	63.2	67.3	65.6	68.2	68.4	70.5
17	64.8	67.1	68.4	69.3	69.5	70.3	64.9	67.8	68.4	70.9	70.6	70.7
18	61.3	63.5	68.6	69.8	70.2	69.6	62.5	64.7	69.5	70.4	71.2	69.6
19	63.7	63.4	65.1	66.5	68.7	68.7	64.4	64.2	66.1	67.1	69.1	70.1
20	66.6	63.9	66.3	67.6	69.9	69.4	67.8	64.6	67.2	68.2	70.9	69.8
Average	63.4 dB	65.4 dB	66.2 dB	68.3 dB	68.6 dB	69.6 dB	64.4 dB	66.4 dB	67.0 dB	69.0 dB	69.5 dB	70.4 dB

Figure 4-2: Average noise level versus different vehicle speed for conventional pavement



4.3 Selection of proper experiment method

Comparison on both experimental results can be observed in Table 4-0 and Table 4-1. Table 4-0 can be simplified under the bar Figure 4-4 as shown below. Based on the result obtained from all experiment, the result indicated small significant in noise reduction. Both comparisons of results also indicate that the hypothesis on noise dampening in experiment cruising method is the valid cause of low noise measurement. Thus Experiment Pass-by method and noise will be considered as a valid result.



5.0 CONCLUSION

The research has completed most of the noise measurement experiment, which are experiment using pass-by method 1.0, pass-by method 2.0 and cruising method. There is limited number of rubberized road constructed in Malaysia. Thus tests were limited to the Sultan Abdul Aziz Shah road in Putrajaya. The Sultan Abdul Aziz road is a dense grade rubberized asphalt pavement and this indicated a slight noise reduction. To date, there are no other rubberized asphalt pavements as some of these pavements have been repaved.

The research has achieved its objective of measuring and comparing noise level between the rubberized pavement and the conventional pavement. The results clearly indicate that the rubberized pavement has better noise reduction ability as compared to conventional pavement. Pass-by method 1.0 & 2.0, and cruising methods show a reduction of approximately 4 dB in this study. Tire characteristics of the vehicle are found affect the results too. As mentioned previously, Toyota Unser equipped with soft compound tires produced lower noise as compared to other vehicles. Different vehicle designs will have different operating noise. The noise level difference might come from air drags, engine and mechanical parts noise. This different source of noise level also exhibits a crucial disturbance to the results. It is important to ensure that the final result of the tire noise is not lower than the reference vehicle operation noise of the result is invalid. This is because the overlapped vehicle noise level might result in the noise level meter to record the vehicle noise instead of the tire noise level. 4 dB noise level reductions is obtained from the experiment. However the reduction is considered little and may not significant to affect the human hearing.

5.2 RECOMMENDATION

The research presents the noise reduction ability of rubberized pavement as compared to conventional pavement. Thus, following recommendations are suggested for better assessment of the influences.

1. A control laboratory can be constructed specifically to conduct noise test on pavement. Currently foreign tire manufacturers have the facilities to research on better tire design. Similar facilities can be introduced to develop a better pavement design. The control laboratory will ensure no environmental noise disturbance during experimentation. Thus the noise result obtained is merely the rolling tire on pavement. In addition, such facilities can assist in developing a better rubberized pavement design.

2. More specific experiment to further verify other influence which might affect the noise level. Below are the suggested experiment

    a. Conduct the noise level experiment but with various loading applied on the tire rolling on both pavements.
    b. Experiment with different tire dimension, age of tires and type of tires on each reference vehicle.
    c. Experiment on different pavement temperature to further verify the effectiveness of noise reduction ability.

3. Collaboration with PETRONAS Research & Scientific Services Sdn. Bhd can be made to further improve noise reduction ability of **Bituminas** Premium-R.

Although the rubberized pavement is not widely used, there is a promising potential for a quiet and comfortable ride to the occupants. In addition, the rubberized pavement gives better performance, better design life and less maintenance cost as compared to conventional pavement.

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APPENDICES

Location : Putrajaya

Pavement type : Conventional Pavement

Reference Vehicle Type : Proton Waja

Date : 28th October 2006

Data:

1	2	3	4	5	6	7	8	9	10
76.5	77.4	77.6	76.7	77.0	76.9	77.5	77.2	81.4	77.3

11	12	13	14	15	16	17	18	19	20
77.7	75.5	77.4	77.6	77.3	76.8	77.4	77.5	76.9	76.9

21	22	23	24	25	26	27	28	29	30
76.7	77.2	77.5	76.7	77.6	77.4	76.8	77.4	76.8	77.1

31	32	33	34	35	36	37	38	39	40
77.1	76.5	76.5	76.8	77.7	76.8	76.6	77.8	77.1	77.0

Average: 71.1475

Location : Putrajaya

Pavement type : Rubberized Pavement

Reference Vehicle Type : Proton waja

Date : 28th October 2006

Data:

1	2	3	4	5	6	7	8	9	10
74.5	73.8	72.3	72.6	73.9	72.9	73.2	74.4	72.7	73.9

11	12	13	14	15	16	17	18	19	20
74.2	73.8	73.1	74.2	74.4	73.5	72.8	74.2	73.1	74.3

21	22	23	24	25	26	27	28	29	30
73.2	74.1	73.2	74.1	73.5	74	73.5	72.4	74.2	72.9

31	32	33	34	35	36	37	38	39	40
74.2	73.2	72.5	73.1	74.2	74.3	72.7	74.5	73.6	73.6

Average: 73.54

Location : Putrajaya

Pavement type : Conventional Pavement

Reference Vehicle Type : Toyota Camry

Date : 24th october 2006

Data:

1	2	3	4	5	6	7	8	9	10
75.1	78.2	71.3	73.7	75.4	74.9	72.2	74.6	75.9	74.5

11	12	13	14	15	16	17	18	19	20
72	71.8	72.6	72.4	74	72.5	73.9	73.4	73.3	72.2

21	22	23	24	25	26	27	28	29	30
72.5	74.1 ~~73.7~~	73.1	74.1	73.8	73.1	74.2	74.4	73.5	75.1

31	32	33	34	35	36	37	38	39	40
74.9	75.1	74	75.5	73.9	73.4	73.3	72.2	72.5	75

Average: 73.7675

Location : Putrajaya

Pavement type : Rubberized Pavement

Reference Vehicle Type : Toyota unser

Date : 24th October 2006

Data:

1	2	3	4	5	6	7	8	9	10
70.4	69.8	69.8	70.1	70	68.7	70.2	70.8	70.6	70.8

11	12	13	14	15	16	17	18	19	20
70.4	68.5	69.5	70.1	70.6	70.4	70.4	70.3	69.2	69.4

21	22	23	24	25	26	27	28	29	30
68.7	70.7	70.8	70.5	70.2	69.4	69.7	70.3	70.5	70.6

31	32	33	34	35	36	37	38	39	40
70.1	70.4	69.4	69.7	70.3	70.5	70.6	70.1	70.5	70.0

Average: 70.055

Location : Putrajaya

Pavement type : Conventional Pavement

Reference Vehicle Type : Waseem Bluebird

Date : 22th October 2006

Data:

1	2	3	4	5	6	7	8	9	10
77.2	77.6	75.8	75.7	76.7	77.2	76.8	79.5	75.8	75.7

11	12	13	14	15	16	17	18	19	20
75.7	76.7	77.2	76.8	75.8	75.7	76.7	77.2	76.8	79.5

21	22	23	24	25	26	27	28	29	30
75.8	75.7	76.8	77.2	77.6	79.5	75.8	75.7	76.8	75.8

31	32	33	34	35	36	37	38	39	40
75.7	76.7	77.2	75.7	76.7	77.2	77.6	76.9	77.5	76.8

Average: 76.765

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Location : Putrajaya

Pavement type : Rubberized Pavement

Reference Vehicle Type : Nissan BlueBird

Date : 22th October 2006

Data:

1	2	3	4	5	6	7	8	9	10
73.3	73.7	73.4	74.2	72.5	74.5	74.1	71.3	72.9	72.8

11	12	13	14	15	16	17	18	19	20
73.2	73.3	73.1	73.9	73.5	71.4	72.4	74.4	72.2	72.8

21	22	23	24	25	26	27	28	29	30
73.7	72.5	72.5	74.8	72.1	72.9	73.3	72.2	72.5	74.1

31	32	33	34	35	36	37	38	39	40
74.1	73.1	72	71.8	72.6	72.4	74	72.5	73.9	73.4

Average: 73.0425

Location : Sultan Abdul Aziz Shah

Pavement type : Rubberized Pavement

Reference Vehicle Type : Nissan BlueBird .

Date : 2? March 2006

Data:

1	2	3	4	5	6	7	8	9	10
69.7	75.5	67.2	76.7	77.5	77.5	76.4	75.8	77.1	69.8

Average: 74.3

UNIVERSITI TEKNOLOGI PETRONAS

Location : Putrajaya

Pavement type : Conventional Pavement

Reference Vehicle Type : Nissan Bluebird

Date : 20 March 2006

Data:

1	2	3	4	5	6	7	8	9	10
79.5	75.8	75.7	76.7	77.2	77.2	77.6	76.9	77.3	76.8

Average: 77.07

noise pollution

noise pollution, human-created noise harmful to health or welfare. Transportation vehicles are the worst offenders, with aircraft, railroad stock, trucks, buses, automobiles, and motorcycles all producing excessive noise. Construction equipment, e.g., jackhammers and bulldozers, also produce substantial noise pollution.

Noise intensity is measured in decibel units. The decibel scale is logarithmic; each 10-decibel increase represents a tenfold increase in noise intensity. Human perception of loudness also conforms to a logarithmic scale; a 10-decibel increase is perceived as roughly a doubling of loudness. Thus, 30 decibels is 10 times more intense than 20 decibels and sounds twice as loud; 40 decibels is 100 times more intense than 20 and sounds 4 times as loud; 80 decibels is 1 million times more intense than 20 and sounds 64 times as loud. Distance diminishes the effective decibel level reaching the ear. Thus, moderate auto traffic at a distance of 100 ft (30 m) rates about 50 decibels. To a driver with a car window open or a pedestrian on the sidewalk, the same traffic rates about 70 decibels; that is, it sounds 4 times louder. At a distance of 2,000 ft (600 m), the noise of a jet takeoff reaches about 110 decibelsâ€"approximately the same as an automobile horn only 3 ft (1 m) away.

Subjected to 45 decibels of noise, the average person cannot sleep. At 120 decibels the ear registers pain, but hearing damage begins at a much lower level, about 85 decibels. The duration of the exposure is also important. There is evidence that among young Americans hearing sensitivity is decreasing year by year because of exposure to noise, including excessively amplified music. Apart from hearing loss, such noise can cause lack of sleep, irritability, heartburn, indigestion, ulcers, high blood pressure, and possibly heart disease. One burst of noise, as from a passing truck, is known to alter endocrine, neurological, and cardiovascular functions in many individuals; prolonged or frequent exposure to such noise tends to make the physiological disturbances chronic. In addition, noise-induced stress creates severe tension in daily living and contributes to mental illness.

Noise is recognized as a controllable pollutant that can yield to abatement technology. In the United States the Noise Control Act of 1972 empowered the Environmental Protection Agency to determine the limits of noise required to protect public health and welfare; to set noise emission standards for major sources of noise in the environment, including transportation equipment and facilities, construction equipment, and electrical equipment and facilities, construction equipment, and electrical machinery; and to recommend regulations for controlling aircraft noise and sonic booms. Also in the 1970s, the Occupational Safety and Health Administration began to try to reduce workplace noise. Funding for these efforts and similar local efforts was severely cut in the early 1980s, and enforcement became negligible.

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APPENDIX B
NOISE STANDARDS COMMONLY APPLIED
TO PROJECTS IN SACRAMENTO COUNTY

Sacramento County Noise Element Policies

The Sacramento County Noise Element establishes land-use compatibility criteria for both interior and exterior areas of various land uses. The County Noise Element policies which pertain to transportation noise follow.

NO-1: Noise created by new transportation noise sources should be mitigated so as not to exceed 60-dB Ldn/CNEL at outdoor activity areas of any affected residential lands or land use situated in the unincorporated areas. When a practical application of the beast available noise-reduction technology cannot achieve the 60-dB Ldn/CNEL standards, then an exterior noise level of 65-dB Ldn/CNEL may be allowed in outdoor activity areas.

N:O-4: Where residential land uses are proposed in areas exposed or projected exterior noise levels exceeding 60 dB Ldn / CNEL or the performance standards described above, an acoustical analysis shall be required as part of the environmental review process.

NO-6: The compatibility of proposed nonresidential projects with existing and future noise levels due to transportation noise sources shall be evaluated through a comparison to the standards described in Table 5 (below) and Table II-3 found in the Sacramento County Noise Element of the General Plan.

NO-7: Proposed Development of Residential land uses should not be permitted in areas exposed to existing or project levels of noise from transportation which exceed 60 dB to 65 dB Ldn / CNEL unless the project design includes effective mitigation measures to reduce noise.

Table of Contents | Executive Summary | Introduction | History of Noise Reducing Pavement | The Process of Producing Rubberized Asphalt | Current Uses of Rubberized Asphalt | Tables | Studies of Rubberized Asphalt Outside of Sacramento County | Sacramento County Rubberized Asphalt Noise Studies | Conclusions of the Studies Conducted in Sacramento County | Appendix A - Acoustical Terminology | Appendix B - Noise Standards Commonly Applied to Projects in Sacramento County

APPENDIX A
ACOUSTICAL TERMINOLOGY

Acoustics The science of sound.

Ambient Noise The distinctive acoustical characteristics of a given space consisting of all noise sources audible at that location. In many cases, the term ambient is used to describe an existing or pre-project condition such as the setting in an environmental noise study.

Attenuation The reduction of an acoustic signal.

A-Weighting A frequency-response adjustment of a sound level meter that conditions the output signal to approximate human response.

Decibel or dB Fundamental unit of sound, A Bell is defined as the logarithm of the ratio of the sound pressure squared over the reference pressure squared. A Decibel is one-tenth of a Bell.

CNEL Community Noise Equivalent Level. Defined as the 24-hour average noise level with noise occurring during evening hours (7 - 10 p.m.) weighted by a factor of three and nighttime hours weighted by a factor of 10 prior to averaging.

Frequency The measure of the rapidity of alterations of a periodic signal, expressed in cycles per second or hertz.

Ldn Day/Night Average Sound Level. Similar to CNEL but with no evening weighting.

Leq Equivalent or energy-averaged sound level.

Lmax The highest root-mean-square (RMS) sound level measured over a given period of time.

Loudness A subjective term for the sensation of the magnitude of sound.

Masking The amount (or the process) by which the threshold of audibility is for one sound is raised by the presence of another (masking) sound.

Noise Unwanted sound.

Peak Noise The level corresponding to the highest (not RMS) sound pressure measured over a given period of time. This term is often confused with the "Maximum" level, which is the highest RMS level.

Threshold of Hearing The lowest sound that can be perceived by the human auditory system, generally considered to be 0 dB for persons with perfect hearing.

Threshold of Pain Approximately 120 dB above the threshold of hearing.

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STUDIES OF RUBBERIZED ASPHALT OUTSIDE SACRAMENTO COUNTY

Rubberized Asphalt Studies in Other California Counties

Rubberized asphalt has been studied in other California counties outside of Sacramento. Orange County studied the effectiveness of rubberized asphalt as a noise mitigation measure in a report entitled Mixed Roadway Surface Noise, prepared by Mestre Greve Associates in February of 1992. The City of Thousand Oaks also conducted a study in 1992 entitled Asphalt Rubber Overlay Noise Study, prepared by Acoustical Analysis Associated, Inc. Both studies determined that rubberized asphalt successfully mitigated traffic noise.

The study conducted for the County of Orange looked at the difference in noise levels between four different pavement types: dense grade asphalt, rubber asphalt (gap graded), rubber asphalt (open graded), and open grade (with latex). The goal of this analysis was to eliminate the effect due to different traffic conditions at each segment of roadway thus resulting in a different noise level due specifically to the asphalt type. *The study concluded that rubber asphalt-open graded was 3.9 dBA quieter than new dense grade asphalt.*

The noise study conducted for the City of Thousand Oaks measured the reduction in traffic noise levels experienced due to resurfacing. The street conditions before resurfacing were poor and therefore, noise reduction due to the new paving was striking. *Noise reduction on the six sites tested ranged from 3-7 dBA, depending on traffic and speed. When compared with the new standard asphalt, rubberized asphalt was found to be 2-5 dBA quieter.*

National Rubberized Asphalt Studies

On a national scale, rubberized asphalt has been studied by many states as well as the federal government. Arizona has been the leader in the production and use of rubberized asphalt. In March 1990, Western Technologies Inc. performed a sound level survey to determine the noise levels produced during peak traffic flow on different types of pavement, including rubberized asphalt. In November of 1995 the Texas Department of Transportation conducted a study on the crumb rubber modifier used in rubberized asphalt as a successful method to reduce tire noise. Finally, the National Research Council conducted a study in 1997 entitled the Relationship between Pavement Surface Texture and Highway Traffic Noise.

Two studies were conducted in Arizona. One was prepared for the City of Phoenix and the other was prepared for the City of Tucson. The study in the City of Phoenix was compared standard chip seal asphalt laid in 1984, and rubberized asphalt that was laid in 1989. *The study concluded that there was an approximate 10 dBA reduction in noise with the rubberized asphalt compared with the chip seal asphalt.*

The study prepared for the City of Tucson compared asphalt rubber concrete pavement and standard concrete pavement. *The study showed that the asphalt rubber concrete was 6.7 dBA quieter than the concrete pavement.*

In 1995, the Texas Transportation Institute conducted a study to identify potential problems with the current rubberized asphalt mix design, develop recommendations on those problems, develop recycling guidelines, and evaluate alternatives. Researchers monitored CRM mixtures paved in 1992 and 1993 in San Antonio, Texas. *The results of the these tests concluded that rubberized asphalt performed well in construction practices, and that the rubberized asphalt mixes gives a higher durability with better stability than dense-grade mixes.*

The National Research Council conducted a study showing the effect of different surface types on noise levels. *The Council studied many types of roadway surfaces and determined that open graded asphalt showed the greatest potential for noise reduction when compared to dense graded asphalt.* The study examined research done by Kansas, that studied the effects of rubberized asphalt. The results in Kansas showed that the open graded asphalt always showed a decrease in noise level. In contrast, when the asphalt rubber pavement was compared to the asphalt surface, there were both reductions and increases in noise level. *Thus, the results of this Kansas study did not show a clear noise reduction trend with rubberized asphalt.* However, the study done by the National Research Council did not examine any other research than the Kansas study.

Global Studies

Rubberized asphalt is a process that is not only of interest in the United States but also globally. In 1995, the Canadian Technical Asphalt Association performed a study for British Columbia on rubberized asphalt. Their study entitled, The Full Scale Evaluation of Rubberized Asphalt Concrete in British Columbia, was a response to the need for improvement of binders in the road building industry. In a paper done by Netherlands researchers, entitled Open Grade Rubberized Asphalt for Traffic Noise Reduction in Urban Areas, research was conducted to analyze the development of rubberized asphalt as a mitigation measure. Other studies have been done in Great Britain, West Germany, Belgium, and other European Countries.

The study conducted in British Colombia compared conventional pavement binders to Rubberized Asphalt (Rub-Arb [TM]) in various locations throughout British Columbia over a period of five years. This study concluded that within the laboratory, the asphalt rubber binder showed improved properties at extreme temperatures compared to convention asphalt. This study also concluded, that modified asphalt rubber binders can be manufactured for a wide range of climate conditions and requirement, it is more flexible at low and sub-zero temperatures, and that the thickness of the asphalt rubber concrete overlay can be reduced from the traditional 50mm overlay down to 38mm of modified asphalt rubber concrete.

In Dordrecht, Belgium a test was conducted using open graded rubberized asphalt in order to study the effectiveness of rubberized asphalt on noise. In this study the researchers concluded that it is possible to design an asphalt mix to reduce traffic noise in urban situations where the traffic noise is dominant. *The study found, that a noise reduction can be achieved of between 2.1 and 3.2 dBA at the speeds of around 50 km/h.*

Additional studies have been conducted in other European countries. *The Societe des Autoroutes du Nord et de l'Est de la France, Paris conducted a study that showed a noise reduction level of 2-3 dBA with rubberized asphalt along the Seine River.* In a paper presented at the 1988 Asphalt-Rubber Conference in Graz, Austria, Helmut Prager, Engineer of Austrian Highways and Bridges showed how the rubber overlay provides better noise reduction. Finally, in Bonn, Germany a study showed that using rubberized asphalt as a sound mitigation measure is more cost effective than using sound barriers.

Most of these studies concluded that rubberized asphalt could reduce noise by 2-3 dBA with few technical problems.

Finally, The European Commission Green Paper, published in the June 1997 edition of Noise/News International, cites the following on Page 87:

"Low-noise porous road surfaces have been the subject of much research. These porous road surfaces reduce both the generation and propagation of noise by several mechanisms - which can be related to the open structure of the surface layer. Results have shown that the emission noise levels can be reduced from levels generated on equivalent non-porous road surfaces by between 3-5 dB(A) on average; by optimizing the surface design, larger noise reductions are feasible. At present, the cost of porous asphalt surfacing is higher than conventional surfaces (for resurfacing, but for new roads, the cost is minimal), but may drop as contractors gain experience with porous surfaces. The material is also less durable. However, improvements are being made to durability and, in many countries, these materials are already being used as part of normal road construction in noise-sensitive areas."

Table of Contents | Executive Summary | Introduction | History of Noise Reducing Pavement | The Process of Producing Rubberized Asphalt | Current Uses of Rubberized Asphalt | Tables | Studies of Rubberized Asphalt Outside of Sacramento County | Sacramento County Rubberized Asphalt Noise Studies | Conclusions of the Studies Conducted in Sacramento County | Appendix A - Acoustical Terminology | Appendix B - Noise Standards Commonly Applied to Projects in Sacramento County

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ise

ı Wikipedia, the free encyclopedia

ımon use the word **noise** means unwanted sound or noise pollution, but in electronics noise can refer to the ›nic signal corresponding to acoustic noise (in an audio system) or the electronic signal corresponding to .sual) noise commonly seen as 'snow' on a degraded television or video image. In signal processing or ıting it can be considered data without meaning; that is, data that is not being used to transmit a signal, but ›ly produced as an unwanted by-product of other activities. In Information Theory, however, noise is still .ered to be information.

ıy of these areas, the special case of thermal noise arises, which sets a fundamental lower limit to what can ısured or signaled and is related to basic physical processes at the molecular level described by well known formulae.

ıtents

onmental noise

Main article: Noise pollution

ımental noise is the collection of offending sounds to which humans are involuntarily exposed. The ıl sources of environmental noise are motor vehicles, aircraft and, increasingly, entertainment from live or .ced music. Environmental noise is commonly referred to as Noise pollution.

ımental noise is governed by noise regulations which set maximum recommended levels of sound levels ific land uses, such as residential areas, schools, areas of outstanding natural beauty, or factories. These ls often specify measurement using a weighting filter, most often A-weighting, but in many cases this is :opriate as it gives a reduced response to low frequency sounds, and does not take account of the ›d annoyance value of bass boom from modern pop music, which penetrates walls and windows more ıan higer frequencies. Standards for the measurement of entertainment noise are currently confused and :esearch projects have recently set out to determine a valid method. There are significant noise health both physiological and psychological. Environmental noise is usually measured in decibels, because of t dynamic range of the human ear.

:ic noise

. speaking of noise in relation to sound, what is commonly meant is meaningless sound of greater than usual ıe. Thus, a loud activity may be referred to as *noisy*. However, conversations of other people may be called for people not involved in any of them, and noise can be any unwanted sound such as the noise of aircraft, bours playing loud music, or road noise spoiling the quiet of the countryside.

lm sound theorists and practitioners at the advent of talkies c.1928/1929, noise was non-speech sound or l sound and for many of them noise (especially asynchronous use with image) was desired over the evils of ue synchronized to moving image. The director and critic René Clair writing in 1929 makes a clear ction between film dialogue and film noise and very clearly suggests that noise can have meaning and be reted: "...it is possible that an interpretation of noises may have more of a future in it. Sound cartoons, using noises, seem to point to interesting possibilities" ('The Art of Sound' (1929)). Alberto Cavalcanti uses noise nonym for natural sound ('Sound in Films' (1939)) and as late as 1960, Siegfried Kracauer was referring to ıs non-speech sound ('Dialogue and Sound' (1960)).

strial noise

rial noise is usually considered mainly from the point of view of environmental health, rather than ce, as sustained exposure causes permanent hearing damage. A-weighted measurements are commonly use s as well, and special exposure meters are available that integrate noise over a period of time to give an Leq equivalent sound pressure level), defined by standards. In the case of industrial noise affecting nearby ıces or other sensitive receptors, the phenomenon is considered noise pollution.

) noise

o, recording, and broadcast systems *audio noise* refers to the residual low level sound (usually hiss and ıat is heard in quiet periods of programme.

o engineering it can also refer to the unwanted residual electronic noise signal that gives rise to acoustic eard as 'hiss'. This signal noise is commonly measured using A-weighting or ITU-R 468 weighting

s often generated deliberately and used as a test signal. Two types of deliberately generated noise in n use are referred to as 'white noise', which has a uniform spectral power density at all frequencies, or ›ise' which has a power spectral density that falls at 3dB/octave with rising frequency. The latter is often seful in audio testing because it contains constant energy per octave (and hence per commonly used 1/3rd , rather than a preponderance of energy at high frequencies. In other words it contains energy that is ted geometrically rather than linearly.

noise

Aain article: Noise (radio)

oise is interference picked up between transmitter and receiver output, often referred to as **static**. Radio n be caused by virtually any electromagnetic source, from lightning to man-made electronics, including iver itself. Transmitter power must be increased to overcome radio noise over long distances.

noise

and television, noise refers to the random dot pattern that is superimposed on the picture as a result of ic noise, the 'snow' that is seen with poor (analog) television reception or on VHS tapes. Interference and other forms of noise, in the sense that they are unwanted, though not random, which can affect radio vision signals.

ronic noise

Main article: Electronic noise

onic noise exists in all circuits and devices as a result of thermal noise, also referred to as Johnson Noise. onductor devices can also contribute flicker noise and generation-recombination noise. In any electronic ;, there exist random variations in current or voltage caused by the random movement of the electrons ıg the current as they are jolted around by thermal energy. The lower the temperature the lower is this ıl noise. This same phenomenon limits the minimum signal level that any radio receiver can usefully ıd to, because there will always be a small but significant amount of thermal noise arising in its input s. This is why radio telescopes, which search for very low levels of signal from stars, use front-end ›ise amplifier circuits, usually mounted on the aerial dish, cooled in liquid nitrogen to a very low :ature.

›nic noise is often measured in uV/root Hz, a term that derives from the fact that doubling the bandwidth of asurement doubles the power level measured, but voltage is proportional to the square root of power. ıted circuit devices, such as op-amps commonly quote equivalent input noise level in these terms (at room 'ature).

also

Wikiquote has a collection of quotations related to: ***Noise***

- Noise (audio) - residual low level "hiss or hum"
- Noise (industrial) - hearing damage and industrial hygiene
- Noise (video) - "snow" on video or television pictures
- Noise (electronic) - related to electronic circuitry.
- Noise pollution - relates to unwanted environmental sound
- Noise (radio) - interference related to radio signals.
- Noise (economic) - relates to a theory of pricing developed by Fischer Black.
- Noise (big-bang) - cosmic microwave background radiation detected by astronomers.
- Noise figure - the ratio of the output noise power to attributable thermal noise.
- Signal noise - in science, fluctuations in the signal being received.
- Thermal noise - sets a fundamental lower limit to what can be measured.
- Neuronal noise
- White noise
- Weighting filter
- TU-R 468 noise weighting
- -weighting
- qual-loudness contour
- mbient noise level
- ist of noise topics
- loise pollution
- loise music - music using sounds regarded as unpleasant or painful.
- loise regulation
- loise (Goidelic mythology)

rnal links

udio Measuring Articles Electronics (http://www.lindos.co.uk/cgi-bin/FlexiData.cgi?SOURCE=Articles)

Emulsion Product Range
Bituminas E/K1-40
Bituminas E/RS-1K

Bituminas E/K1-40 Specifications

Property	Unit	Specifications	Test Method
Viscosity (Engler) at 20 °C	°E	<4	BS 434-1(App G1)
Storage Stability Test, 24 h	%	<1	ASTM D244
Residue on 710 um BS sieve	% mass	<0.05	BS 434-1 (App D1)
Residue on 150 um BS sieve	g/100 ml	<0.15	BS 434-1 (App D2)
Particle Charge Test	-	Positive	BS 434-1 (App C)
Binder Content	% mass	>38	BS 434-1 (App F)

Bituminas E/RS-1K Specifications

Property	Unit	Specifications	Test Method
Saybolt Furol Viscosity: @ 25 °C	Sec	<50	ASTM D244
Storage Stability Test, 24 h	%	<1	ASTM D244
Sieve Test	%	<0.1	ASTM D244
Particle Charge Test	-	Positive	ASTM D244
Residue from Distillation	% mass	>50	ASTM D244
Test on Residue from Distillation Test			
Penetration at 25 °C, 100g, 5sec.	dmm	60 - 200	ASTM D244
Solubility in Trichloroethylene	% mass	>97.5	ASTM D244

Introduction

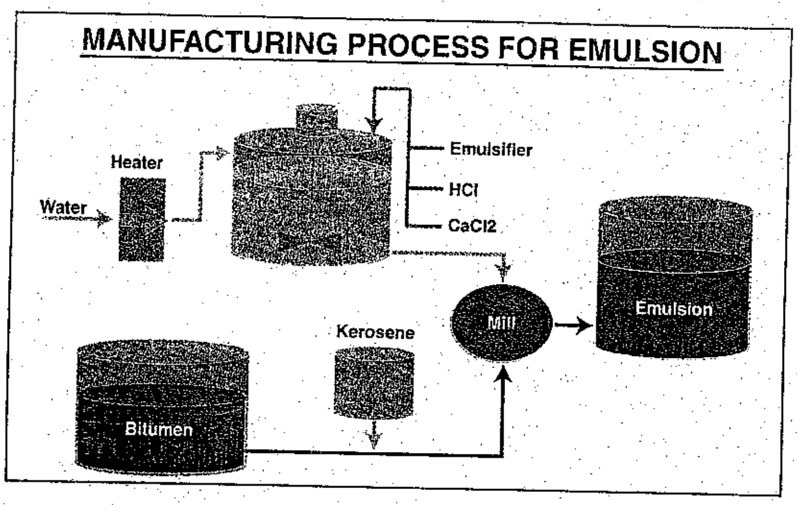
Liquid bitumen mixed with aggregate particles to form a viscoelastic material is often used for preparing cold mixes. Bituminous cold mix has been traditionally used as patching material to repair potholes in asphalt pavement in view of its ease and small volume requirements. Besides cold mixes, liquid bitumen is also used in microsurfacing, slurry seal, chip seal and as prime coat and tack coat during road construction and maintenance.

Bitumen by itself is a highly viscous liquid and would require heating to high temperature to reach fluidity. Alternatively, it can also be made fluid by adding a suitable solvent as in the case of cut-back bitumen. However, the use of solvent can result in pollution of the atmosphere during the evaporation stage and at the same time possess fire hazard during handling and storage.

Solution

Compared to cut-back bitumen used in the same applications which tends to release volatile organic compound (VOC) thus polluting the air and are fire hazard, bitumen emulsions are user and environment friendly as it releases only water through evaporation.

Bitumen Emulsions are dispersion of bitumen droplets in a pre-blended soap solution consisting suitable amount of emulsifier. Typical emulsions contains between 38% to 72% bitumen and droplet sizes in the range 1 to 10 micrometer in diameter. It does not require heating when applied and it has the advantage over hot bitumen that it can be used with cold and even on damp aggregates. Emulsion is stabilised by the presence of emulsifier. Bitumen emulsion are of two types, cationic and anionic. For road construction, cationic emulsions are the preferred type as they are compatible with a broad range of aggregates and exhibit even breaking characteristics.



Applications

Tack Coat

Tack coat is a light spray of bitumen emulsion, is used to ensure the bond between an old surface and a new bitumen premix layer. The tack coat must be very thin and must cover the entire surface evenly. Rapid setting emulsion with bitumen content 40% to 60% are used. The rate of application should be 0.3 to 0.7 litres per m2 depending on the surface being sprayed.

Prime Coat

Prime Coating is normally applied to a granular base layer as a precursor to the application of the first layer of premix over the granular pavement layers. Slow setting emulsion with bitumen content 55% to 60% is used. Normal spray rates are 0.7 to 1.2 liters per m2 depending on the properties of the granular base. High binder content and slow setting product is recommended for this application in order for the bitumen to penetrate into the aggregates and forms a strong bonding between the crusher run and the new premix laid.

Bituminas E/RS-1K and Bituminas E/K1-40 are highly recommended for tack coat.

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Application Information

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...er of road maintenance solutions & Services
...facture & supply of Bitumen & Polymer Modified
...en related products for the road construction industry

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Application Information

...one Mastic Asphalt

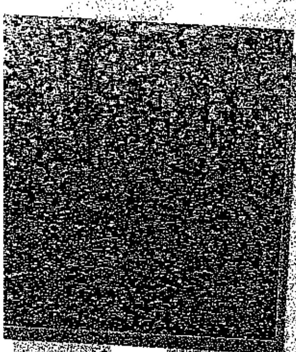
...e Mastic Asphalt is a hot mix consisting of high stone to stone contact to provide ...with a rich mortar binder for flexible, durable and coarser surface texture in order to ...ood skid resistants

*...: **BITUMINAS** is designed as a surface-wearing course on any high profile,high volume ...and accident areas, where a skid resistance and durable surface is required.*

*...nents with cracking or raveling it is suggested that SMA using **BITUMINAS** can be ...d for use as an overlay in conjunction with a mill and pave operation. Rutting or ...ems should be addressed before placement of the surface course.*

***BITUMINAS** is also an integral part of the Perpetual Pavement concept acting as a ...uctural layer-wearing surface.*

*...: **BITUMINAS** Modified Asphalt in SMA can costs more than conventional wearing ...h benefits associated with longer performance and an environmentally friendly ...urface.*



*...exture of **SMA***

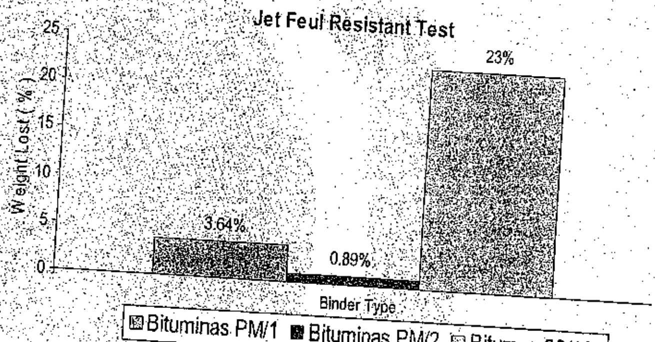
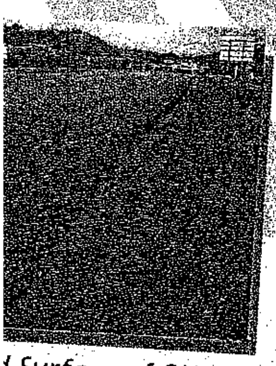


Figure 1: Jet Fuel Resistant Test



*...l Surface of **SMA***

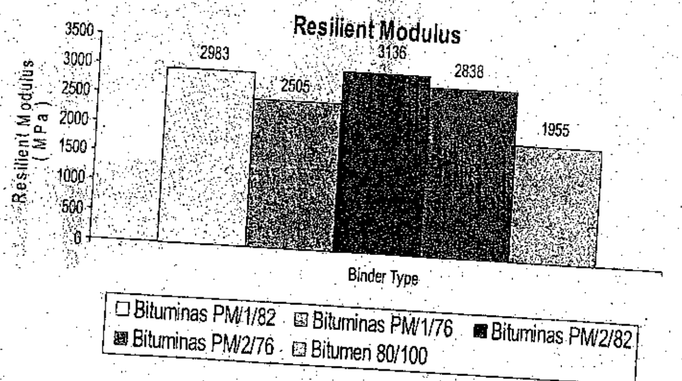


Figure 2: Resilient Modulus Test

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Application Information

...phalt

*...phalt using **BITUMINAS** is a special type of pavement that allows water to pass ... thereby reducing the runoff from a site and surrounding areas.*

*...sphalt pavement consists of an open-graded coarse aggregate, bonded together by ...cement (**BITUMINAS**), with sufficient interconnected voids to make it highly ...e to water. The porous pavement surface is typically placed over an impermeable ...e void spaces in the aggregate layers act as a storage reservoir for runoff.*

*...pavement using **BITUMINAS** may substitute for conventional pavement on highways, ...t areas and the shoulders of airport taxiways, provided that the grades, sub soils, ...e characteristics, and groundwater conditions are suitable. Slopes should be flat or ...ntle.*

*...lvantages of using **BITUMINAS** porous pavement is improved road safety because of ...skid resistance and reduced surface water.*

*...mended type of **BITUMINAS** use in SMA and Porous Asphalt:*

...UMINAS PM/1
...UMINAS PM/2
...UMINAS MR/76

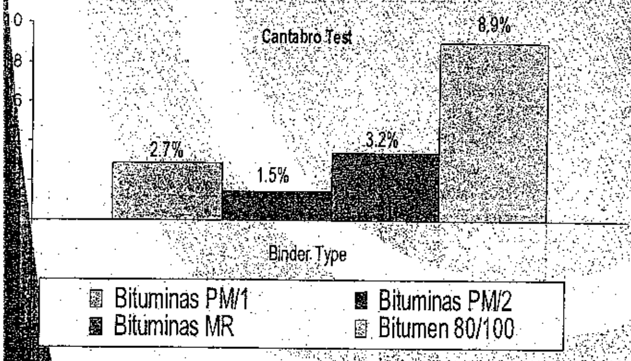
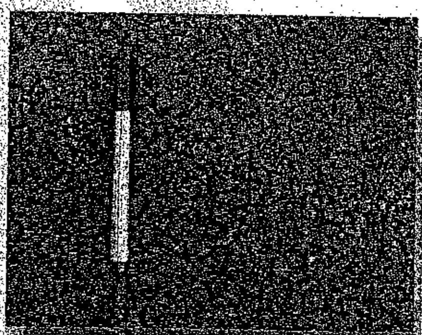


Figure 3: Cantabro Test



Texture of Porous Asphalt

*Drainability after Raining on **Porous Asphalt***

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BITUMINAS MODIFIED ASPHALT
Application Information

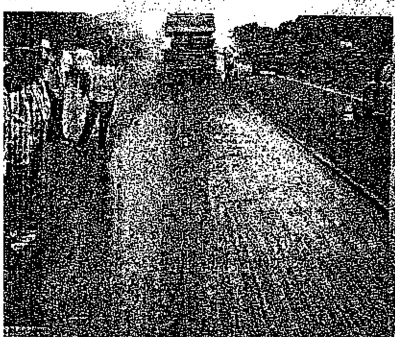
…ss Absorbing Membrane Inter-Layer

…ength to inhibit and impede the reflection of existing cracking (crack propagation) …ower pavement layer to the new overlay

*…ears, paving fabrics or geomembranes have been used to reduce reflective cracking …nderlying pavement joints or cracks. A membrane can be established through the … of liquid asphalt cement (**BITUMINAS**), fabric and an Asphalt Concrete overlay.*

*…top of **BITUMINAS** modified asphalt can be effective in developing a waterproof …inimize surface water intrusion. If water in the pavement structure is a potential …abric and **BITUMINAS** can aid in the development of a waterproof membrane.*

*… of fabrics will be more effective if the crack or joint is a nonworking joint, such …tudinal joint in a pavement. An example of a possible use would be as a spot … on asphalt pavement sections that show signs of alligator cracking related to a …sub grade condition. Fabric would be placed on top of **BITUMINAS** just before the …ncrete being laid.*



…MINAS Layer as a Part of a SAMI

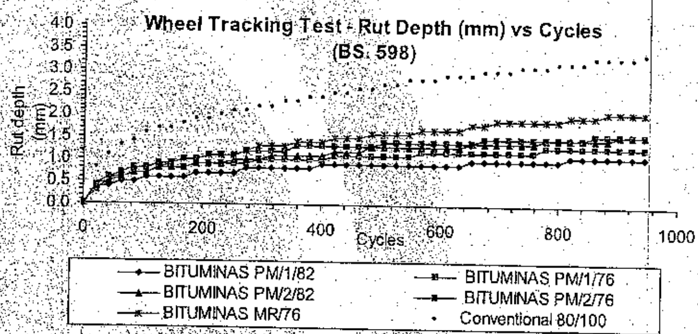
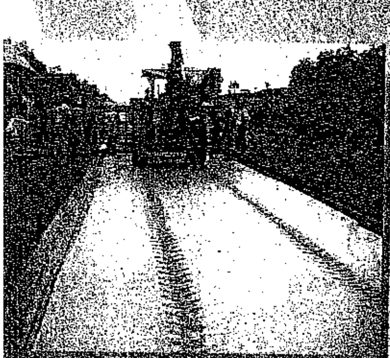


Figure 4: Wheel Tracking Test



…g Fabric on top of BITUMINAS Layer to Form SAMI

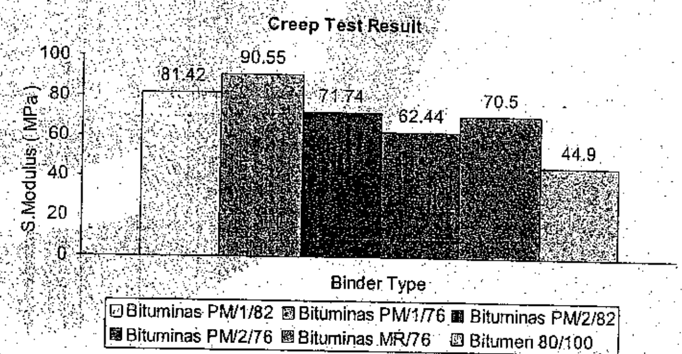


Figure 5: Creep Test

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BITUMINAS MODIFIED ASPHALT
Application Information

sion Treated Bases

odification or stabilisation for upgrading substandard or granular material to cohesion properties, insensitivity to water and mechanical strength

*n of bitumen emulsion **SS-1** to new or reclaimed gravels offers the following*

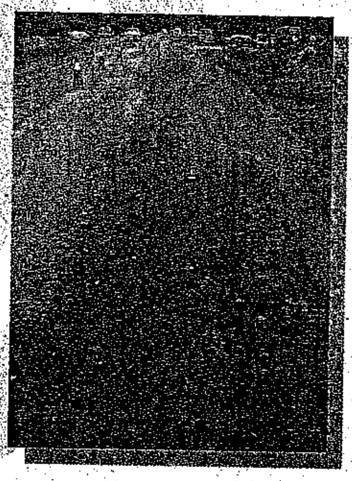
es the internal friction of the gravel, crusher run or crushed stone during tion thus improving its compacted density and its workability.
es water susceptibility and improves cohesion by binding the fine aggregate.
*ion of a fairly small amount of emulsion **SS-1** can significantly increase the of the material.*
s the development of potholes in the base when the surface is damaged.
ent of the upper base layer during construction usually eliminates the priming

ated base may be used in a wide range of applications, from surface coarse for ent structures to base for high volume roads. This is possible as the emulsion be varied and the appropriate base material selected to yield mixes with suitable properties.

*ed type of **EMULSION** use in ETB:*

-1

Recycled Area



Completed Surface prior to Surfaces

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Application Information

ion of Bituminous material to a pavement surface with a cover of mineral aggregate to provide anti-skid properties, good drainage & cost saving (not involve milling &

ing consists of spraying liquid asphalt (**BITUMINAS**) on the existing pavement, then the asphalt with a layer of mineral aggregate. **BITUMINAS** helps prevent moisture etrating into the pavement, thus slowing the formation of cracks and potholes. The e chips, which are pressed into the pavement, help provide a anti-skid texture to the ace.

p traffic control is the first phase of a sealing operation. Next, the road is swept oom machine to remove debris from the surface. The actual sealing operation begins ication of **BITUMINAS** on top of the existing pavement. Following close behind is an (gravel chip) spreading machine. Next in line are rolling machines, which compact l into the layer of **BITUMINAS** and pavement. The road is once again swept with a ichine to remove excess gravel once the **BITUMINAS** layer has hardened sufficiently the majority of the chips.

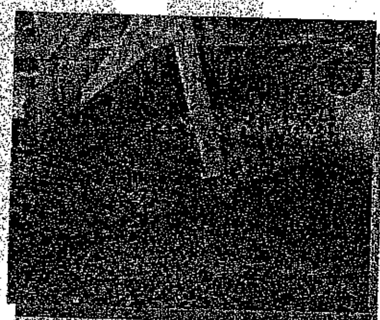
ng extends pavement life and gives safety to the roads and increased skid resistance

nded type of **BITUMINAS** use in SAMI and Chip Seal:

S PM/1

Spraying BITUMINAS

Texture of Chip Seal



Spreading Chipping on top of BITUMINAS

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Rubberized asphalt mixtures: a novel approach to pavement noise reduction

B. J. Putman & S. N. Amirkhanian
Department of Civil Engineering, Clemson University, U.S.A.

Abstract

Noise, which is defined as unwanted sound, is present everywhere whether at home, in an office, or on the road. When noise reaches a certain level, it becomes annoying or uncomfortable to the human ear. Highway noise is one such noise that has become a serious issue in many cities in the United States. Highway noise eminates from three main sources of a vehicle: the interaction between the tires and the pavement, engine and exhaust noise, and noise resulting from the aerodynamic effects of the vehicle. In an effort to mitigate highway noise, local, state, and/or federal agencies typically construct noise barriers adjacent to the highway. These barriers effectively reduce the noise heard by those located behind the barrier, but this method of noise reduction can come at a cost of up to $290/m^2 in some cases. In addition, some sound barriers are not aesthetically pleasing to the public. An alternative to constructing noise barriers is to address the highway noise problem at the source with the use of rubberized asphalt concrete as a surface course on the highways. Such rubberized asphalt mixtures have been proven to reduce the noise generated by the interaction between the vehicle and the pavement resulting in perceived noise reductions of 50% in some cases. Not only does the rubberized asphalt reduce noise generation, but it also provides more durable pavements that are less susceptible to the effects of temperature.
Keywords: highway noise, asphalt, rubberized asphalt, asphalt-rubber, noise pollution, open graded friction course.

1 Introduction

Throughout the United States, as with many other countries, once suburban areas are beginning to show signs of the urban areas they surround. One of these signs

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3.4.1 Sources of airborne tyre noise

Airborne tyre noise has dominated the wayside noise levels caused by vehicles travelling at higher speeds for years, and more recently has begun to affect the low-speed acceleration tests used for type approval. As a result, a proposed EC Directive aims to reduce the problem by setting noise limits for different tyre types [C30/8, 28/1/98].

There is some debate over the sources of airborne tyre noise. The two noise-generating mechanisms given most attention are:

1. Noise generated when air is pumped in and out of tyre tread and road cavities during the contact process – the so-called air-pumping noise.
2. Noise generated by vibrations in the tyre caused by the contact process.

The most plausible explanation for the doubt over noise-generating mechanisms is that both may prove significant depending on:

- tyre construction and tread pattern;
- road surface;
- speed of the tyre.

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- most of the noise originates near to the contact patch;
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Tonal tyre noise is more speed-dependent than random tyre noise. Random tyre noise is strongly affected by the characteristics of the road surface. A simple empirical relationship between noise levels at 7.5 m and the tyre noise caused by coasting vehicles is presented in (Nilsson, 1976).

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ere

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urface roughness;
ne ability to shed surface water;
ound absorption.

PETRONAS Bituminas

...for tomorrow's roads...

BITUMINAS ***MODIFIED ASPHALT***
Application Information

...halt

*...halt using **BITUMINAS** is a special type of pavement that allows water to pass ... thereby reducing the runoff from a site and surrounding areas.*

*...phalt pavement consists of an open-graded coarse aggregate, bonded together by ...cement (**BITUMINAS**), with sufficient interconnected voids to make it highly ...e to water. The porous pavement surface is typically placed over an impermeable ...e void spaces in the aggregate layers act as a storage reservoir for runoff.*

*...pavement using **BITUMINAS** may substitute for conventional pavement on highways, ... areas and the shoulders of airport taxiways, provided that the grades, sub soils, ...e characteristics, and groundwater conditions are suitable. Slopes should be flat or ...ntle.*

*...vantages of using **BITUMINAS** porous pavement is improved road safety because of ...skid resistance and reduced surface water.*

*...mended type of **BITUMINAS** use in SMA and Porous Asphalt:*

...UMINAS PM/1
...UMINAS PM/2
...UMINAS MR/76

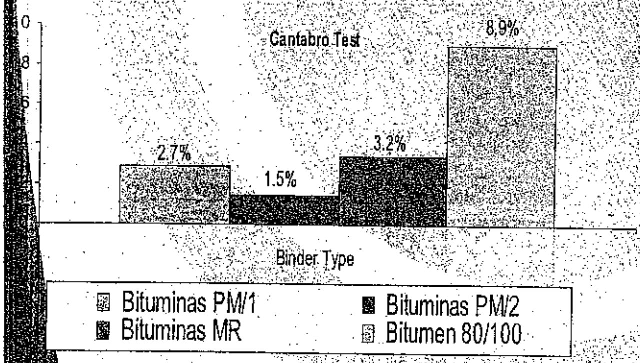
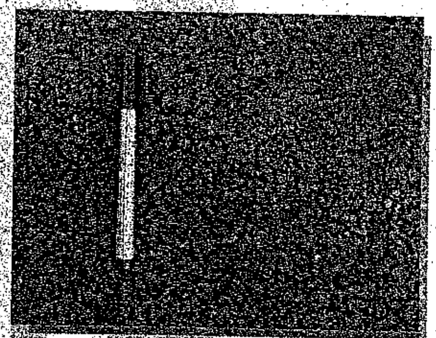


Figure 3: Cantabro Test



Texture of Porous Asphalt

*Drainability after Raining on **Porous Asphalt***

PPMS

...Sdn Bhd, 35-1 &35-2, Jalan Ara SD 7/3B, Bandar Sri Damansara, 52200 Kuala Lumpur

...tomorrow's roads...

PETRONAS Bituminas

BITUMINAS MODIFIED ASPHALT
Application Information

...ss Absorbing Membrane Inter-Layer

...ength to inhibit and impede the reflection of existing cracking (crack propagation) ...lower pavement layer to the new overlay

*...years, paving fabrics or geomembranes have been used to reduce reflective cracking ...underlying pavement joints or cracks. A membrane can be established through the ...n of liquid asphalt cement (**BITUMINAS**), fabric and an Asphalt Concrete overlay.*

*...top of **BITUMINAS** modified asphalt can be effective in developing a waterproof ...inimize surface water intrusion. If water in the pavement structure is a potential ...fabric and **BITUMINAS** can aid in the development of a waterproof membrane.*

*...n of fabrics will be more effective if the crack or joint is a nonworking joint, such ...itudinal joint in a pavement. An example of a possible use would be as a spot ...n on asphalt pavement sections that show signs of alligator cracking related to a ...sub grade condition. Fabric would be placed on top of **BITUMINAS** just before the ...ncrete being laid.*

...UMINAS Layer as a Part of a SAMI

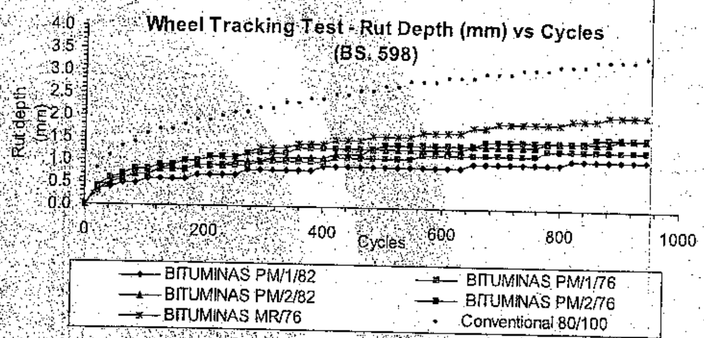
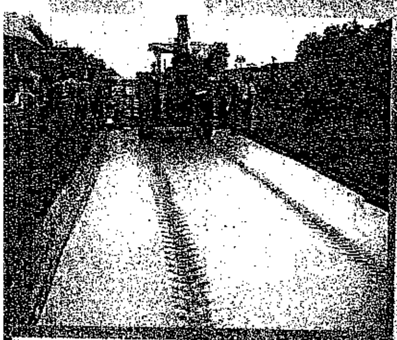


Figure 4: Wheel Tracking Test



...ng Fabric on top of BITUMINAS Layer to Form SAMI

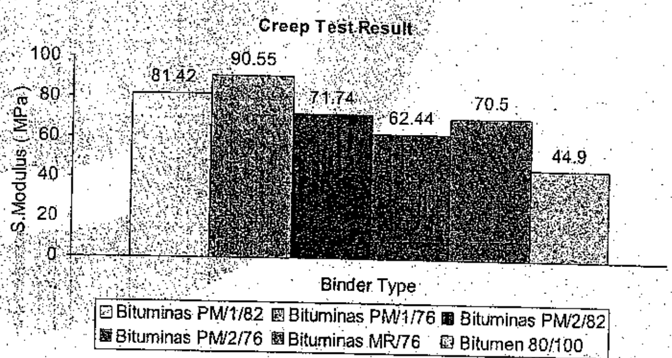


Figure 5: Creep Test

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BITUMINAS MODIFIED ASPHALT
Application Information

'sion Treated Bases

nodification or stabilisation for upgrading substandard or granular material to e cohesion properties, insensitivity to water and mechanical strength

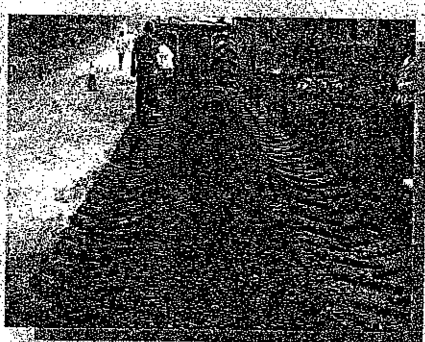
on of bitumen emulsion **SS-1** to new or reclaimed gravels offers the following :

ces the internal friction of the gravel, crusher run or crushed stone during ction thus improving its compacted density and its workability.
:es water susceptibility and improves cohesion by binding the fine aggregate.
:ion of a fairly small amount of emulsion **SS-1** can significantly increase the S of the material.
es the development of potholes in the base when the surface is damaged.
ent of the upper base layer during construction usually eliminates the r priming

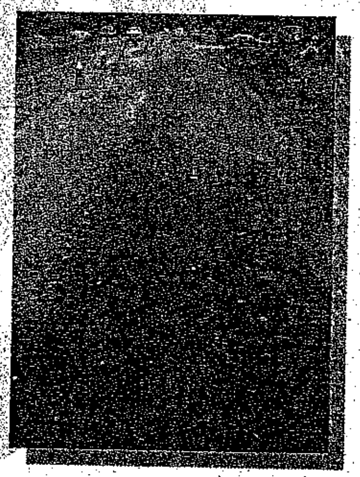
eated base may be used in a wide range of applications, from surface coarse for ent structures to base for high volume roads. This is possible as the emulsion be varied and the appropriate base material selected to yield mixes with suitable properties.

ed type of **EMULSION** use in ETB:

S-1



Recycled Area



Completed Surface prior to Surfaces

...ed for tomorrow's roads...

PETRONAS Bituminas

BITUMINAS MODIFIED ASPHALT
Application Information

...al

...ion of Bituminous material to a pavement surface with a cover of mineral aggregate ...g, to provide anti-skid properties, good drainage & cost saving (not involve milling &

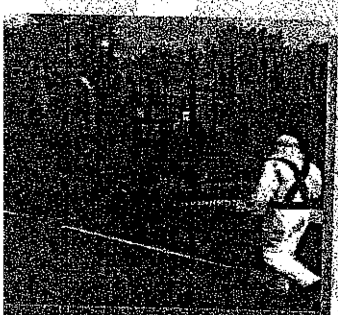
...ling consists of spraying liquid asphalt (**BITUMINAS**) on the existing pavement, then ...the asphalt with a layer of mineral aggregate. **BITUMINAS** helps prevent moisture ...netrating into the pavement, thus slowing the formation of cracks and potholes. The ...e chips, which are pressed into the pavement, help provide a anti-skid texture to the ...face.

...p traffic control is the first phase of a sealing operation. Next, the road is swept ...room machine to remove debris from the surface. The actual sealing operation begins ...lication of **BITUMINAS** on top of the existing pavement. Following close behind is an ...e (gravel chip) spreading machine. Next in line are rolling machines, which compact ...el into the layer of **BITUMINAS** and pavement. The road is once again swept with a ...achine to remove excess gravel once the **BITUMINAS** layer has hardened sufficiently ... the majority of the chips.

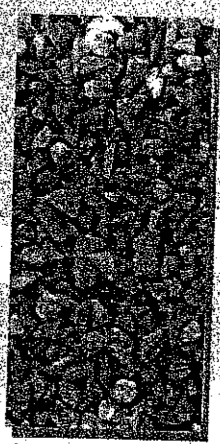
...ing extends pavement life and gives safety to the roads and increased skid resistance

...nded type of **BITUMINAS** use in SAMI and Chip Seal: -

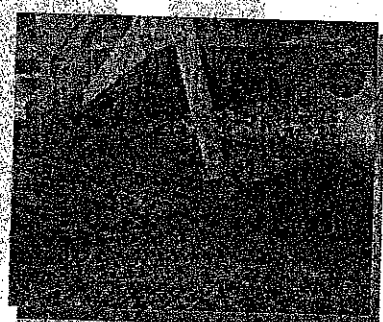
...S PM/1



Spraying BITUMINAS



Texture of Chip Seal



Spreading Chipping on top of BITUMINAS

...echnologies Sdn Bhd, 35-1 &35-2, Jalan Ara SD 7/3B, Bandar Sri Damansara, 52200 Kuala Lumpur
Tel: +60 3 62803969 Fax: +60 3 62803...

Rubberized asphalt mixtures: a novel approach to pavement noise reduction

B. J. Putman & S. N. Amirkhanian
Department of Civil Engineering, Clemson University, U.S.A.

Abstract

Noise, which is defined as unwanted sound, is present everywhere whether at home, in an office, or on the road. When noise reaches a certain level, it becomes annoying or uncomfortable to the human ear. Highway noise is one such noise that has become a serious issue in many cities in the United States. Highway noise eminates from three main sources of a vehicle: the interaction between the tires and the pavement, engine and exhaust noise, and noise resulting from the aerodynamic effects of the vehicle. In an effort to mitigate highway noise, local, state, and/or federal agencies typically construct noise barriers adjacent to the highway. These barriers effectively reduce the noise heard by those located behind the barrier, but this method of noise reduction can come at a cost of up to $290/m^2 in some cases. In addition, some sound barriers are not aesthetically pleasing to the public. An alternative to constructing noise barriers is to address the highway noise problem at the source with the use of rubberized asphalt concrete as a surface course on the highways. Such rubberized asphalt mixtures have been proven to reduce the noise generated by the interaction between the vehicle and the pavement resulting in perceived noise reductions of 50% in some cases. Not only does the rubberized asphalt reduce noise generation, but it also provides more durable pavements that are less susceptible to the effects of temperature.
Keywords: highway noise, asphalt, rubberized asphalt, asphalt-rubber, noise pollution, open graded friction course.

1 Introduction

Throughout the United States, as with many other countries, once suburban areas are beginning to show signs of the urban areas they surround. One of these signs

3.4.1 Sources of airborne tyre noise

Airborne tyre noise has dominated the wayside noise levels caused by vehicles travelling at higher speeds for years, and more recently has begun to affect the low-speed acceleration tests used for type approval. As a result, a proposed EC Directive aims to reduce the problem by setting noise limits for different tyre types [C30/8, 28/1/98].

There is some debate over the sources of airborne tyre noise. The two noise-generating mechanisms given most attention are:

1. Noise generated when air is pumped in and out of tyre tread and road cavities during the contact process – the so-called air-pumping noise.
2. Noise generated by vibrations in the tyre caused by the contact process.

The most plausible explanation for the doubt over noise-generating mechanisms is that both may prove significant depending on:

- tyre construction and tread pattern;
- road surface;
- speed of the tyre.

The air-pumping mechanism has been shown to be significant for tyres with deep cross-grooves (known as cross-bar or cross-lug tyres) (Wilken et al., 1976). The effect of a single cross-groove cut into a treadless tyre was studied. Filling the groove with foam helped identify that the air-pumping mechanism is reinforced by acoustic resonance of the groove near its quarter wavelength frequency. Opening the closed end of the groove to circumferential grooves helped control this resonance.

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