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ABSTRACT

The application of crumb rubber modifier (CRM) and low-density polyethylene (LDPE) in asphalt mixtures is intended to improve the properties of bitumen in the bituminous mixture. The objective of this study is thus to evaluate the behavior of bituminous mix when added with different types of waste materials and evaluate the performance of this mixture. In this study, a laboratory investigation was conducted on the properties of CRM and LDPE binders as a function of percentages. Evaluation of the binder included the following testing procedures: penetration and softening point test while for the bituminous mixture: Marshall Test, creep test as well as indirect tensile stiffness modulus test. Based from previous literature, it is expected that the results from this study will indicate that the higher CRM and LDPE percentages up to a certain optimum point for binders will lead to a higher viscosity, a better rutting resistance and a less chance for low temperature cracking. However, other factor which is affecting this binder performance is going to be mentioned and recommendations on this area for future study will be stated.

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CHAPTER 1
PROJECT BACKGROUND

1.1 Background of Study

Economic growth might be teetering across the world, but the amount of garbage generated by global cities is only going up. Together, urban centres generate 1.3 billion tonnes of solid waste a year and it is set to grow to 2.2 billion tonnes by 2025, according to projections by the World Bank. Most of the waste is sent to landfills, or worse, to open dumps, raising concerns about air pollution, social unrest, and impact on poverty and so on. Managing solid waste has costs—$205.4 billion at present—and it's growing. It is set to touch $375.5 billion by 2025 (Ramnath, 2012). Malaysia, like most of the developing countries, is facing an increase of the generation of waste and of accompanying problems with the disposal of this waste. Overall, the local communities generate 16,000 tons of domestic waste per day and the amounts per capita vary from 0.45 to 1.44 kg per day depending on the economic status of the areas concerned (Lau, 2004). With the rapid economic growth and urbanization that is taking place in currently, solid waste generation and management is becoming a major social and environmental issue. One of the approaches towards solving the issue would be recycling of waste materials. The number of motorcar waste tires produced annually in Malaysia was estimated to be 8.2 million (Thiruvangodan, 2006). Besides that, waste tire is neither categorized as solid waste or hazardous waste. It is generally considered as industrial or trade waste and hence there is no specific law or regulation which governs waste tire management (Thiruvangodan, 2006). Another major contributor to solid waste production is plastic waste which is ranked the second highest with 24% out of the total waste disposed, compared to only 10% in Indonesia, 16% in Vietnam, 19% in Netherlands and 14% in Germany (Lai, 2012).

Figure 1 : Discarded Vehicle Tires

Figure 2 : Plastic Wastes

1.1.1 Modified Bituminous Mix

Investigations in India and countries abroad have revealed that properties of bitumen and bituminous mixes can be improved to meet requirements of pavement with the incorporation of certain additives or blend of additives. These additives are called "Bitumen Modifiers" and the bitumen premixed with these modifiers is known as modified bitumen. Modified bitumen is expected to give higher life of surfacing depending upon degree of modification and type of additives and modification (S, 2012).

Bituminous pavement are subjected to a variety of loading conditions which result in the development of internal tensile stresses, one source of failure which is likely to be induced in bituminous mixtures as a result of this inherent tensile characteristics in bituminous mixtures is cracking. A number of researchers have experimented with the use of various materials as additives and modifiers in bituminous mixtures (Kamaruddin, 1998).

1.2 Problem Statement

1.2.1 Problem Identification

Taking into view, the significant effects of improper management of solid waste management such as rubber tire and plastic bags may lead to very serious environmental related issues. Various studies reveal that about 90% of solid waste is disposed of unscientifically in open dumps and landfills, creating problems and hazards to public health and the environment (Sharholy, Ahmad, Mahmood, & R.C., 2007).

Besides that, the failures of pavement have increased significantly over the year due to the increase in road traffic which is proportional to the insufficient degree of maintenance. Structural failures in highway pavements such as cracks and rutting have always been an issue in highway construction. Natural rubber has been used in asphalt mix for many years however the bitumen with this modifier is traded at a very high cost. New approach using waste material should be developed to solve both problems using waste material should be developed to solve both problems.

1.2.2 Significance of project

The aim of the project is to study the performance of crumb rubber (CRM) and low density polyethylene (LDPE) in modified bitumen. By doing this, we will be able to reduce the cost and also improve the performance of flexible pavement for future highways construction due to the involvement of a more environmental friendly materials. Not to forget, the contribution it does to the reduction solid waste generation.

1.3 Objective

There are several objectives that need to be achieved when completing this project. The objectives are:

- To compare, under controlled laboratory conditions, the performance of the bitumen modified with an optimum percentage of crumb rubber and LDPE using the standard 80/100.
- To evaluate the behavior of bituminous mix when added with crumb rubber and LDPE and compare the result with conventional bituminous mix.
- To assess the different engineering implications and physical characteristics with the addition of waste materials into the binder mixture.
- To evaluate the economical implication with the use of crumb rubber and LDPE modified bitumen mixture as compared with the standard mixture.

1.3.1 Scope of Study

The research will involve the study of performance of modified bitumen using waste materials identified. Crumb rubber and low density polyethylene will be added as modifier to the bituminous mixture by carrying out laboratory procedure using the equipment available in the Highway Laboratory. The bituminous mixture sample will then be tested for its performance and analysis will be carried out based on the results.

1.4 Relevancy of Project

This project will focus on the topic of bituminous mixture with different composition and percentage of materials and performance analysis test for this mixture. These topics are much related to the course of Highway Engineering and knowledge of this subject is needed to perform research for this project. This project we will be focusing on highway pavement materials and design. Furthermore, the result of this project will allow waste material to be recycled as a modifier for bitumen mixture which enhances the performance of the mixture and also to serve as a one of the alternative for solid waste management.

1.5 Feasibility of the Project within the Scope and Time frame

The project is definitely within the scope since Highway Engineering is one of the core subjects of Civil Engineering. This helps since the author already have a basic idea about the project. The project is divided into two sections. The first section is basically about finding, collecting, and reading of journals, technical papers, and books of the research topic. After the literature review part, the author then start with the planning of the laboratory experiment. The second section of the project is mainly on carrying out experiment in the laboratory to prepare bitumen sample and to conduct the necessary test to analyse the performance of these materials. The author was given roughly around nine months to complete this project which is adequate to conduct all the laboratory work, data gathering, and analysis of result and also the documentation of the whole project.

CHAPTER 2
LITERATURE REVIEW

The majority of modern-day surfacing in the western world is bitumen-bound; only minor road surfacing is now composed of soil–aggregate materials (O'Flaherty, 2007). When a surfacing is composed of bituminous materials it may comprise a single homogeneous layer or course; more usually, however, with heavily-trafficked roads, two distinct sub-layers known as a wearing course and a base course are laid in separate operations.

2.1 Modified bitumen for road pavement in Malaysia

In Malaysia, rubberised bitumen is equally used for resurfacing jobs for roads and airports. According to Mustafa and Sufian (1997), rubber additives for road construction had been used in this country since the 1940's but there has not been any recorded evidence of such practices. The evidence available indicated that rubber was used in the early 1980's. However, these works were also not monitored and as a consequence there were no published reports on it. The Public Work Department (PWD) started monitoring and reporting the use of rubber additives for its road construction since the late 1980's. The first recorded trial was in 1988 for the rehabilitation of Jalan Vantooran in Kelang. Subsequently, several more field trials were constructed under a collaborative agreement between the PWD and Rubber Research Institute of Malaysia (RRIM). The trials used varying forms and techniques of incorporating rubber. Some examples of field trials involving rubberised bitumen are shown in Table 6.

Trials Sections	Date of Construction	Types of Rubber Additives
Rembau-Tampin	December 1993	Rejected glove rubber powder, tyre shaving and latex
Sungai Buloh	December 1997	Tyre shaving
Kuantan - Gambang	2002	Rejected tyre-rubber powder

Table 1 : Field Trial Sites Involving Rubberised Bitumen in Malaysia
(Mustafa and Sufian, 1997)

2.2 Performance of Waste Material in Modified Bitumen

With the rapid development of the automobile industry, we are facing problem related to the disposal of large-scale waste tires. Due to this, some studies has been conducted to minimize waste tires pollution and improve properties of asphalt mixtures where the properties of recycled tire rubber modified asphalt mixtures using dry process are studied in laboratory. In one of the research conducted in 2006, tests of three types asphalt mixtures containing different rubber content (1%, 2% and 3% by weight of total mix) and a control mixture without rubber were conducted. Based on results of rutting tests (60 °C), indirect tensile tests (−10 °C) and variance analysis, the addition of recycled tire rubber in asphalt mixtures using dry process are found to improve engineering properties of asphalt mixtures, and the rubber content has a significant effect on the performance of resistance to permanent deformation at high temperature and cracking at low temperature (Cao, 2006).

Test results by Marshall mix design

Rubber contents (%)	Engineering properties						
	Bulk specific gravity	Air voids (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (0.01 cm)	OAC (%)
0	2.392	4.0	17.4	77.0	11.6	28	5.7
1	2.383	3.8	16.9	77.5	10.8	43	6.0
2	2.348	3.9	17.2	77.3	10.0	40	6.2
3	2.314	4.1	17.5	76.6	9.1	38	6.4

Figure 3: Test Results by Marshall Mix Design

In the table above, it is found that bulk specific gravity, stability, flow and OAC of asphalt mixtures are affected by the addition of tire rubber. Because the specific gravity of rubber is far less than that of aggregate, the bulk specific gravity of rubber modified asphalt mixtures decrease with the increase in rubber contents. Due to lower compressive strength and higher elasticity of rubber, the stability and flow decrease with the increase in rubber contents. The values of stability and flow are both satisfied with the Marshall criteria.

Results of rutting test and indirect tensile test

Rubber contents (%)	Dynamic stability (cycles/mm)				Failure stiffness modulus (MPa)			
	Average				Average			
0	2356	2236	2488	2360	1011.8	1200	1009	1073.6
1	2387	2519	2662	2523	975.3	968.9	983.2	975.8
2	3236	3007	3418	3220	809.4	816.6	853.9	826.6
3	4456	4272	4559	4429	725.7	729.9	772.8	742.8

Figure 4 : Results of Rutting Test and Indirect Tensile Test

In contrast to a conventional mixture without rubber, dynamic stability (DS) of rubber modified asphalt mixtures increase with the increase in rubber content, while failure stiffness modulus (FSM) of rubber modified asphalt mixtures decrease. It could be concluded that the addition of tire rubber in asphalt mixtures using dry process could improve the properties of resistance to permanent deformation at high temperature (60°C) and cracking at low temperature (10°C).

In another research conducted, the study on the use of Low Density Polyethylene (LDPE) and Crumb Rubber Modified Bitumen (CRM) reveals that the Marshal Stability value has shown increasing trend and the maximum values have increased by about 25 % by addition of LDPE and CRM. The density of the mix has also increased in both the cases of LDPE and CRM when compared with 60/70 grade bitumen (S, 2012). The tables below shows the results of the studies which concluded that the performance of modified bitumen can be improved further using waste material as modifier.

S. No	Bitumen %	Marshal stability (Kg)	Flow value (mm)	Bulk Density (gm/cc)	Air voids % Vv	VMA	VFB %
1	4.50	845	2.86	2.234	4.93	14.97	67.23
2	4.75	865	3.10	2.236	4.44	15.05	70.12
3	5	945	3.26	2.245	3.64	14.85	74.58
4	5.25	880	3.71	2.235	3.24	14.98	77.1
5	5.50	850	3.98	2.23	3.04	15.29	77.96

Table 2 : Results of SDBC mix design using 60/70 grade bitumen

S.No	LDPE %	Bitumen %	Marshal Stability (Kg)	Flow value (mm)	Bulk Density (gm/cc)	Air voids % Vv	VMA	VFB %
1	3%	5.0	1050	3.10	2.24	3.86	15.04	74.12
2	6%	5.0	1120	3.88	2.25	3.43	14.66	76.23
3	9%	5.0	1185	3.91	2.25	3.21	14.48	77.18

Table 3 : Results of SDBC mix for varying percentage of LDPE

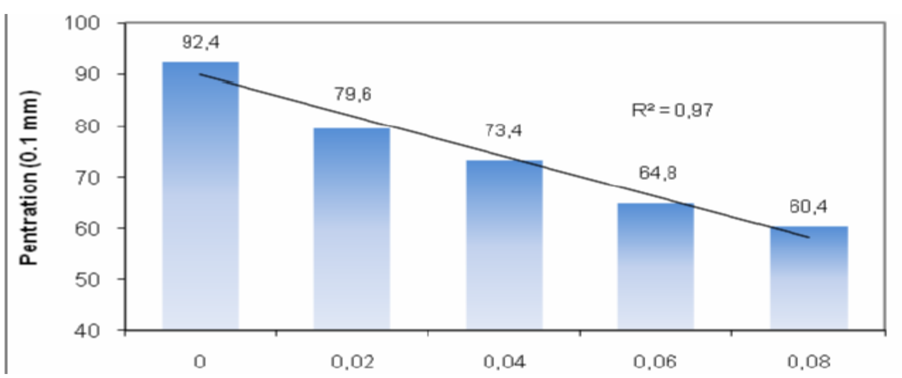
S. No	Crumb Rubber %	Bitumen %	Marshal stability (Kg)	Flow value (mm)	Bulk Density (gm/cc)	Air voids % Vv	VMA	VFB %
1	8%	5	1065	3.10	2.23	3.87	14.99	74.12
2	10%	5	1190	3.62	2.24	3.86	15.03	74.35
3	12%	5	1180	3.76	2.26	3.98	15.24	73.25

Table 4 : Results of SDBC mix for varying percentages of Crumb Rubber

This will provide more stable and durable mix for the flexible pavements. The serviceability and resistance to moisture will also be better when compared to the conventional method of construction.

Besides that, to compare the performance of bitumen as binder, the Centre for Transportation Engineering of Bangalore University has conducted laboratory studies on the possible use of the processed plastic bags as an additive. The processed plastic was used as an additive with heated bitumen in different proportions (ranging from zero to 12 % by weight of bitumen) and mixed well by hand, to obtain the modified bitumen. The properties of the modified bitumen were compared with ordinary bitumen. It was observed that the penetration and ductility values of the modified bitumen decreased with the increase in proportion of the plastic additive, up to 12 % by weight. The softening point of the modified bitumen increased with the addition of plastic additive, up to 8.0 % by weight (C.E.G. Justo & A. Veeraragavan, 2002).

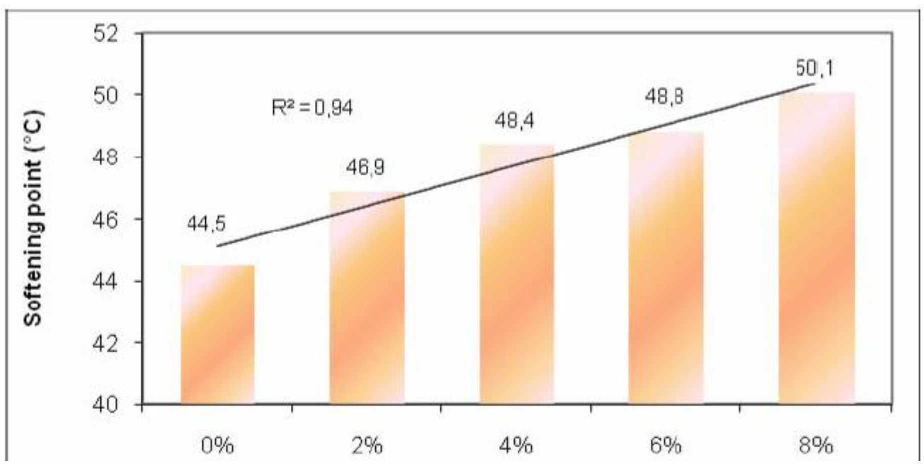
Another research to support this stated that the addition of LDPE makes the modified bitumen harder and more consistent ((Mahrez & Karim, 2010). Figure 5 below indicates that the consistency of the LDPE modified bitumen decreases as the LDPE content increases in the mix. Reduction of around 10% to 40% in penetration values with the addition of 2%, 4%, 6% and 8% of LDPE into the bitumen. This is good in one sense since it might improve the rutting resistance of the mix but on the other hand this may affect flexibility of the bitumen by making asphalt much stiffer, thus the resistance to fatigue cracking can be affected. This issue should be taken into consideration in using this waste material as modifier.



LDPE content (%)

Figure 5 : Penetration value of Bitumen with addition of LDPE

Figure 6 shows that the softening point increases with increasing LDPE content. It appears clearly from the results that the addition of LDPE into bitumen increases the softening point value and as the LDPE content increases, the softening point value also increases. This increase ranges from 5% to 13% with the addition of 2% to 8% contents. This phenomenon indicates that the resistance of the binder to the effect of heat is increased and it will reduce its tendency to soften in hot weather. Thus, with the addition of LDPE the modified binder will be less susceptible to temperature changes (Mahrez & Karim, 2010). The effect of softening point of a binder on resistance to permanent deformation of bituminous pavement mixes has been studied by various researchers. An example is hot rolled asphalt where it was found that the rate of rutting in the wheel tracking test at 45°C, was halved by increasing softening point by approximately 5°C (Bing, Hong, Thomas, & Lawrence, 2006). Therefore, it is expected that by using the LDPE in the bituminous mix, the rate of rutting will decrease due to the increase in softening point.



LDPE content (%)

Figure 6: Softening Point test of bitumen with addition of LDPE

Hence as a summary, it can concluded that both additives, rubber crumb and LDPE are proven to be successful in improving some of the properties of either the bitumen individually or as bituminous mixture. From previous researches, it is expected the properties of bituminous mixture will improve by incorporating rubber crumb and LDPE as additive to the binder.

2.3 Materials

Bituminous mixture consists of aggregate, filler and finally binder that can bind all of this material together and also to give the mixture its durability. The properties of each material and their function in the bituminous mixture are described in the following sections.

2.3.1 Aggregate

Aggregates are granular mineral particles; the aggregate used should be strong, tough, durable, and has the ability to be crushed into bulky particles without many flaky particles. In addition to gradation requirements, the aggregate are also required to possess the strength to carry and transmit the applied loads. There are four types of aggregate gradation namely, well-graded, gap graded, open graded and uniform graded (Atkins, 2003). Some typical terms are used in describing the aggregates depending on their sizes. Coarse aggregate (gravel size) is the aggregate particles mainly larger than 4.75mm. Fine aggregate is defined for aggregate particles between 4.75mm and 0.075mm while filler is used to describe particles that are smaller than 0.075mm (Atkins, 2003). The aggregate percentage and sieves sizes commonly used in wearing course construction in highways are indicated in the table below as represented in Jabatan Kerja Raya (JKR) Malaysian Standard.

Mix type	Wearing course
Mix designation	ACW 20
B.S Sieve	% passing by weight
37.5 mm	-
28.0 mm	100
20.0 mm	76-100
14.0 mm	64-100
10.0 mm	56-81
5.0 mm	46-71
3.35 mm	32-58
1.18 mm	20-42
0.425 mm	12-28
0.150 mm	6-16
0.075 mm	4-8

Table 5 : Percentage of aggregate gradation of JKR standard 1988

2.3.2 Filler

Filler in the mix basically fill up the voids left in the aggregates, namely the coarse and fine aggregates. At least 75 % of filler shall pass 75 micron test sieve. One of the criteria's that will affect the suitability of a filler to be used is its fineness. The loads are transmitted mainly by the cementing agent in asphalt mixture (Atkins, 2003). There are various materials which can be used as fillers such as quarry dust, Portland cement and fly ash.

2.3.3 Bitumen

Typically there are four types of bitumen namely penetration grade bitumen, oxidized bitumen, hard bitumen and cut back bitumen (Whiteoak, 1990). To minimize the deterioration in flexible pavement, the bituminous layers should be improved with regard to performance related properties. One way of increasing the quality of a flexible material layer is by enhancing the properties of existing asphalt material. This can be achieved by modifying the bitumen using different additives to increase the overall performance of the binder (Elkhalig, 2009). Modified bitumen materials can bring real benefits to highway maintenance and construction in terms of better and longer lasting roads and savings in vehicle operating cost (VOC).

2.3.4 Waste Materials

Polymers most often used in modifying bitumen can be grouped in two general categories, elastomers and plastomers. Rubber crumb is categorized as elastomers. As the name suggest, elastomers can be stretched like a rubber band and recover their shape when the stretching force is released. Therefore, elastomers have the ability to resist permanent rutting better. On the other hand, polyethylene which is categorized as plastomers form tough, rigid, three dimensional networks within the bitumen. These plastomers give high initial strength to the bitumen to resist heavy loads (Tech, 2012).

2.2.4.1 Crumb Rubber (Waste Tyre)

Crumb rubber, also called ground rubber, is produced by shredding and grinding scrap tires into very small particles. In the process, most of the steel wires and reinforcing fibers or fluff of the recycled tires are removed. The fine grinding is done by either the ambient method or the cryogenic method. The crumb rubber is often sieved and separated in categories based on gradation to meet the requirements of a particular application or agency.

Past year studies stated that usually there are few sources to obtain crumb rubber. One study conducted used the ambient grinding method to process scrap passenger tires into crumb rubber and the other used the cryogenic grinding process (Soon-Jae Lee, 2007). Each method can produce crumb rubber of similar particle size, but the primary difference between them is the particle surface texture. Crumb rubber particles resulting from ambient processing have an irregular shape with a rough texture due to the tearing and shredding action of the rubber particles in the cracker mills. The crumb rubber particles produced by the cryogenic method, on the other hand, have smooth surfaces, which resemble shattered glass. This difference in particle surface texture results in the ambient particles having higher surface area than the cryogenic crumb rubber (BJ, 2005).

Generally, in the crumb rubber market, there are three main classes based on particle size:

- Type 1 or Grade A: 10 mesh coarse crumb rubber;
- Type 2 or Grade B: 14 to 20 mesh crumb rubber;
- Type 3: 30 mesh crumb rubber.

Mesh size designation indicates the first sieve with an upper range specification between 5% and 10% of material retained. Previous study used the following composition proposed by Potgieter (Mindo, 2009).

Seive size (mm)	Proportion of Crumb rubber retained (%)
1.18	0
0.6	45
0.075	52.5
Pan	2.5

Figure 6 : The gradation used for the crumb rubber added into the bituminous mixture

2.2.4.2 Polyethylene

Plastic material can be classified into 6 major types (American Society of Plastics Industry):

- LDPE- Low Density Polyethylene (film and trash bags)
- HDPE- High Density Polyethylene (milk jugs)
- PVC- Polyvinyl chloride (pipes, siding and flooring)
- PP- Polypropylene (battery casings and luggage)

- PS- Polystyrene (egg cartons, plate and cups)
- PET- Polyethylene Terepthalate (mineral water and soda bottles)

In this study, we are focusing more on LDPE. Generally, polyethylene has been found to be one of the most effective polymer additives (Hinisliglu, 2004). Polyethylene is the most popular plastic in the world. Polyethylene is semi-crystalline materials with excellent chemical resistance, good fatigue and wear resistance and a wide range of properties. It has a very simple structure. A molecule of polyethylene is a long chain of carbon atoms, with two hydrogen atoms attached to each carbon atom They are light in weight; provide good resistance to organic solvents with low moisture absorption rates (Awwad, 2007).

Low-density polyethylene (LDPE) is a thermoplastic made from the monomer ethylene. It was the first grade of polyethylene, produced in 1933 by Imperial Chemical Industries (ICI) using a high pressure process via free radical polymerization (B.Malpas, 2010). LDPE is commonly used for packaging like foils, trays and plastic bags both for food and non-food purposes. Below are some of -the characteristics of LDPE (DynaLab Corp) :

- Maximum Temperature: 176°F 80°C
- Minimum Temperature: -58°F -50°C
- Autoclavable: No
- Melting Point: 248°F 120°C
- Tensile Strength: 1700 psi
- Hardness: SD55
- UV Resistance: Poor
- Translucent
- Excellent flexibility
- Specific Gravity: 0.92

Recycled polyethylene from grocery bags may be useful in asphaltic (bituminous) pavements, resulting in reduced permanent deformation in the form of rutting and reduced low - temperature cracking of the pavement surfacing (Flynn, 1993).

2.3.5 Preparation of Materials

According to the Asphalt Rubber Usage Guide (Caltrans, 2006), wet and dry process can be defined as follow:

D**ry process** - any method that adds the waste material as a substitute for a percentage of the aggregate in the asphalt concrete mixture, not as part of the asphalt binder. The waste material is mixed with the aggregate fraction before adding the asphalt cement. Different gradations or sizes of granulated can be used depending on the application or procedure. The percentage of the material added in the dry process varies. The particles of materials are initially added to the pre-heated aggregate, before the conventional bitumen is added. For example (Visser, A.T., & Verhaegle, B, 2000), the waste material are added into the aggregates and are heated at temperatures between 200 and 210ºC, for about 15 seconds, until a homogeneous mixture is obtained. Later, the conventional bitumen is heated at temperatures between 140 and 160ºC and added to the aggregate-rubber mixture. Since the waste material is added as a portion of the aggregates, this is an advantage since we can add as much waste material as we want and replace the aggregate which contribute to the reduction in cost as well as maximizing the amount of waste material.

Wet Process - the method of modifying asphalt binder with waste material before incorporating the binder into the asphalt paving materials. The wet process requires thorough mixing of the waste material in hot asphalt cement (375ºF to 435ºF, 190ºC to 224ºC) and holding the resulting blend at elevated temperatures (375ºF to 425ºF, 190ºC to 218ºC) for a designated minimum period of time (typically 45 minutes) to permit an interaction between the material and asphalt. For example, the binder mixing used in one of the study conducted by Soon-Jae Lee (2007) was the wet process, in which the CRM is added to the base asphalt binder before introducing it in the asphalt concrete matrix. The CRM binders were manufactured using two CRMs and three base binders in the laboratory at 177°C for 30 min by an open blade mixer at a blending speed of 700 rpm. This mixing condition matches the field practices used in South Carolina to produce field mixtures. Another study conducted in UTP laboratory used grinded powder waste materials to be added to the bitumen and the mixture is heated to 100-120°C and stirred well with help of mechanical stirrer. The mix is stirred at the speed of 637 RPM to get a homogenous mixture. The stirring is carried out for 2-3 hours (Mindo, 2009).

The table below states the advantages and disadvantages for both dry and wet process (Amit Gawandea, G. Zamarea,V.C. Rengea, Saurabh Taydea, G. Bharsakale, 2012).

	Advantages	Disadvantages
Dry Process	• Plastic is coated over stones – improving surface property of aggregates. • Coating is easy & temperature required is same as road laying temp. • Use of waste plastic more than 15% is possible. • Flexible films of all types of plastics can be used. • Doubles the binding property of aggregates. • No new equipment is required. • Bitumen bonding is strong than normal. • The coated aggregates show increased strength. • As replacing bitumen to 15% higher cost efficiency is possible. • No degradation of roads even after 5 -6 years after construction. • Can be practiced in all type of climatic conditions. • No evolution of any toxic gases as maximum temperature is 180ºC.	• Applicable to plastic waste material only.
Wet Process	• Can be utilized for recycling of any type, size, and shape of waste material (Plastics, Rubber etc.) • Chemically react with binder for a longer time (longer contact time and more surface area)	• Time consuming- more energy for blending. • Powerful mechanical is required. • Additional cooling is required as improper addition of bitumen may cause air pockets in roads. • Maximum % of waste plastic can be added around 8 %.

Table 6 : Advantages & Disadvantages of Dry & Wet Process

2.3 Pavement Distress

2.3.1 Cracking

The phenomenon of fatigue in the asphalt coating is evident in the form of cracks. Cracking can be described as series of interconnected cracks caused by fatigue failure of the pavement under repeated traffic loading (Interactive, 2009). This phenomenon occurs due to the repeated traffic load and also due to the lack of flexibility or elasticity of the asphalt pavement, which cannot support the requirements of the heavy traffic without cracking (Martins, 2004).

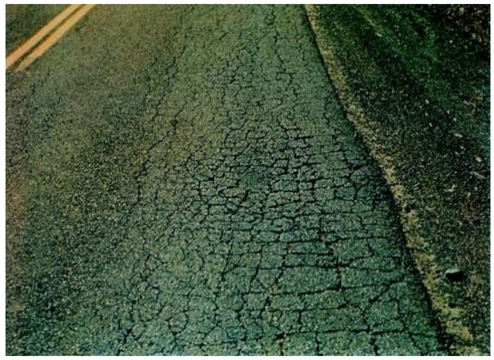


Figure 7 : Severely fatigued cracked pavement

Figure 8 : Alligator Cracking

Figure 9 : Block Cracking

Among the possible causes of cracking are:

- Decrease in pavement load supporting characteristics
- Loss of base, subbase or subgrade support (e.g. poor drainage or spring thaw resulting in a less stiff base).
- Stripping on the bottom of the pavement layer (the stripped portion contributes little to pavement strength so the effective pavement thickness decreases)
- Increase in loading (e.g., more or heavier loads than anticipated in design)
- Inadequate structural design
- Poor construction (e.g., inadequate compaction)

2.3.2 Rutting

Rutting is due to the buildup of excessive compressive strain at the top of subgrade layer or surface depression in the wheelpath. There are two basic types of rutting: mix rutting and subgrade rutting. Mix rutting occurs when the subgrade does not rut yet the pavement surface exhibits wheelpath depressions as a result of compaction/mix design problems. Subgrade rutting occurs when the subgrade exhibits wheelpath depressions due to loading. In this case, the pavement settles into the subgrade ruts causing surface depressions in the wheelpath (Interactive, 2009).

Figure 10 : Severe mix rutting

Permanent deformation in any of a pavement's layers or subgrade usually caused by consolidation or lateral movement of the materials due to traffic loading. Specific causes of rutting can be:

- Insufficient compaction of pavement layers during construction. If it is not compacted enough initially, pavement may continue to densify under traffic loads.
- Subgrade rutting (e.g. as a result of inadequate pavement structure)
- Improper mix design or manufacture (e.g. excessively high asphalt content, excessive mineral filler, insufficient amount of angular aggregate particles)
- Ruts caused by studded tire wear present the same problem as the ruts described here, but they are actually a result of mechanical dislodging due to wear and not pavement deformation.

CHAPTER 3
METHODOLOGY

Different findings and methodologies are gathered from the research work of other researchers and to be incorporated in this project. First and foremost, various journals and technical papers were read through the get the general understanding on the project. It is also needed to identify the objective of this project and to come up with a proven method to run the experiment later.

3.1 Project Activities

In order to achieve the objectives of the project, several key factors have to be taken into account so that research and execution is done in a systematic manner.

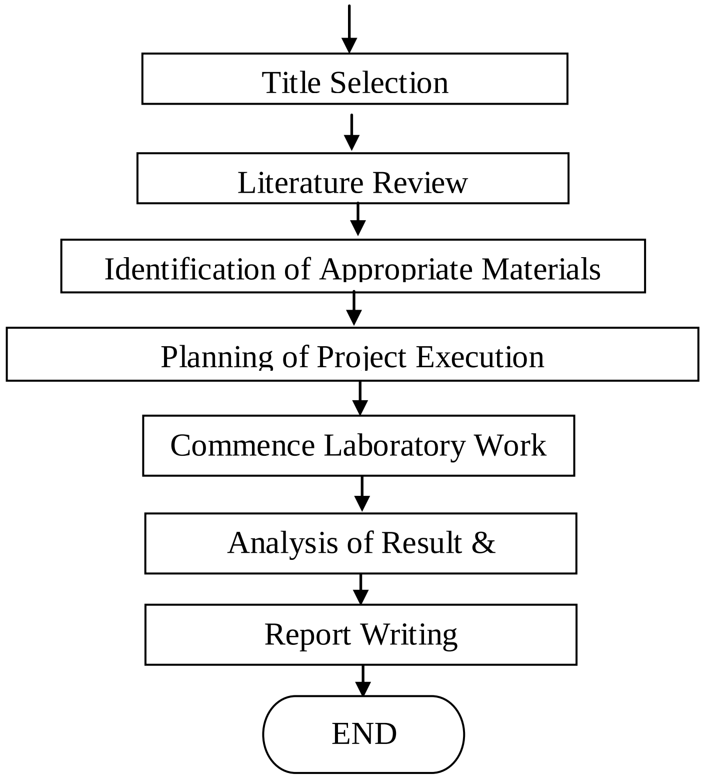


Figure 11: Project Activities Flow

Meeting with supervisor will be conducted whenever necessary to report on the progress of the project as well as to clarify doubts related to the project.

The methodology created, describes three main phases in the execution of the project.

❖ **Phase 1** : Research & Planning

- Background Study
- Materials to be considered
- Planning laboratory work
- Testing method

❖ **Phase 2** : Laboratory Work

- Collection of material
- Material preparation for laboratory test

- Tabulation of results

- ❖ **Phase 3** : Analysis & Conclusion

Figure 12 : Breakdown of detailed activities

Phase	Start Date	End Date
Phase 1	Jan 2013	March 2013
Phase 2	April 2013	June 2013
Phase 3	July 2013	September 2013

Table 7 : Timeline of each phase

3.2 Experimental Programme and Test Methods

3.2.1 Experimental Programme

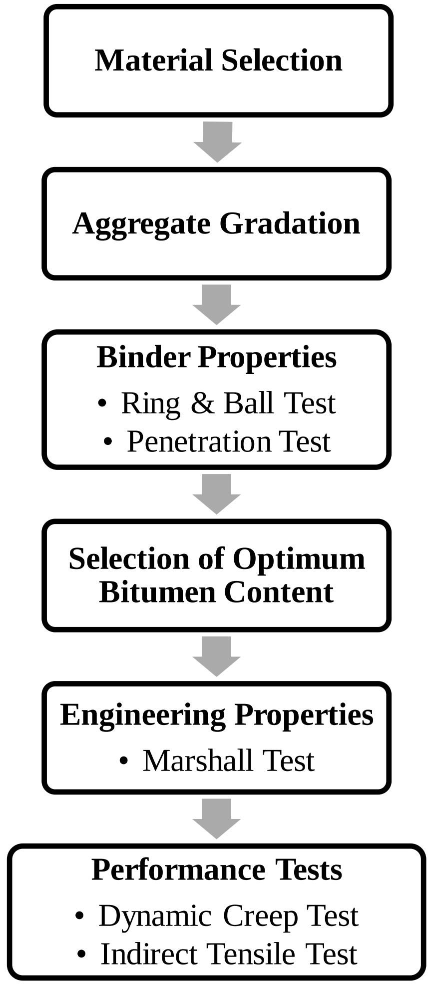


Figure 13 : Experimental Programme

3.2.2 Material Selection and Preparation

For this study the mixture components were granite as the coarse aggregate, the river sand as the fine aggregate and the Ordinary Portland cement (OPC) as the filler. For the binder the standard bitumen 80/100 were used. Two waste materials that have been identified are Low-Density Polyethylene (LDPE) and rubber crumb (CRM). The LDPE in the form of semi-powder are from Lim Seng Plastic Sdn Bhd. On the other hand, rubber crumb is supplied by Keng Heong Enterprise, a company selling vehicle shredded tires to be used as recycled material. Both companies are located in Ipoh, Perak.

Figure 14 : LDPE

Appearance	Gas at normal temperature and pressure
Colour	Colourless
Odour	Sweet odour
Solubility in water	Slightly
Boiling point	103.7 degree C (- 154.7 degree F)
Flash point	1 136 degree C (- 213 degree F)
Auto-ignition temperature	450 degree C (842 degree F)
Freezing point	1 169.2 degree C (- 272.6 degree C)
Melting point	Not applicable

Table 8 : Physical & Chemical Properties of LDPE (Lotte Chemical Titan, 1999)

For this study, the crumb rubber supplied is the ambient type which means the rubber particles are in cubic smooth-sided regular shape. There are samples of different sizes of crumb rubber; -60 mesh, -40 mesh and carbon black. The crumb rubber was supplied in various sizes and the proportion to which it was added followed the following composition proposed by Potgieter (2008) as mentioned earlier.

Figure 15 : Sieved rubber crumb

Sieve Size (mm)	Percentage Passing (%)							8%	8%	8%	8%	8%	50%	10%		JKR	
	CA					FA	Filler	CA					FA	Filler			
	20mm	14mm	12.5mm	10mm	4.75mm			20mm	14mm	12.5mm	10mm	4.75mm			Total	Lower Limit	Upper Limit
20	100	100	100	100	100	100	100	8	8	8	8	8	50	10	100	100	100
14	0	100	100	100	100	100	100	0	8	8	8	8	50	10	92		
12.5	0	0	100	100	100	100	100	0	0	8	8	8	50	10	84	78	100
10	0	0	0	100	100	100	100	0	0	0	8	8	50	10	76	68	90
4.75	0	0	0	0	100	100	100	0	0	0	0	8	50	10	68	52	72
2.36	0	0	0	0	0	87	100	0	0	0	0	0	43.5	10	53.5	38	85
0.6	0	0	0	0	0	51	100	0	0	0	0	0	25.5	10	35.5	20	36
0.3	0	0	0	0	0	28	100	0	0	0	0	0	14	10	24	12	25
0.15	0	0	0	0	0	11	100	0	0	0	0	0	5.5	10	15.5	7	16
0.075	0	0	0	0	0	4	60	0	0	0	0	0	2	6	8	4	8

Figure 16 : Gradation Percentage of CA, FA and Filler

Figure 16 shows the gradation percentage for coarse aggregate (CA), fine aggregate (FA) and filler. Using trial and error method, it has been determined that the mixture should consists of **40% CA, 50% CA and 10% filler** which adhere to the JKR Standard 1998. Since the coarse aggregates available in UTP are not in stock pile form (aggregates are separated according to sizes), we have to determine the sizes separately. From figure 15, it can be seen that 8 % of the total mass is consist of aggregate size of 20, 14, 12.5, 10 and 4.75 mm each. Batching of aggregates was carried out using 40% CA, 50% FA and 10% filler to ease sampling preparation in the future.

3.2.3 Mixing/Blending of Waste Material with Bitumen

Wet process method is used in preparing the materials. Although the percentage of waste materials that we can use is higher if dry process method is used but it requires a high temperature to make sure the particles will be in contact with each other which the equipment in UTP Highway Laboratory cannot provide. Due to this, wet process method is chosen which requires a slightly lower temperature. Besides that, based on past year project conducted by other students, it was proven that the machines and equipment in the laboratory is capable of performing for a wet method process. Another method to ensure the optimum contact area is achieved is by mixing the mixture longer (longer contact time).

For this study, both rubber crumb and LDPE were mixed using high shear mechanical mixer in the conditions mentioned below:

Contact time : 75 minutes

Temperature : 170°C

Speed : 2900 rpm

The temperature was kept at 190°C by means of placing a hot plate underneath the mixing pan.

From past studies and literature review, it was decided that **10% of rubber crumb** and **3% LDPE** should be mixed with the bitumen.

Figure 17 : Mechanical Mixer and Hot Plate

3.2.4 Binder Properties

Tests such as the penetration test and softening point test can give the basic engineering properties of the bitumen.

3.2.4.1 Penetration Test

This test is design to measure the consistency of penetration grade bitumen which adheres to the conformity with BS 2000: Part 49: 1983. This test consists of a standard dimension needle, with a standardized weight of 100gram which will penetrate the sample for a standard time of 5 seconds, at a standard temperature of 25°C (Nicholas J. Garber, 2009). The results of this test are presented on chapter 4 and the figure below shows the apparatus of the penetration test.

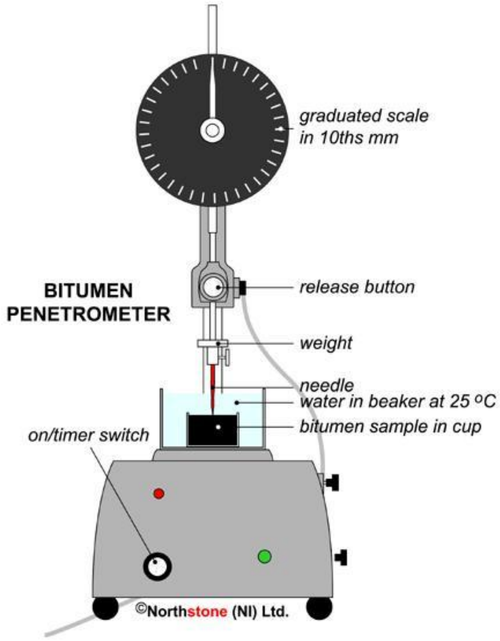


Figure 18 : Penetration Test Setup

Instead of maintaining bitumen in water bath at 25°C, the sample was kept in an incubator with temperature of 25°C.

Figure 19 : Penetration Test Apparatus

3.2.4.2 Ring and Ball Test

The ring and ball softening test is used to measure the susceptibility of blown asphalt to temperature changes by determining the temperature at which the material will soften to allow a standard ball to sink through it (Nicholas J. Garber, 2009). The test is conducted by first placing a sample of the material to be tested in the brass ring which is cooled and immersed in water bath for 15 minutes that is maintained at 5°C. The temperature of the water bath is raised at a constant standard rate. This test was done in accordance to the BS 2000: Part 58: 1983 and the results are presented in chapter 4.

Figure 20 : Ring and Ball Apparatus

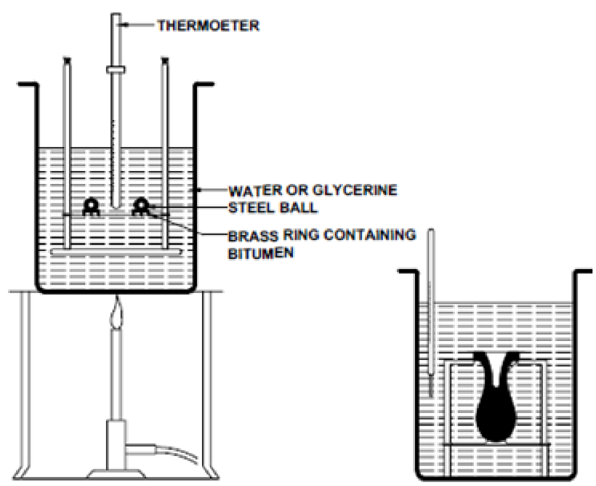


Figure 21 : Ring and Ball Test Setup

3.2.5 Engineering Properties of Mixtures

Below are the factors which affect the engineering properties of bituminous mix (Kamaruddin, 1998):

1. Stability;
2. Flow;
3. Density;
4. Porosity.

The stability and the flow are determined by the Marshall testing machine while the other properties are obtained though calculations.

3.2.5.1 Marshall Mix Design

Approximately 1200gm of aggregates and filler is heated to a temperature of 150°C. Bitumen is heated to a temperature of 150°C with the first trial percentage of bitumen (4.5 to 6.5% by weight of the mineral aggregates for determination of optimum bitumen content). The heated aggregates and bitumen are thoroughly mixed at a temperature of 160°C. The mix is placed in a mould and compacted by a gyratory compactor with the following conditions:

Stress : 200 kPa
Angle of gyration : 1.25°
No. of gyration : 200

Figure 22 : Gyratory Compactor

Three types of sample will be produced which are samples:

a) without any polymer added (conventional bitumen)
b) with addition of 3% LDPE
c) with addition of 10% CRM

Test	Number of Sample needed
Penetration Test	3 samples
Softening Point Test	3 samples
Optimum Bitumen Content	5 samples of conventional bitumen
Marshall Stability	3 samples
Creep Test	3 samples
Indirect Tensile Test	3 samples

Table 9 : Number of sample needed

3.2.5.2 Marshall Stability and Flow

In conducting the test, the specimen is immersed in a bath of water at a temperature of 60°C for 30 minutes. It is then placed at the Marshall testing machine and loaded at a constant rate of deformation of 50.8mm per minute until failure occurs. The stability and flow are automatically recorded. For each conventional and modified bitumen, three specimens were tested and the average is recorded.

3.2.5.3 Bulk Density of Compacted Specimen

The bulk density of the sample is determined by weighing the sample in air and in water. The specific gravity of the specimen is given by

$$\rho = \frac{W_a}{W_a - W_w}$$

where,

ρ = Density

W_a = Weight of sample in air (g)

W_w = Weight of sample in water (g)

3.2.5.4 Porosity of Compacted Specimen

The main purpose of compaction is to increase particle interlock in mixture and thus reduce porosity which will increase durability of mixture. This property indicates the proportion of openings/pores in the bituminous mixture. The porosity can be calculated using the equation below:

$$SG_{mix} = \frac{100}{\frac{\%_{CA}}{SG_{CA}} + \frac{\%_{FA}}{SG_{FA}} + \frac{\%_{filler}}{SG_{filler}} + \frac{\%_{bitumen}}{SG_{bitumen}}}$$

$$\%\ Porosity = \left(1 - \frac{\rho}{SG_{mix}}\right) 100\%$$

where,

SG = Specific Gravity

3.2.6 Performance Test

Besides comparing the engineering properties of the bituminous mixture, the mixture is also compared in terms of their performance. The performance tests conducted were the creep test and the indirect tensile test using the MATTA universal testing machine, present at Highway laboratory of Universiti Teknologi PETRONAS.

Figure 23 : MATTA Universal Testing Machine

3.2.6.1 Dynamic Creep Test

A dynamic axial stress is applied to a cylindrical specimen for a fixed period of time during which axial strain is continuously monitored. The axial stress is then removed and both the permanent and recovered strain determined. Investigations have shown that dynamic creep correlates better with in-service pavement rutting measurements than static creep.

For this study, the test was conducted at a constant temperature of 40°C for 1800 cycles which lasts around an hour. Before the test was conducted, the specimen is placed in the incubator of the MATTA machine to ensure that the skin temperature of the specimen is equal to the chamber temperature. The specimens are preloaded for 120 seconds with a low pressure of 0.01MPa before being subjected for the high pressure of 0.10 MPa for an hour. Through the creep stiffness test results, the relationship between the mixture stiffness and the binder stiffness could be obtained (Kamaruddin, 1998).

3.2.6.1 Indirect Tensile Stiffness Modulus Test

The values of Indirect Tensile Stiffness Modulus Test may be used to evaluate the relative quality of bituminous mixtures in conjunction with laboratory mix design testing and for estimating the potential for rutting or cracking.

A cylindrical specimen is loaded diametrically across the circular cross section. The loading causes a tensile deformation perpendicular to the loading direction, which yields a tensile failure. By registering the ultimate load and by knowing the dimensions of the specimen, the indirect tensile stiffness modulus of the material can be computed. The test was carried out using a loading of 80 kPa at temperature of 25°C.

Figure 24 : Indirect Tensile Strenth Test Setup

3.3 Specifications and Test Methods

Specifications and standard are extremely necessary to be followed to ensure error can be minimized and also increasing the chance of a better results. For this research the specifications & test methods applied are as follows:

Specifications

- Indian Standards on CRMB
- JKR Manual, 1985

Test Methods

- Technical methods for highway TMH 1
- ASTM (American Society for Testing and Materials)

3.4 Gantt Chart & Key Milestones

Final Year Project 1

No	Description / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Selection and Confirmation of Project Topic															
2	Preliminary Research Work			★												
3	Preparation & Submission of Extended Proposal						★									
4	Proposal Defence Presentation								★							
5	Continue Project Work											★				
6	Preparation & Submission of Interim Draft Report														★	

Final Year Project 2

No	Description / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project & Lab Work Continues															
2	Submission of Progress Report								★							
3	Data Gathering															
4	Result Analysis & Evaluation															
5	Conclusion & Recommendation															
6	Pre-SEDEX											★				
7	Submission of Reports (Draft Report, Dissertation & Technical Paper)												★			
8	Oral Presentation														★	
9	Submission of Project Dissertation (Hard Bound)															★

★ Key Milestones

3.5 Tools Required

3.5.1 Software

- **Microsoft Excel** - performance analysis purpose (e.g. graph, charts etc.)

3.5.2 Hardware/Equipment (available at the highway laboratory)

- Penetrometer Apparatus
- Softening Point Apparatus
- Mechanical Compactor
- High Shear Mixer
- Marshall Test Apparatus
- MATTA Testing Machine
- Gyratory Compactor

CHAPTER 4
RESULTS & DISCUSSION

The study was conducted through standardized laboratory test methods. The objective of the tests was to determine the characteristics and performance of the materials. The study also attempted to obtain the difference in engineering characteristics between mixtures containing the modified bitumen and mixtures containing the standard 80/100 bitumen. All tests were conducted at the Highway Laboratory at the Universiti Teknologi PETRONAS.

4.1 Mixing/Blending of Waste Material with Bitumen

Initially, after mixing was done between the waste material and bitumen, the modified binder was kept in tin container for one day at room temperature before being tested for its binder properties. However, it was found out that both the rubber crumb and LDPE did not dissolve fully in the blending process and thus after it was stored for one day, separation process occurred.

Figure 26 : Modified Binder with LDPE (after one day storage)

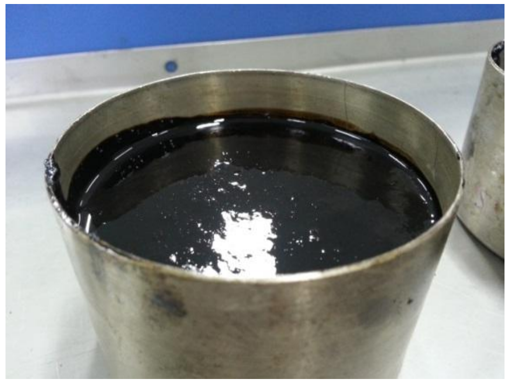


Figure 27 : Modified Binder with rubber crumb (after one day storage)

Uneven layer of modified binder can definitely be observed in figure 26 and 27. This shows that modified binder is not suitable for storage purpose and has to be mixed straight away for asphalt mix after mixing is done with the waste materials. Second batch of modified binder was done where the binder is straight away tested for its binder properties after mixed. Besides that, instead of using mixed gradation of crumb rubber, shredded tires in terms of powder form is used.

4.2 Penetration Test

	Trial 1 (mm)	Trial 2 (mm)	Trial 3 (mm)	Average Penetration (mm)
Conventional bitumen	98	99	100	**99**
3% LDPE (Stored)	45	46	50	**47**
3% LDPE	61	58	58	**59**
10% CRM (Stored)	65	64	63	**64**
10% CRM	68	70	67	**68**

Table 10 : Penetration Test Result

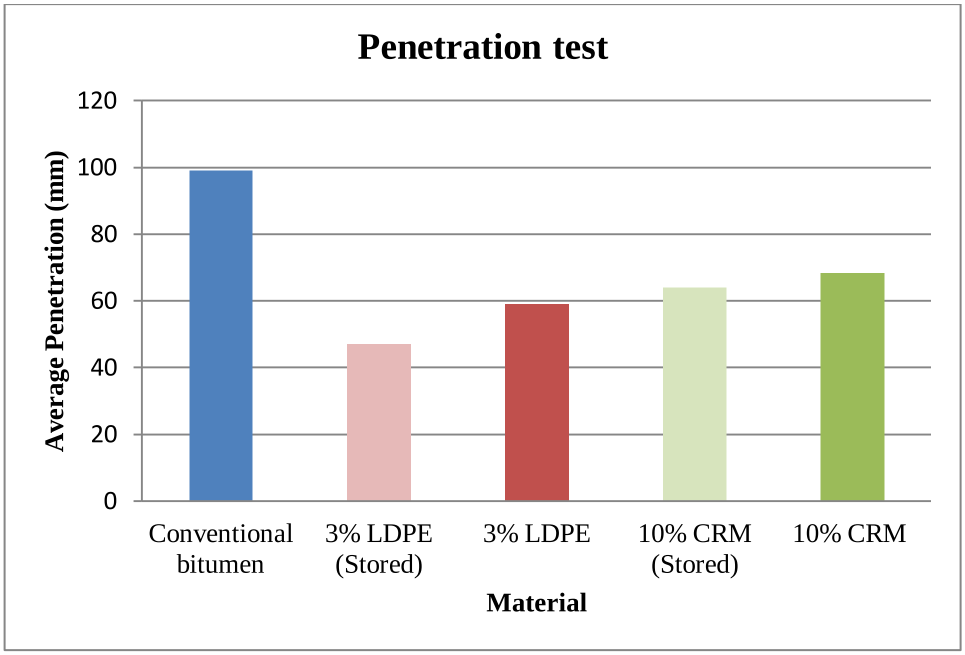


Figure 28 : Penetration Test Result

The results portray the fact that the incorporation of rubber as well as LDPE resulted in harder bitumen as manifested by the reduction in penetration values. The values were reduced from the roughly 100 dmm of penetration to an average of 70 dmm for rubber and 60 dmm for LDPE. By norm the lower the penetration grade will imply a high viscosity, thus the modified bitumen has higher viscosity compared to standard bitumen. Another point to note would be the difference in terms of storage stability factor. Earlier it was mentioned that there is an issue regarding the storage stability. The samples prepared earlier were tested for penetration test to see the effect. From the graph, it can be concluded that modified bitumen will have lower penetration grade if stored longer which means it is more viscous. This result shows that the modified bitumen has a large tendency for separation towards the top. It is not known whether this separation is due to insufficient blending of the additives and the bitumen, incompatibility between the additives and the bitumen or a third reason. However, this result is not so reliable considering the fact that the point where the needle penetrates might be penetrating the semi-solid undissolved particles of rubber or LDPE and thus causes the reading to be lower than the actual one.

4.3 Softening Point Test

	Ball 1 (°C)	Ball 2 (°C)	Mean (°C)	Average (°C)
Conventional bitumen	43	43	43	43.25
	44	43	43.5	
3% LDPE	47	48	47.5	47.5
	48	47	47.5	
10% CRM	50	51	50.5	50
	49	50	49.5	

Table 11 : Softening Point Test Result

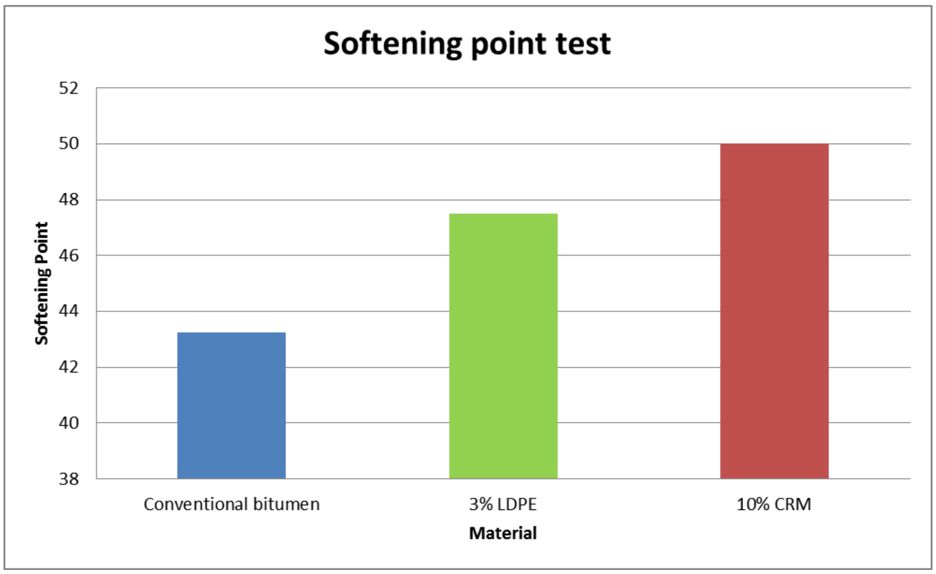


Figure 29 : Softening Point Test Result

From the results it can be observed that the variation of the softening point with the addition of rubber and LDPE added into the bitumen varies in an orderly manner. The softening point is generally higher for the LDPE modified bitumen compared with the rubber modified and the standard 80/100 bitumen due to the rhetoric properties.

It appears clearly from the results that the addition of LDPE into bitumen increases the softening point value just like mentioned earlier in the literature review. This phenomenon indicates that the resistance of the binder to the effect of heat is increased and it will reduce its tendency to soften in hot weather. Thus, with the addition of LDPE the modified binder will be less susceptible to temperature changes. Rubber modified bitumen also shows the same increment in softening point value, although the effect is not as much as LDPE modified bitumen.

4.4 Determination of Optimum Binder Content (OBC)

The optimum binder content (OBC) was determined in this experiment using the Marshall Design method. This method is the most widely used method to determine the OBC. The Marshall Design method takes into account the different factors that influence the behavior and performance of the bituminous mix. Therefore for each mixture four elements are considered in the determination of the OBC namely Stability, Flow, mix density and air voids (porosity). Figure 30 to figure 33 presents all the graphs from the Marshall test.

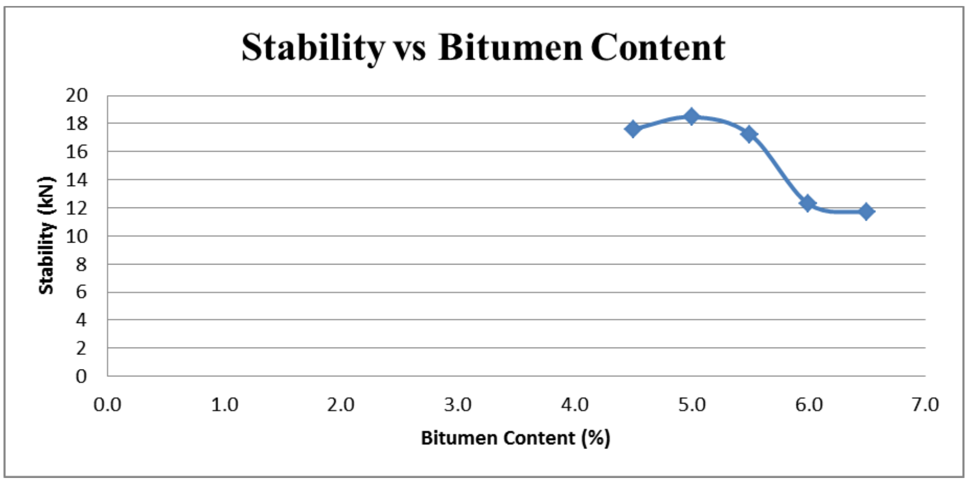


Figure 30 : Stability Graph for OBC determination

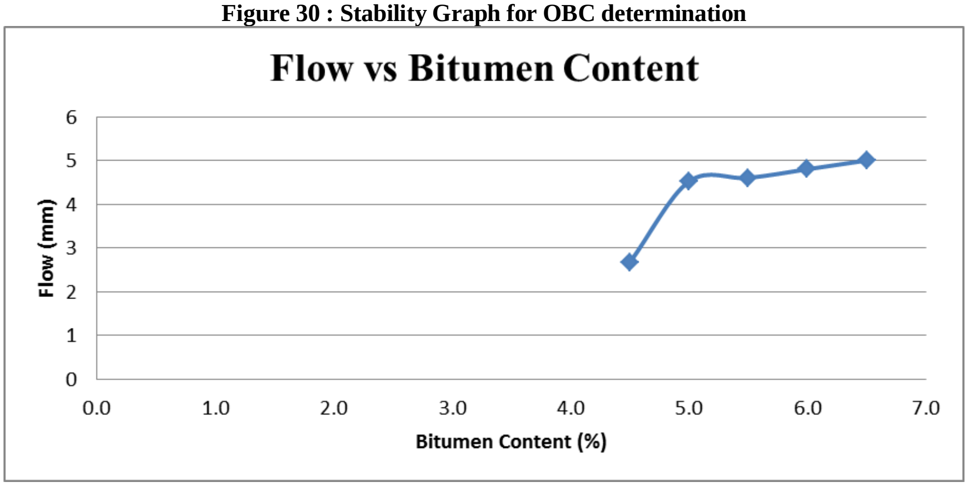


Figure 31 : Flow Graph for OBC determination

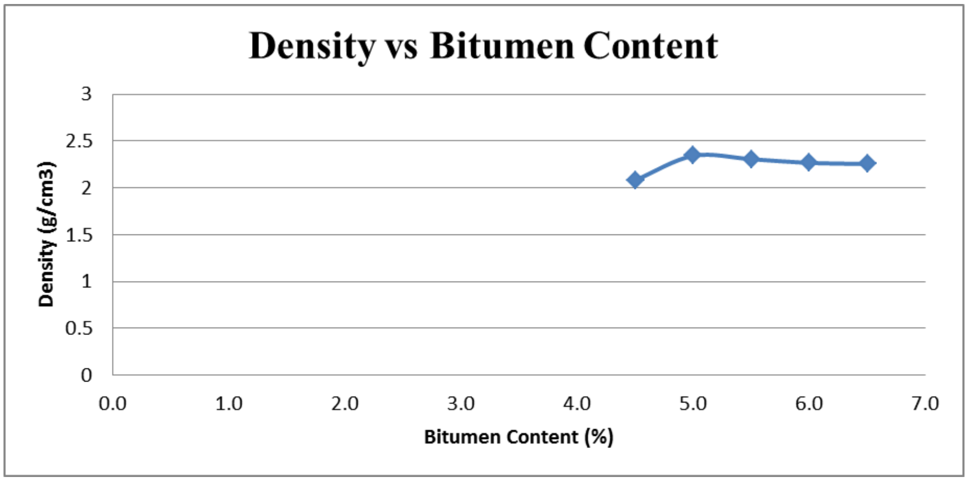


Figure 32 : Density graph for OBC determination

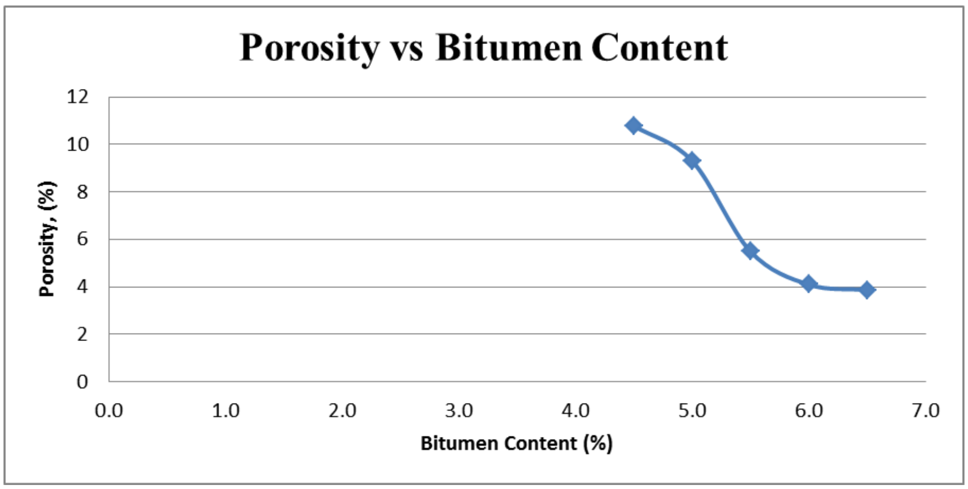


Figure 33 : Porosity graph for OBC determination

From the results above, it was determined that the optimum binder content for the bituminous mixture is 5%.

4.5 Engineering Properties of Mixtures

4.5.1 Marshall Test

A good mix design is the backbone for an asphaltic mixture with sufficient strength and stability to meet the demands of traffic and sufficient workability to allow the placement on site to be done without segregation. At the same time the mix should have enough voids to ensure its durability. Stability is a measure of the ability of bituminous mixture to resist deformation from imposed loads. It is dependent on both internal friction and cohesion. Below are the equations used to determine the engineering properties of the mix.

$$\rho = \frac{W_a}{W_a - W_w}$$

where,

ρ = Density

W_a = Weight of sample in air (g)

W_w = Weight of sample in water (g)

$$SG_{mix} = \frac{100}{\frac{\%_{CA}}{SG_{CA}} + \frac{\%_{FA}}{SG_{FA}} + \frac{\%_{filler}}{SG_{filler}} + \frac{\%_{bitumen}}{SG_{bitumen}}}$$

$$\%\ Porosity = \left(1 - \frac{\rho}{SG_{mix}}\right) 100\%$$

where,

SG = Specific Gravity

From table 11, it can be seen that crumb rubber modified bituminous mixture has the highest value of stability compared to conventional mix. However, for LDPE modified mix, the stability decreased slightly compared to the conventional mix.

High flow values generally indicate a plastic mix that will experience permanent deformation under traffic, whereas low flow values may indicate a mix with higher than normal voids and insufficient bitumen for durability and one that may experience premature cracking due to mixture brittleness during the life of the pavement. For this study, LDPE has the highest value of flow which is roughly 1mm higher than the flow value of conventional mix. This means that the sample has the highest tendency to experience permanent deformation under traffic since high flow indicates plastic mix. Crumb rubber modified mix has the lowest value of flow but the difference is roughly around 0.5mm compared to the conventional mix which is not that significant.

An indication of the probable durability and service performance of bituminous pavement may be determined by analyzing a compacted paving mixture for air voids and VMA. Porosity or air void is the sum of the pores in the bituminous mix. Basically, the porosity should be high enough to allow binder's expansion under hot weather conditions. Besides that, it should also be high enough to provide the mixture with a certain amount of elasticity as well as to provide safety space for further compaction due to traffic loading. However, the porosity should not be too high because too high porosity will cause flow of air and moisture into the mix which can result in disintegration. When the porosity is too low, the pavement is likely to flush or bleed.

Sample	Flow (mm)	Stability (kN)	VMA (%)	Air Void (%)	Air Voids filled with bitumen
Conventional	2.67	17.58	18.61	7.66	58.82
Crumb	2.19	28.32	17.70	6.64	62.46
LDPE	3.86	16.26	15.53	4.30	72.31

Table 12: Marshall Test Results

From table 12, it can be seen that the porosity is affected by the incorporation of the additives. The porosity of both crumb rubber and LDPE mix decreased by 0.4% and 3% respectively. The same trend can be observed for Voids in Mineral Aggregate (VMA). With the addition of crumb rubber and LDPE into the binder, the VMA reduced by 0.4% and 3% respectively. The VMA should be sufficiently large to ensure enough room between particles in the thoroughly compacted mixture to contain a volume of pores, plus the minimum amount of binder required for a durable surfacing. To sum it up, the influence on engineering properties of both the crumb rubber and LDPE modified bituminous mixture are not that significant except for the stability where the stability of the bituminous mixture improves tremendously after crumb rubber is added as additive into the bitumen.

4.6 Performance Test

4.6.1 Dynamic Creep Test

In this study, resistance to permanent deformation was measured by the application of dynamic creep test. The results of the creep test presented here are the average values obtained from three specimens. From figure 34, at 40° the strain after one hour loading, it can be seen that the deformation in terms of accumulated strain is the highest for conventional bitumen followed by LDPE and crumb rubber modified bitumen. This simply means that both the LDPE and crumb rubber modified bituminous mixture can take more load as compared to the conventional mixture and best of all they are more resistant to deformation, thus the probability of rutting occurrence is lowered with the addition of both additives.

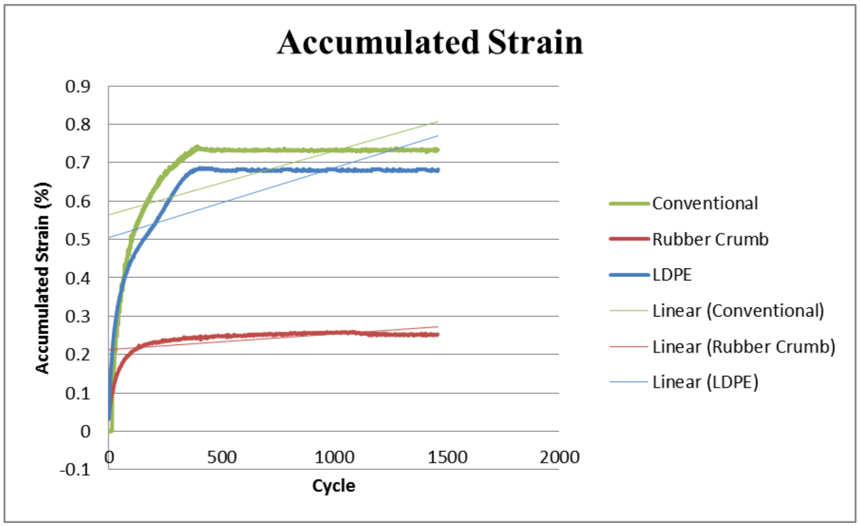


Figure 34 : Accumulated Strain

Based on the results obtained from the creep test, the structural rut depth of a pavement as it occurs with increasing number of traffic loading can be estimated. Since the mechanics of rutting leading to permanent deformation in roads is similar to that in laboratory creep tests, the measurements on specimens in the laboratory creep test can be used to derive a model for the behavior of bituminous materials. Every action of load causes a deformation which is the sum of reversible and irreversible (permanent) deformation (Napiah, 1993). Basically, the mechanism starts with the loading being applied and thus there would be initial deformation in the spring and then a continuing deformation in the dashpot. When this load is removed, the energy stored in the spring is discharged by reverse deformation in the dashpot. This reverse deformation represents the elastic recovery of the material which can be used to determine the permanent deformation. Usually, the permanent deformations increase rapidly during the first few thousand load cycles, and then tend to stabilise (shakedown). For higher stress levels, this stabilisation is not observed, and permanent deformations continue to increase, eventually leading to failure.

Below are the formulas used to calculate the rut depth.

$$(S_{bit})v = \frac{3\eta}{NT_w}$$

where,

$(S_{bit})v$ = the viscous component of the stiffness modulus of the bitumen

η= the viscosity of the bitumen as a function of PI and ring and ball temperature

N=the number of wheel passes in standard axles

T_w = the time of loading for one wheel pass

$$R_d = C_m \times H \times (\frac{\sigma_{av}}{S_{mix}})$$

where,

R_d= calculated rut depth of the pavement

Cm= correlation factor for dynamic effect, varying between 1.0 and 2.0

H=pavement layer thickness

σ_{av}=average stress in the pavement, related to wheel loading and stress distribution

S_{mix}=stiffness of the design mixture derived from creep test at a certain value of stiffness which is related to the viscous part of the bitumen.

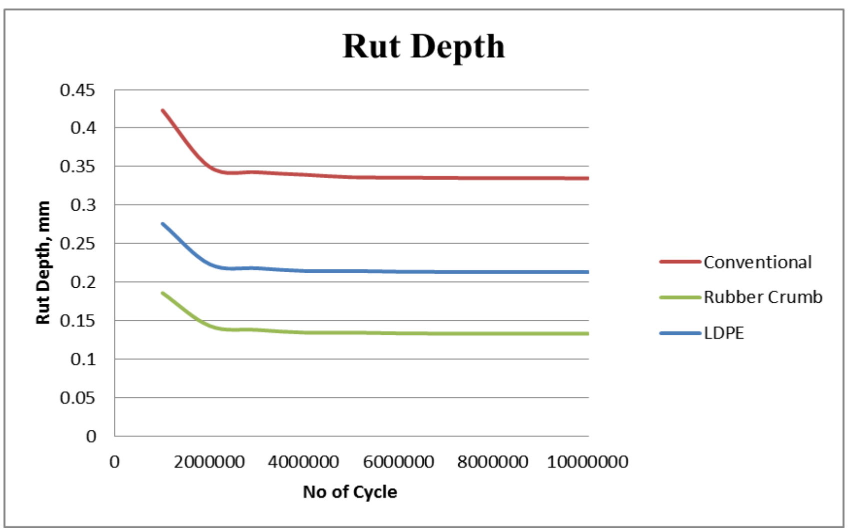


Figure 35 : Calculated Rut Depth

Figure 35 above shows the results of rut depth estimation related to number of standard axle repetitions. The estimated rut depth of both rubber and LDPE modified are lower than the estimated rut depth of conventional mixes. One reason could be due to the viscosity where both rubber and LDPE modified binders are more viscous compared to the conventional modified mix. We can say that a binder that is more viscous has a higher stiffness and thus deform less under traffic loading. The effect of additives was found to be the dominant factor in the permanent deformation resistance.

4.6.2 Indirect Tensile Stiffness Modulus Test

The stiffness modulus is a measure of the load-spreading ability of the bituminous layers. It controls the levels of the traffic-induced tensile strains at the underside of the lowest bituminous bound layer which are responsible for fatigue cracking, as well as the stresses and strains induced in the subgrade that can lead to plastic deformations. The non-destructive indirect tensile test has been identified as a potential means of measuring this property (Zoorob, 2002).

Below is the formulas used to calculate the stiffness modulus.

$$S_m = \frac{L(v + 0.27)}{Dt}$$

where,

S_m= stiffness modulus (MPa)

L= peak value of the applied vertical load (N)

v= Poisson's ratio (= 0.35)

D= mean amplitude of the horizontal deformation obtained from two or more applications of the load pulse (mm)

t= mean thickness of the test specimen (mm).

Material	Stiffness Modulus (Mpa)
Conventional	828.17
Rubber Crumb	780.12
LDPE	802.58

Figure 36 : Stiffness Modulus of Bituminous Mixture

Figure 36 shows that rubber crumb modified mix has the lowest stiffness modulus followed by LDPE and conventional mix respectively. The fact that rubber crumb modified mix has lower stiffness values can be explained by relating it to the properties of rubber crumb as elastomer while LPDE is plastomer which means that the rubber crumb has higher elasticity if compared with plastomer. In terms of brittleness, LDPE modified mix which has the higher stiffness modulus means it is more brittle compared to the rubber crumb mix which is considered more flexible. The brittleness of the mixtures is due to the loss of adhesive and cohesive strength of the material. In this case, that would mean the conventional mix is the most brittle compared to the other two mixture.

The increase in stiffness generally appears to be lower for mixtures with rubber indicating that the softening effect of flexible rubber particles may have contributed to compensate the increased effect of bitumen hardening (Rahman, 2009). For potential performance, crumb rubber modified mix is more preferable since it improved the resistance towards deformation as shown by the indirect tensile stiffness modulus tests.

CHAPTER 5
CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusion

From the study, the following can be concluded:

1. The incorporation of crumb rubber and low-density polyethylene (LDPE) affects the properties of the conventional bitumen. This can be seen through the penetration and ring and ball test whereby the binder properties are observed to undergo changes due to the addition of the rubber crumb and LDPE. From the penetration test results, the penetration values of crumb rubber and LDPE modified bitumen both are lower than the conventional bitumen. The penetration values decreased from around 100 dmm for conventional bitumen to around 70 and 60 dmm for rubber crumb and LDPE modified bitumen respectively. This means that the incorporation of both additives results in the increase in stiffness of the conventional bitumen. The same trend can be observed for the ring and ball test. The test results show that the softening point value increased from 43°C for conventional bitumen to around 48°C and 50°C for LDPE and rubber crumb modified bitumen respectively. Hence, the inclusion of both the additives into the conventional bitumen increases the viscosity of the conventional bitumen.

2. Besides that, in terms of storage, it can be concluded that both modified bitumen are not suitable for long-term storage. After mixing with additives, modified bitumen should not be stored temporarily because separation process will occur between the bitumen and the additives. This is due to the fact that both the rubber crumb and LDPE did not dissolve fully in the blending process and thus after it was stored for one day, separation process occurred.

3. For this study the mixture components selection were done in accordance with JKR recommendations. The mixture components consist of granite as the coarse aggregate, the river sand as the fine aggregate and the Ordinary Portland cement

(OPC) as the filler. For the binder the standard bitumen 80/100 were used. Two waste materials that have been identified are Low-Density Polyethylene (LDPE) and rubber crumb (CRM). The crumb rubber used was obtained on used tires from passenger cars and trucks while the LDPE from the recycled material from the factory.

4. The properties of the bituminous mixtures were determined from the results of the Marshall. The five properties that were analyzed are porosity, VMA, stability and flow. From the results the following conclusions can be drawn:
   - The stability load is slightly decreased with the incorporation of LDPE but increased extremely with the addition of rubber crumb. This is due to the formation of a stronger binder proving the formation of the binding gel.
   - For flow properties, LDPE has the highest value of flow which means that the sample has the highest tendency to experience permanent deformation under traffic since high flow indicates plastic mix. Crumb rubber modified mix has the lowest value of flow but the difference is roughly around 0.5mm compared to the conventional mix which is not that significant.
   - The porosity of the binder is reduced with the addition of crumb rubber and LDPE. The proportion of voids decreases with addition of crumb rubber and LDPE which is justified by a courser binder resulting from the partial digestion of the crumb rubber and LDPE in the reaction with bitumen.

   The result of Marshall Test shows that the influence on engineering properties of both the crumb rubber and LDPE modified bituminous mixture are not that significant except for the stability where the stability of the bituminous mixture improves tremendously after crumb rubber is added as additive into the bitumen.

5. Both the performance tests namely dynamic creep stiffness and indirect tensile stiffness modulus test prove that the addition of crumb rubber and LDPE improves the performance of the bituminous mixture by improving its resistance towards deformation. Comparing all three mixtures, it can also be deduced that the

deformation resistance is the highest for the rubber bitumen asphalt compared with the conventional asphalt and LDPE modified asphalt.

5.2 Issues Identified & Recommendations for Further Research

This study presents laboratory findings of the influence of incorporating rubber crumb and LDPE as additives to the binder and investigates the effect on the binder properties and the performance of the bituminous mixture. However, for a better assessment on their influences as additives to the binder as well as to verify and validate the results obtained in this investigation, the following recommendations are suggested:

1. In terms of modification of binder, there are other aspects affecting the performance of binder such as:

    - **The type of tire grinned** – different tires have different properties. For example, conduct a test using different types of tires such as motorcar, truck and bicycle tires.
    - **The proportion of crumb rubber and LDPE added to the standard bitumen** – Previous investigations have shown that the amount of additive added can cause adverse effect if too much or too less amount is added to the bitumen. Hence, further study need to be conducted using different percentage of additive to know the optimum content.
    - **The temperature** – The influence of temperature is known to be one of the factors to influence fatigue response of material. In this study, the performance test was only carried out at only one temperature. Therefore, in order to better understand the performance, test should be carried out at various temperatures preferably between the lowest and highest temperature the pavement may be exposed.
    - **The compatibility between the crumb rubber and LDPE with the bitumen** – It was mentioned earlier that the additives failed to dissolve completely in the bitumen after mixing. One thing that can be done to improve this is to conduct study by adding certain solvent such as extender oil or maybe gasoline to ensure the additives can dissolve completely. It is reported that the addition of extender

oil could improve the workability of the asphalt mixture without affecting much the characteristics of the binder.

- **Storage stability** – Further study can be conducted to see how long a modified binder can last before separation process occur prior to mixing of bituminous mixture. It would be beneficial if the optimum storage can be estimated for economic purpose.

2. In one of the conducted to develop recommendations for use of modified binders in India**,** polymer modified bitumen with elastomers is most commonly used with success on major highways in the developed countries because elasticity in this the modified bitumen provides resistance to both rutting and fatigue cracking. Superpave performances grades have been made successfully with this modified bitumen therefore recommended for heavily trafficked roads in India. On the other hand, polymer modified bitumen with plastomers are hardly used in flexible pavements in the developed countries because although they provide higher strength initially, they are prone to cracking at high strains and do not rebound after deforming force is removed. Therefore, there is no need to have a specification in India for PMBs with plastomers to avoid its unnecessary and improper use (Tech, 2012). Therefore, for future study, further and a more detailed research regarding this issue can be conducted with respect to Malaysian Highway. The result of this study can benefit many parties.
3. This issue can be related to another issue which is in terms of cost of the whole process. This can be understood and clarified by doing a cost analysis which focuses on the amount of money that can be saved in a larger scale if we incorporate this waste material as a part of the modified bitumen. For example, the amount of bitumen used for a bituminous mixture is definitely reduced due to the percentage of waste material added and thus in a bigger picture, the cost is reduced. Not only that, since the waste generation is reduced, the cost to manage the solid waste is also reduced. It may look insignificant in a small scale. However, if viewed in a bigger picture, the cost could play a very big role.

NOMENCLATURE

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
BS	British Standard
CA	Course Aggregate
CRM	Crumb Rubber
FA	Fine Aggregate
JKR	Jabatan Kerja Raya
LDPE	Low-Density Polyethylene
OBC	Optimum Bitumen Content
OPC	Ordinary Portland Cement
SABS	South African Bureau of Standards
TMH	Technical Methods for Highways
SG	Specific Gravity
TRH	Technical Recommendations for Highway

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APPENDICES

Appendix A

Spreadsheets for OBC determination

Weight of bitumen	**Sample No.**	**Binder Content by Mass of Mix**	**Diameter**	**Height**	**Mass of Specimen**			**Weight**	**Volume**	**Density**	**Specific Gravity**		**Air voids**				**Flow**	**Stability (kN)**		
(g)		(%)	(mm)	(mm)	In air (g)	SSD weight (g)	In water (g)	(g)	(cm3)	(g/cm3)	Bulk	Theory	Total Mix Vv	Vb	VMA	VFB	(mm)	Measured	C.F.	Corrected
49.5	1	4.5	100.0	65.12	1078.1	1091.2	573.2	1105	511.52	2.160238	2.081274	2.381816	9.3028975	9.40436	18.707257	50.27118	2.67	16.93	1.04	17.6072
55.0	2	5.0	100.0	66.66	1215.1	1230.4	711.4	1100	523.61	2.100783	2.341233	2.354566	10.778335	10.20789	20.986221	48.6409	4.52	19.24	0.96	18.4704
60.5	3	5.5	100.0	64.23	1194.6	1205	687	1110	504.53	2.200082	2.306178	2.327932	5.4919989	11.65349	17.145486	67.96825	4.6	16.56	1.04	17.2224
66.0	4	6.0	100.0	64.01	1173.5	1184.4	666.4	1110	502.80	2.207644	2.265444	2.301894	4.0944653	12.75659	16.851054	75.70202	4.8	11.81	1.04	12.2824
71.5	5	6.5	100.0	63.99	1170.3	1180.1	661.1	1100	502.64	2.188439	2.254913	2.276432	3.8653927	13.82396	17.689349	78.14847	5	11.22	1.04	11.6688

Figure 37 : OBC determination

Appendix B

Sample spreadsheets for estimation of rutting depth

	Trb (°C)
Conventional bitumen	43.25
3% LDPE	47.5
10% CRM	50.0

Figure 38 : Ring and ball test result (softening point)

	Average Penetration (mm) PI	Pr	SPr	PIr	T-Trb	η
Conventional bitumen	99.0	64.35	50.65	-0.418781	16.75	200
3% LDPE	59.0	38.35	56.59	-0.280465	12.50	360
10% CRM	68.3	44.42	54.90	-0.314499	10.00	400

Figure 39 : Viscosity of bitumen as a function of (T-$T_{R\&B}$) and Plasticity Index (PI)

N	Sbit		
	Conventional	3% LDPE	10% CRM
1000000	0.0300	0.0540	0.0600
2000000	0.0150	0.0270	0.0300
3000000	0.0100	0.0180	0.0200
4000000	0.0075	0.0135	0.0150
5000000	0.0060	0.0108	0.0120
6000000	0.0050	0.0090	0.0100
7000000	0.0043	0.0077	0.0086
8000000	0.0038	0.0068	0.0075
9000000	0.0033	0.0060	0.0067
1E+07	0.0030	0.0054	0.0060

Figure 40 : S_{bit} as a function of number of load cycle

3% LDPE		
Time	**Sbit**	**Smix**
2	50000	139.06
10	10000	140.966
20	5500	148.259
50	3300	149.663
100	1000	149.812
200	660	150.896
500	330	164.266
1000	130	182.879
1800	100	200.968
3600	9	201.498

Figure 41 : Smix as a function of time and Sbit (LDPE)

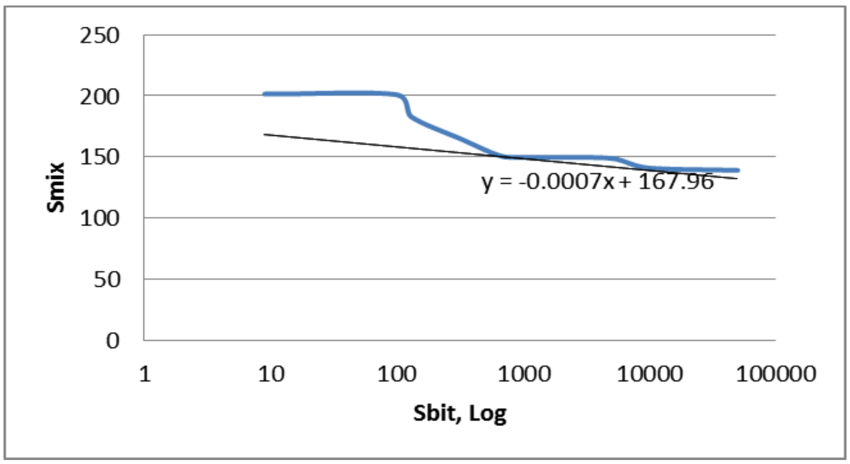

Figure 42 : Plot of Smix against Sbit (LDPE)

From equation,		Smix=-0.0007Sbit+167.96	
N	**Sbit (Pa)**	**Smix (Mpa)**	**Rd**
1000000	50000	132.96	0.423059567
2000000	10000	160.96	0.349465706
3000000	5500	164.11	0.342757906
4000000	3300	165.65	0.339571385
5000000	1000	167.26	0.336302762
6000000	660	167.498	0.335824905
7000000	330	167.729	0.3353624
8000000	130	167.869	0.335082713
9000000	100	167.89	0.335040801
10000000	9	167.9537	0.334913729

Figure 43 : Determination of Rd using Smix obtained from equation (LDPE)

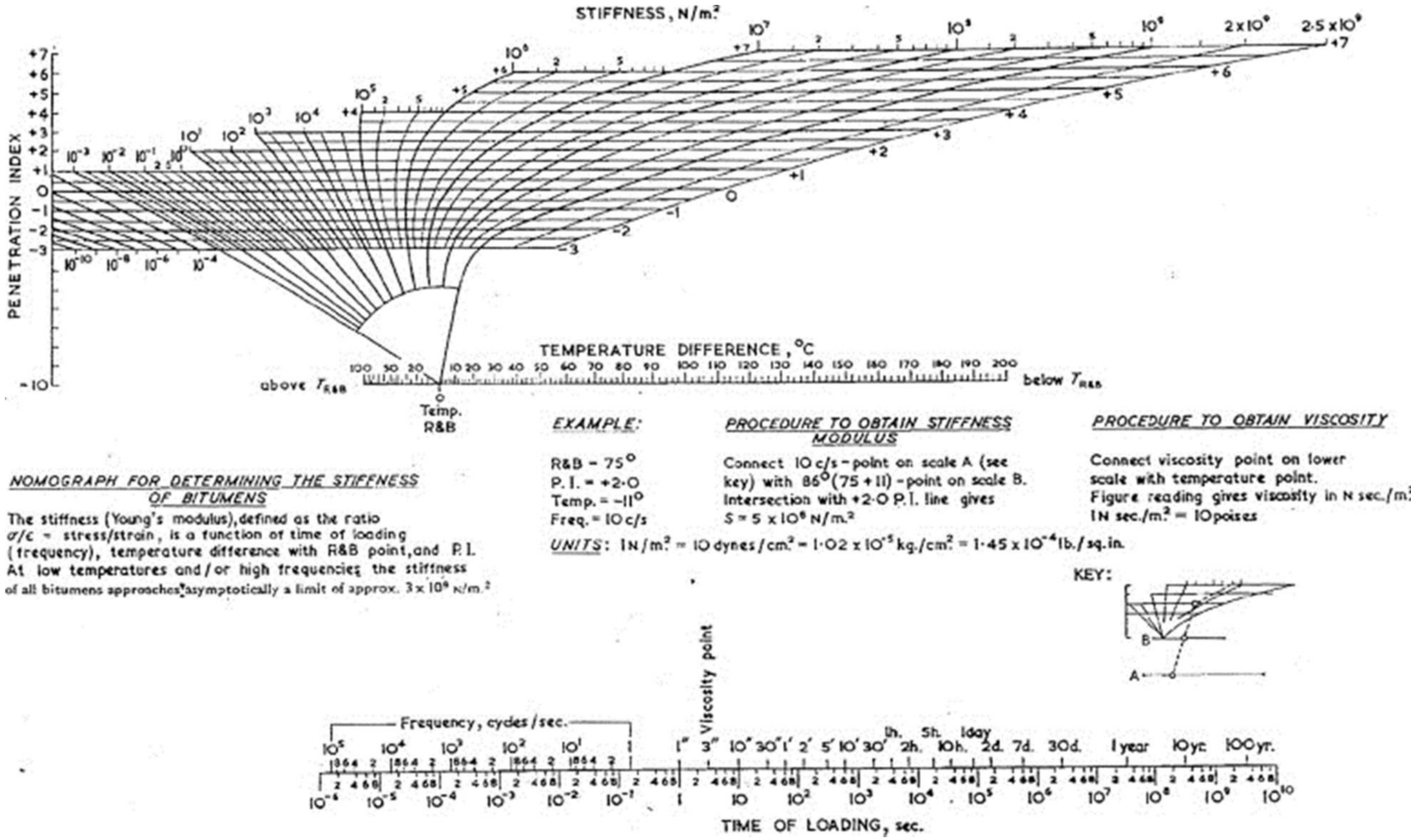

Figure 44 : Van der Woel nomograph for determining stiffness modulus of bitumens