CERTIFICATE 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

NORASHIKEN BINTI RAMLI

ABSTRACT

Moisture susceptibility in bituminous mixture reduces the strength and durability of the bitumen pavement due to the presence of water. Water disrupts the bond between aggregate and bitumen. Because aggregate comprises 95% of bituminous mixtures, it has a major effect on the performance of mixture. Thus, the choice of right aggregate is important to reduce the presence of water. There are two points that have been identified in stripping: a failure of bonding of the binder to the aggregate (failure of adhesion) and a failure within the binder itself (failure of cohesion). The lab tests were conducted by employing four combinations of granite and limestone with two different aggregate gradations to find the effect between these two aggregates in the moisture susceptibility of bituminous mixtures. The result from Indirect Tensile Strength ratio and Retained Marshall shows that granite and gap graded have high potential to water susceptibility. The stripping of aggregate was not clearly show by visual inspection. It is appear that the failure may be derive from the adhesion or cohesion failure within the mixture.

ACKNOWLEDGEMENT

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CHAPTER 1

INTRODUCTION

Bituminous mixtures evolved from dry stone mixture. These composite relied on the interlocking between the stone for their strength. Principal road layer consist of a mixture of stone in the form of graded aggregate and binder in the form of petroleum bitumen. The bituminous mixture will be laid on the top of the road layer.

Because of bituminous mixture layer lay on the top of the layer, it has a contact with the traffic to give smooth surface and also to protect the sub base. So, the strength of bituminous layer must be achieved to ensure that road structures will not collapsed.

Moisture is one of the elements that can cause damaged to the road structure. Water will seep through the bituminous mixture from the surface and damaged the pavement and next will seep through the sub base and damaged the basement of the road. The study of moisture susceptibility in the bituminous mixture is important to achieve the strength of the pavement.

Stripping (moisture sensitivity) in Hot Mix Asphalt (HMA) mixtures is a major form of distress in asphalt concrete pavement. This problem has been recognized since the advent of asphalt paving technology (Kim, 2005, in Hubbard, 1938). The stripping problem can be caused by the loss of adhesive bond between the asphalt binder and the aggregate (a failure of the bonding of the binder to the aggregate) or by softening of the cohesive bonds within the asphalt binder itself (a failure within binder itself). Both of the causes will happen due to the action of loading under traffic with the presence of moisture.

This distress generally happen at the bottom of HMA layer and will progressed upward to the surface as shown in Figure 1. Stripping usually hard to be detected with an examination from the surface of HMA layer alone, it has to dig into the pavement and observed the material removed. Traditionally, the potential of moisture sensitivity has been evaluated from laboratory testing.

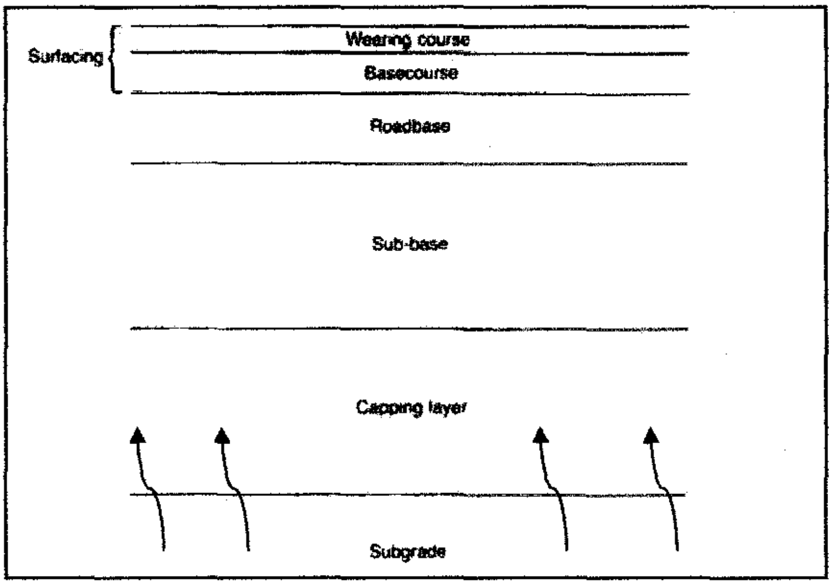

Figure 1: Distress of pavement layer

There are several factors that have been identified that affecting moisture sensitivity in HMA as the type and use of the mix, the characteristics of asphalt binder and the aggregate and environment effects during and after construction and the use of anti-stripping additives (Kim,2005, in Kinggundu,1988).

1.1 Problem Statement

Moisture damage in asphalt mixtures refers to loss in strength and durability due to the presence of water. The level and the extent of moisture damage, also called moisture susceptibility, depend on environmental, construction, and pavement design factors; internal structure distribution; and **the quality and type of materials** used in the asphalt mixture. This study evaluates the moisture susceptibility of asphalt mixtures with take into account on the effect of aggregate types and gradation characteristic (Arambula, E et.al 2007).

Two types of aggregates that used in this study are granite and limestone. From Table 1, shown the chemical and mineral composition of (Bagampadde et. al, 2006)

Table 1:Composition Data of the Aggregate Used in the Impact of Bitumen and Aggregate Composition on Stripping in Bituminous Mixtures Experiment by U. Bagampadde et al (2006)

Chemical Composition (% Weight)								
Aggregate	SiO_2	$Al2O_3$	CaO	MgO	Na_2O	K_2O	Fe_2O	MnO_2
AG1	71.2	18.0	6.30	0.30	0.82	1.70	1.61	0.06
AG2	71.9	15.4	1.64	1.14	2.70	5.35	1.80	0.11
AG3	53.7	22.4	8.10	0.54	2.80	1.64	10.63	0.20
AG4	89.5	9.3	0.04	0.06	0.06	0.40	0.64	0.04

Mineralogical composition (%)						
	Rock name	Quartz	Alkali feldspar	Lime feldspar	Ferro magnesian	Others
AG1	Granite	42	10	42	ND	7
AG2	Syeno-granite	27	53	13	ND	7
AG3	Tonalite	18	4	54	19	6
AG4	Quartzite	99	ND	ND	ND	Trace

ND = Not Detected

Until recently, it had been believed that only well graded gradations made a strong mixture. No doubt, well graded mixtures, when properly designed and constructed, will make strong pavement. However, recent studies suggest that gap graded and coarse matrix high binder mixtures have great potential to form strong and durable pavements (Mohammad et. al 2001).

In order to know the result on the inquiries about moisture sensitivity on HMA, there are certain experiments need to be performed.

1.2 Objective

The objectives of this study are

i. To determine the effect of using granite and limestone on moisture susceptibility of bituminous mixture

ii. To determine the effects of aggregate gradation on moisture susceptibility of bituminous mixture.

1.3 Scope of Study

The scope of this study is to find the effect on different aggregate types and gradation in the influence of moisture susceptibility of bituminous mixtures. In this study, the types of aggregates that will be focused on are granite and limestone. The gradations that will be used for both types of aggregates are well graded and gap graded.

Preliminary work is research about the facts and information on the topics that relate to this study. This task will be done by searching articles, journals and book which are related. The information from those documents will help on carry out this study. Any info that is related will be references until the end of this study.

Because of this study need testing to find the result, lab tests will be carry out. To find the moisture susceptibility of bituminous mixtures, four combinations of bituminous mixtures will be mixed and tested during the lab tests. The combinations are:

i. Granite + well graded,

ii. Granite + gap graded,

iii. Limestone + well graded; and

iv. Limestone + gap graded.

The tests result will be evaluated and discussed to find the effects of materials that will contribute to the moisture susceptibility in bituminous mixtures and to determine the best mixtures for the used of road pavement.

CHAPTER 2

LITERATURE REVIEW

2.1 The Definition and the Cause of the Moisture Damage in HMA

Moisture damage in HMA may be generically defined as the separation of the asphalt coating from the aggregate in a compacted HMA mixture in the presence of water under the action of repeated traffic loading (Kim, 2005). There are two points that have been identified in stripping: a failure of bonding of the binder to the aggregate (failure of adhesion) and a failure within the binder itself (failure of cohesion).

2.1.1 Adhesive Failure

Adhesion is defined as the property of bitumen that has the tendency to cling to the aggregate surface and to be able to sustain this condition in the presence of moisture. From researches that have been conducted, it has been said that adhesive mode of failure was the main factor that lead to moisture damage in HMA. Majidzadeh (1968) cited by Kim (2005) has stated, "....stripping of the binder from aggregate in presence of water (i.e., moisture damage) result in adhesive failure which is considered as an economic loss and an engineering failure in the design of a proper mixture." Kim (2005) cited from Kennedy and Tunicliff (1982) explained that stripping was the loss of adhesion between the asphalt binder and the aggregate due to the action of water, and suggested that stripping was the displacement of the asphalt binder film from the aggregate surface, which he explained using the chemical reaction theory of adhesion.

From the above opinion, a number of hypotheses relative to the adhesive bond between asphalt and aggregate have been developed in order to better understanding the phenomenon of stripping.

Hicks (1991) cited by Kim (2005) provided a general idea of previous research on adhesion. Below are the rough theories that have been developed by Hicks to explain the adhesion of asphalt binder to aggregate:

a) **Mechanical adhesion** theory (Kim, 2005, in Lee, 1954) suggests that the adhesion of asphalt binder to the aggregate is affected by several aggregate physical properties, including surface texture, porosity or absorption, surface coatings, surface area, and particle size. In general, a rough, porous surface had a tendency to provide the strongest interlock between aggregate and asphalt.

b) **Chemical Reaction** between the asphalt binder and the aggregate has been generally accepted to explain why different types of aggregate demonstrate different degrees of adhesion between the binder and the aggregate in the presence of water. In other words, the surface pH values of the aggregate and of the binder affect the quality of the surface adhesion (Kim, 2005, in Barksdale,1991)

c) **The differential degree of wetting of the aggregate** by asphalt and water can be explained by using energy surface theory. Rice (1958) cited by Kim (2005) reported data which indicated that the adhesion tension for water-to-aggregate is higher than that for asphalt-to aggregate. Hicks (1991) cited by Kim (2005) stated "...water will tend to displace asphalt cement at an aggregate–asphalt cement interface where there is contact between the water, asphalt, and aggregate." Mark (1935) cited by Kim (2005) indicates that interfacial tension between the asphalt and aggregate varies with both the type of aggregate and the type of asphalt cement.

d) **Molecular orientation** theory affirms that when asphalt binder comes into contact with an aggregate surface, the molecules in the asphalt align themselves on the aggregate surface to satisfy the energy demand of the aggregate (Kim, 2005, in Hubbard, 1958)

2.1.2 Cohesive Failure

Cohesion or cohesive attraction or cohesive force is a physical property of a substance, caused by the intermolecular attraction between like-molecules within a body or substance that acts to unite them.

In moisture damage of HMA, cohesive failure has been regarded as a less factor that contribution to the stripping failure. However, Bikerman (1960) cited by Kim (2005) suggested that possibility of cohesive failure was much greater than of adhesive failure. This has been proved by the work of Kanitpong and Bahia (2002), which is supported by the observation of failure surfaces in asphalt mixtures obtained from the Tensile Strength Ratio (TSR) test, where the failure was visually observed within the binder coating without evidence of apparent loss of adhesion to the aggregate particles.

This cohesive failure can be partially explained by emulsification of water in the asphalt phase, which is different to conventional emulsified asphalts in which the asphalt is emulsified in a water phase (Kim, 2005, in Fromm, 1974). Fromm's work showed that water could enter into the asphalt film and form a water-in-asphalt emulsion. This emulsification of water in the asphalt film causes asphalt particles to separate from the asphalt film (cohesive failure) and ultimately leads to an adhesive failure at a critical time when this emulsification boundary propagates to the aggregate surface.

From the above, the mechanism of cohesive failure has lead to the adhesive failure, for instance, the cohesive failure may only be inferred rather than observed, and the final result (adhesive) is reported as the cause (Kim, 2005, in Terrel, 1994). Thus, even though the definition of moisture damage in HMA has been regarded as the failure of adhesive and cohesive bonds between the asphalt and the aggregates in the presence of water, it has proven difficult to distinguish between the two modes of failure in predicting failure mode unless the failure surface of HMA is visually inspected a posteriori (Kim, 2005, in Terrel, 1994).

2.1.3 Factors Influencing Moisture Damage in HMA

Several surveys (Kim, 2005) have been conducted to find the factor that should be considered in evaluating the moisture damage in HMA. Many variables, including the type and use of the mix, asphalt characteristics, aggregate characteristics, environmental effects during and after construction, and the use of anti-stripping additives (Kim,2005), have been identified.

Based on work Hicks (1991) cited by Kim (2005), Table 2 summarize the factors influencing moisture damage.

Table 2: Summary of factors in influencing moisture damage by Hicks (1991)

Factor	Desirable Characteristics
1) Aggregates	
a) Surface texture	Rough
b) Porosity	Depend on pores size
c) Mineralogy	Basic (pH=7) aggregate are more resistance
d) Dust coating	Clean
e) Surface moisture	Dry
f) Surface chemical comp.	Able to share electron or form hydrogen bond
g) Mineral filler	Increase viscosity of asphalt
2) Asphalt cement	
a) Viscosity	High
b) Chemistry	Nitrogen and phenols
c) Film thickness	Thick
3) Type of mixture	
a) Voids	Very low or very high
b) Gradation	Very dense or very open
c) Asphalt content	High
4) Environmental effect during	
const.	Warm
a) Temperature	None
b) Rainfall	Sufficient
c) Compaction	
5) Environmental effect after const.	
a) Rainfall	None
b) Freeze-thaw	None
c) Traffic loading	Low traffic
6) Modifiers or additive	Use

2.1.4 The Mechanism of Moisture Damage in HMA

In the moisture damage of HMA, the essential problem that should be identified was how water penetrated the asphalt film and/or interfaces between asphalt and aggregate. From literature, several different mechanisms have been identified.

The approach from Rice and Thelen (1958) cited by Kim (2005) for this problem by using a proposed adhesion mechanism such as surface energy theory and chemical reaction between asphalt binder and aggregate. Surface energy theory suggested that the differential amount of interfacial tension and work of stripping between asphalt, water and aggregate caused by adhesion failure between asphalt and aggregate. Stripping was more observed in quartz rather than limestone because of differential chemical reactivity between the asphalt and the aggregate. Water is polar nature and asphalt is either non-polar or weakly polar. Water will be attracted to molecules which also have polar. In addition, molecules of silica and silicates have high dipole moments (higher than that of water), and carbonate rocks are also polar but to certain degree. Thus, siliceous aggregate will more attracted to water rather than asphalt because of polarity between them. Extent on that, limestone which poor polarity or non-polar, will exhibit less stripping because cohesive force of water are greater than adhesive forces between water and limestone. Therefore, non-polar asphalt does not preferentially exhibit stripping from limestone.

Cited from Kim (2005), Fromm (1978) suggested and demonstrated the emulsification of water in asphalt and the rupture (degradation) of the coating film. He explained the mechanism that the asphalt film can be rupture (degraded) due to the different amount of interfacial tension in many air-water-asphalt junctures which are formed when water enters the HMA mixture. Therefore, the rupture of asphalt film will reduce the effective film thickness of the asphalt so that the emulsified water can move rapidly to the aggregate surface.

Lottman suggested some of the major damage mechanism relates with the pore pressure in HMA (Kim, 2005, in Lottman, 1982). The development of pore water pressure in the mixture increase by the repetition of wheel-loadings, thermal expansion and contraction with condition and this can be categorized as mechanical disruption. Instead of pore pressure, he also states the damage mechanism by emulsification by mean of removal of asphalt in the mixture by water at moderate to high temperature. Other damage mechanisms are adhesion failure based on surface tension theory and water interaction with clay mineral in the aggregate fines. From these hypotheses, Lottman has developed a mechanical laboratory test protocol generally referred as the Lottman test.

2.2 Aggregates

Aggregates, as described in Bituminous Manual, Department of Transportation Minnesota, 2006 are defined as sand, gravel, crushed rock, salvaged aggregates, salvaged crushed concrete, and salvaged asphaltic pavement, and mineral filler, or combinations of these materials. Aggregates used in conjunction with bituminous materials vary greatly according to their intended use.

Aggregates may be mixed with various amounts of Asphalt Binder to improve its load carrying capacity or stability and also to reduce the wear under traffic. The properties of a Hot Mixed Asphalt (HMA) are dramatically affected by the shape, texture, and gradation of the aggregate from which they are produced. The HMA properties such as, Voids in Mineral Aggregate (VMA), Air Voids, and Fines to Effective Asphalt ratio, are critical to the performance of the Asphalt pavement. To consistently maintain these properties in a desirable range, the aggregate properties should be uniform with time. A high quality end product that is durable under traffic and weather is dependent on aggregates that are hard and strong, not susceptible to moisture damage, or to freeze/thaw damage.

Aggregate might be mixed with different amounts of asphalt binder to increase the strength for sustaining the load. The properties of Hot Mixed Asphalt (HMA) are affected by the shape, texture and gradation of aggregate. Voids in Mineral Aggregates (VMA) and Air Voids in HMA properties are critical to the performance of Asphalt Pavement. According to the Waddah (1998), the absolute total volume of void was not the only reason caused to voids content, the size and continuity of the void also the factors that must be considered in calculate the total volume of voids.

There is connection between the total volumes of void with the gradation of aggregates. As said by Waddah (1998):

"Large size air pocket are associated with coarse graded mixes, and the larger the air pockets, the greater the possibility to obtain continuity between them. Once continuity is established, water can easily flow through these connected voids, and eventually this causes serious damage to the asphalt pavement layer underneath."

From the above statement, it can be give a hypothesis that gap graded aggregate will give the same result as mention. Because gap graded aggregate has missing some size of aggregates that will interlock the aggregates together.

2.2.1 Aggregate properties

The most important engineering properties of the aggregates used in road pavement are cleanliness, size and gradation, shape and surface texture, hardness and toughness, durability and relative density (O'Flaherty, 2002).

The degree of cleanliness of road stone is usually regarded as being defined by the amount of clay, silt and dust. Which present on the fine and coarse fractions. The preferred method mention in BS 812: Part 103 to eliminate this dust is to washing and sieving (Nicholls1998, in BSI, 1985a).

The aggregate size and gradation, i.e. the maximum particle size and the blend of sizes in an aggregate mix, affect the strength, density and cost of a pavement. When particles are to be bound together by a Portland cement or bituminous binder, a variation in gradation will change the amount (and consequently the cost) of binder needed to produce a mix of given stability and quality. Aggregate size and gradation have a major influence upon the strength and stiffness characteristic of bituminous mix, as well as permeability, workability and skid resistance.

Particle shape and surface are used to describe aggregates and to provide guidance regarding their internal friction properties, i.e. those which (the interlocking of particles and the surface friction between adjacent surface) resist the movement of aggregates past each other under the action of an imposed load.

A research (Robert, 1997, in Brown et.al, 1989) confirms that aggregate framework and skeleton is the most important factor in determining the success of the material when laid. Scheming this framework to achieve the maximum interlocking through shape and gradation while allowing sufficient space for binder is the factor to success in bituminous technology.

The hardness of aggregate gives the ability of aggregate to resist the abrasive effects of traffic over a long time. Tough aggregates are those which are better able to resist fracture under applied loads during construction and under traffic. The aggregates in each pavement layer must be tough enough not to break down under the crushing weight of the rollers during construction or the repeated impact and crushing actions of loaded commercial vehicles.

Durability of aggregates are those that are able to resist the disintegrating actions of repeated cycles of wetting and drying, freezing and thawing or changes in temperature. Aggregates with higher water absorptions (>2%) have high tendency to frost action if they are placed in a pavement within 450mm of the road surface.

BS 812: Part 2 (Nicholls, 1998, in BSI, 1995) has mention there are three different outlines for expressing the relative density (specific gravity) of an aggregate; it may expressed as oven-dries relative density, saturated-surface relative density or the apparent relative density. , whereas water absorption is expressed as the difference in mass before and after drying at (105±5) °C for 24 hours.

According to Bituminous Manual, Department of Transportation Minnesota, 2006; aggregate properties can be divided into five categories: aggregate qualities, percent crushing, stripping susceptibility, aggregate durability and gradation. Two characteristic will be emphasized in this study which are stripping susceptibility (types of aggregate) and aggregate gradation.

2.2.1.1 Gradation

The aggregate gradation, or particle size distribution, directly affects the void structure in the final HMA pavement. The void structure is a fundamental property and is checked by measuring the Laboratory Compacted Air Voids, the Laboratory Compacted Voids in Mineral Aggregate (VMA), and the Field Compacted Air Voids (density). Aggregates having different maximum particle size can have different degrees of workability.

In production of HMA, usually there are three types of mix which are dense graded, open graded and gap graded and this three mixes based on the gradation of the aggregate. For this study, two only two type of mixes will be considered. The range of aggregate in dense graded type is from large stone mix until sand mix (continuously). In gap graded mixes utilize an aggregate gradation that ranges in size from coarse to fine with some intermediate sizes missing or present in small amounts.

2.2.1.2 Aggregate Stripping

Base on Bituminous Manual, Department of Transportation Minnesota, 2006; moisture sensitivity testing in terms of how the aggregate reacts with the asphalt and how the properties of the finished mix design react in the presence of water is evaluated by performing an aggregate stripping test. The stripping test is commonly referred to as the **Lottman test** or the **Tensile Strength Ratio (TSR) test**. Adhesion is the ability of the asphalt to stick to the aggregate in the paving mixture. Cohesion is the ability of the asphalt to hold the aggregate particles firmly inplace in the finished pavement. Aggregate stripping due to cohesion occurs when moisture weakens the bond between the aggregate and the asphalt binder. The inherent electrical charges of the binder and the aggregate may result in a bond that is susceptible to moisture damage. The Lottman or TSR test is performed by soaking an asphalt puck in a warm water bath for a specific period of time, cooling the puck to room temperature, and breaking the puck in a stability machine. Unconditioned pucks are also broken in the stability machine, and the Tensile Strength Ratio is calculated as the strength of the conditioned puck divided by the strength of the unconditioned puck. Typically Tensile Strength Ratios of 70% to 80% are required.

2.2.2 Aggregate Type

According to one experiment on Impact of Bitumen and Aggregate Composition on Stripping in Bituminous Mixtures by U. Bagampadde et al (2006), they made a conclusion that mixtures with aggregates containing alkali metals (sodium and potassium) exhibited relatively high moisture sensitivity, regardless of the bitumen used. In contrast, indications of moisture sensitivity were nit apparent in mixtures made with aggregates containing calcium, magnesium and iron. From the above conclusion, the composition of aggregates (type of aggregates) made a significant result in stripping of bituminous mixtures.

In general, it is belief that aggregate with high silica contents which sometimes called hydrophilic (water loving) are preference to stripping problem. Aggregate with low or no silica content, sometimes called hydrophobic (water hating) are less or no predisposition of stripping problem. From the experience of practical practice, there are few aggregates that completely resist the action of water under all conditions of use (Asphalt

Institute, Educational Series No. 10). Although the siliceous aggregate are more prefer to stripping problem but it is used widely and successful in many areas when proper attention is given to mix designs, mix properties and construction practice. When the safer against moisture damage is consent, it is actually preferred to use hydrophobic aggregate (carbonate) but because of limestone (one of preferred carbonate aggregate) has a history of polishing under traffic, so it is not advised to use it in surface courses.

2.2.2.1 Granite

Granite is quite literally as old as the earth. It is formed from liquid magma, the molten rock still found at the core of the planet, cooled slowly to form a substance approaching the hardness and durability of diamond. Granite is an igneous rock, the name reflecting its fiery beginnings. The chemical composition of granite is similar to that of lava. However, granite owes its hardness and density to the fact that it has been solidified deep within the earth, under extreme pressure. Over the eons, seismic activity has changed the crust of the planet, forcing veins of granite to the surface. Glaciers scraped off layers of dirt, sand and rock to expose granite formations. Typically revealed by outcrops, the deposits have been discovered on all the continents.

Granite consists of different chemical component in the average proportion. Some of the chemical components present in granite are:

Table 3: Granite chemical composition

Silicon dioxide	70.18%
Aluminium oxide	14.47%
Potassium oxide	4.11%
Sodium oxide	3.48%
Calcium oxide	1.99%
Iron II oxide	1.78%
Iron III oxide	1.57%
Magnesium oxide	0.88%
Water "molecule"	0.84%
Titanium dioxide	0.39%
Diphosphorus pentoxide	0.19%
Manganese Oxide	0.12%

2.2.2.2 *Limestone*

Limestone is a sedimentary rock composed largely of the mineral calcite (calcium carbonate, $CaCO_3$). It makes up about ten percent of the total volume of all sedimentary rocks. A unique feature of this rock is that its main constituent, calcite, is produced chiefly by shell-producing and coral-building living organisms. Numerous caves, gorges, sinkholes, and other natural formations have been formed by the action of acidic water on limestone deposits.

Limestone can be found in many varieties, depending on its mineral composition and physical structure. When composed of calcium carbonate alone, it is white or nearly white. Other colors are produced by the presence of minor constituents such as chert, clay, flint, sand, organic remains, iron oxide, and other materials. In addition, limestone may be crystalline, clastic, granular, or massive, depending on the method of formation. Crystals of calcite, quartz, dolomite, or barite may line small cavities in the roc

2.3 Bituminous Mixture

Hot Mixed Asphalt (HMA) or bituminous mixtures composed of a mixture of mineral aggregates, mineral filler and bituminous material (hot asphalt binder). This mixture shall be mixed at a central mixing plant in the proportions hereinafter specified to provide a homogeneous and workable mixture. The performance of bituminous mixture were effected by the above three materials. Asphalt mixtures may be produced from many different aggregate types and combinations. Each mixture has its own characteristics suited to a specific design and construction use. The design of HMA and other mixtures mostly involves selecting and proportioning ingredients to obtain specific construction and pavement performance properties. The goal of HMA is to find an economical blend of gradation and type of aggregates and asphalt binder that give a mixture that has:

- Enough asphalt binder to ensure a durable compacted pavement by thoroughly coating and bonding the aggregates

- Enough workability to permit mixture placement and compaction without aggregate segregation (Patrick, 2003).

Because aggregate comprises 95% of bituminous mixtures, it has a major effect on the performance of mixture. The particle size distribution, or gradation, of an aggregate is one of the most influential aggregate characteristics in determining how it will perform in term of moisture susceptibility as a pavement material (Mohammad et al 2001). There are two types of gradation that are concern in this study which are well graded (dense) and gap graded aggregates.

Well graded means that within a material that is well graded there is a good distribution of all the aggregate sizes from largest to smallest, coarse aggregate to "dust" (Braja,2002). With a well graded material all the different size aggregate particles will position themselves within the total matrix in such a way to produce a tightly knit layer of maximum possible density, when compacted correctly. A well graded material is better able to carry and spread load imposed on it than a poorly graded material. A well graded material will possess good stability, with good distribution of load / stress spreading out uniformly through the material to the road pavement layer below.

The term gap graded refers to a material when one or more of the aggregate sizes in a normal downward distribution of aggregate particle sizes are missing, hence producing a "gap" in the grading where there is little or no aggregate of a particular size to be found ((Braja, 2002). They require more binder and filler than other mixes, and their stability is much more dependent on the stiffness of the bituminous binder. HMA gap graded mixes can be prone to segregation during placement.

In HMA, gradation helps determine almost every important property including stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance and **resistance to moisture damage** (Roberts et al., 1996). Because of this, gradation is a primary concern in HMA mix design and thus most agencies specify allowable aggregate gradations for both. HMA consists of two basic ingredients: aggregate and asphalt binder. HMA mix design is the process of determining what aggregate to use, what asphalt binder to use and what the optimum combination of these two ingredients ought to be.

The other influential aggregate characteristics in determining how it will perform in term of moisture susceptibility as a pavement material is types of aggregate. In this study, two types of have been chosen which is granite and limestone. From Waddah (1998) has come out with the specific gravity and water absorption for three types of aggregates as below:

Table 4: Specific Gravity and Water Absorption of Three Aggregates Types (Waddah, 1998)

Sieve size	Aggregate Type					
	Limestone		Basalt		Granite	
	Specific gravity	Absorption (%)	Specific gravity	Absorption (%)	Specific gravity	Absorption (%)
25.4mm – 19mm	2.467	2.526	2.705	2.185	2.734	0.855
19mm – 12.7mm	2.470	2.517	2.700	2.285	2.706	1.080
12.7mm – 9.5mm	2.457	3.126	2.714	2.135	2.689	1.310
9.5mm – 6.4mm	2.438	3.425	2.721	2.567	2.666	1.595
6.4mm – no.4	2.426	3.656	2.729	2.797	2.638	1.600
No. 4 – no.8	2.459	3.178	2.722	2.941	2.594	2.190
No. 8 – no. 16	2.445	3.872	2.759	3.827	2.613	1.555
No. 16 – no. 30	2.465	3.599	2.788	3.245	2.694	1.350
No. 39 – no. 50	2.484	3.174	2.806	2.820	2.822	1.940
No. 50 – no. 100	2.539	2.336	2.832	2.609	2.844	1.925
No. 100 – no. 200	2.636	1.026	2.895	1..774	2.827	1.884
Filler	2.773	-	2.961	-	2.722	-

CHAPTER 3

METHODOLOGY

3.1 Flow of Methodology

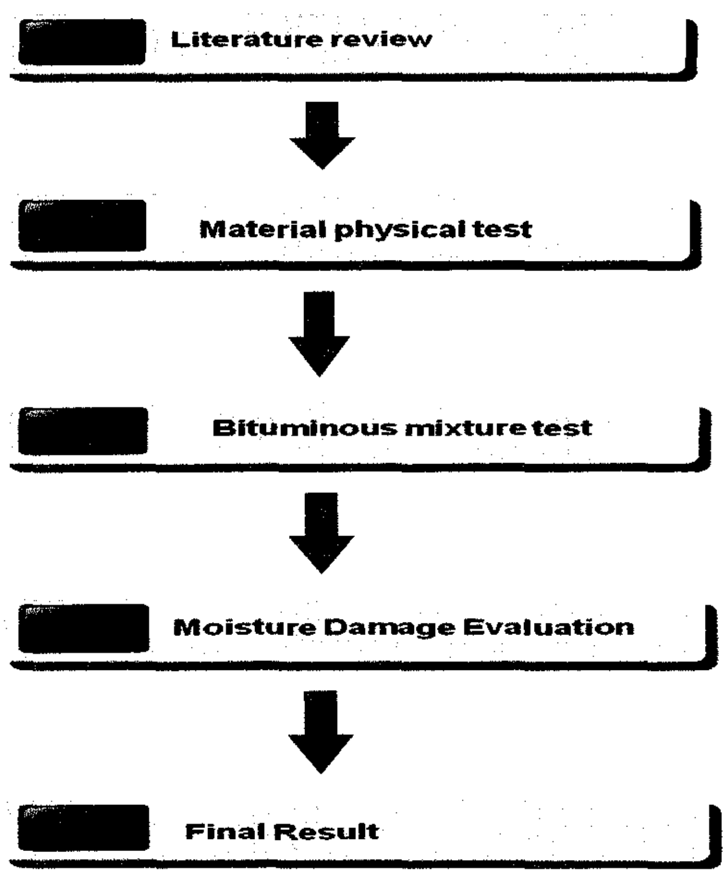

Figure 2: Flow of methodology

The study of this project started with some planning. The activities that involved in this study are roughly shown in the flow of methodology. Generally the sequence of work start from research of literature review, lab test of material, mixing mixture until testing on moisture damage are based on this flow. The detailed programme is shown in Appendix B.

Once the materials to be used have been selected and characterized and the planning have been scheduled, the next step to be considered is the laboratory procedure to be develop to satisfy the concern raised from problem statement and literature review (develop moisture susceptibility test compatible with the Superpave Mix Design system and traffic loading and environment).

3.2 Lab Test

Instead of search for the literatures review, materials and other information, to achieve the objective that has been stated, there are other processes that have to conduct. For the material such as aggregate and bitumen, lab test for this material will be conducted as shown in Appendix C to determine various parameters and to test these prior to implementing a more complex study.

3.2.1 Selection of Aggregate and Gradation

Two types of aggregate have been chosen for this study which is granite (quartz) and limestone (carbonate). These two aggregate will go through the properties test. The gradations that will be used in this study are well graded and gap graded. These criteria will mixes up to form a condition for HMA.

3.2.2 Sample Preparation

After testing on the properties of aggregate and bitumen, the design of bituminous mixture will be conducted. On this stage, the aggregate and bitumen will be mixed to form asphalt mixed concrete (HMA) to obtained compaction sample. Sample compaction was to be undertaken using Superpave Gyratory Compactor. The target mixture air void content is an important factor in Superpave mixture evaluation as well as any test for moisture susceptibility. Using the standard design of HMA, this mixed will then has to be tested for Marshall Test and stripping test for the moisture susceptibility effect in the HMA. To test on the bitumen stripping in HMA, Lottman Test will be conducted (U. Bagampadde et al, 2006).

3.2.3 Sample Pre-Conditioning

The properties of sample e.g. theoretical specific gravity, specimen height and diameter, bulk specific gravity and air void are determined before the samples are put in precondition. The sample then sort into two subsets, conditioned subset (moisture conditioned) and non-conditioned subset (dry conditioned). The control subsets (unconditioned) are stored at room temperature for 24 hours. Moisture conditioned subsets (conditioned) are partially saturated with distilled water at room temperature using a vacuum chamber. After 24 hours, the sample are removed from the vacuum chamber and immersed into the 25±1.0°C water bath. From this condition, the immersed mass, saturated surface dry mass, volume of partial saturated, volume of absorb water and degree of saturation for each sample are determined.

3.2.4 "Conditioned "Sample

After 24 hours of moisture conditioned period, the conditioned sample then soaked into water bath for 1 hour at 25±1.0°C to adjust the temperature of sample. Then the weight of sample, saturated surface dry weight, diameter and height and water absorption are determined from each sample. Volume of moisture condition followed by volume of absorbs water and degree of saturation is then being calculated.

To determine the moisture susceptibility effect, the sample will tested under real condition with saturated and under repeated traffic loading. It was felt that a repeated load should be applied to saturated and immersed samples to more closely reflect the real conditions.

The conditioned sample then tested by using a loading apparatus to determine indirect tensile strength and modulus elasticity.

3.2.5 "Unconditioned" Sample

After 24 hours, the dry samples are soaked into water bath for 20 min at 25±1.0°C to adjust the sample temperature. The sample then placed into loading apparatus to determine the indirect tensile strength and modulus elasticity.

3.3 Hazard Analysis

During the lab test, the consideration of Health Safety and Environment has been put in first place. When conducting the test, proper Personal Protection Equipment (PPE) is required to use. At the highway lab, proper attire such as lab coat or apron and full covered shoes are required to protect the student from physical harm.

Gloves, coverall, aprons and coats are commonly used in the lab to protect the hands, arms and body of students from cut, abrasion, chemicals, electrical shock and temperature extremes. For this lab test, gloves are used to protect hands from hot stuff when handling the bituminous mixture which is required to used an oven.

Instead of knowing the PPE stuff, the rules and regulation on the lab also take into the consideration. The test will be held at the place that allocated for it to avoid any incident. After the test, all the materials that have been used will be placed back at the original location.

CHAPTER 4

RESULT AND DISCUSSION

In this chapter, the results obtained from the laboratory tests are shown and analyzed. The final conclusion are developed and presented from the discussion of the results.

4.1 Physical Properties of Material

The results from material physical properties test are shown in Table 4 and followed by the discussion for each of the result.

Table 5: Material properties

Test / Material	Granite	Limestone	Sand	Filler	Bitumen
Specific Gravity	2.56	2.50	2.58	3.32	1.03
Water Absorption, %	1.10	3.20	0.508	-	-
Aggregate Impact Value (AIV), %	23.90	25.39	-	-	-
Los Angeles Abrasion, %	18	52	-	-	-
Softening Point, °C	-	-	-	-	48.30
Ductility, mm	-	-	-	-	112.25
Standard Penetration, mm	-	-	-	-	86

4.1.1 Specific Gravity

Specific gravity also known as particle density is a measurement that determines the density of substance. Specific gravity is a ratio of the density of given substance to density of water, when both at the same temperature. Two substances may be the same size, but their weight may be very different. The specific gravity of a substance determines how heavy it is by its relative weight to water. The specific gravity value is expressed upon how much greater the weight of the substance is to an equal amount of water. Specific gravity is a unitless measure, because it is derived from the density of the substance divided by the density of water and thus all units cancel.

Water has a specific gravity of 1. If a mineral has a specific gravity of 2.7, it is 2.7 times heavier than water. The Mineral and Gemstone Kingdom (no date) has stated that minerals with a specific gravity below 2 are considered light, between 2 and 4.5 averages, and greater than 4.5 heavy. Specific gravity of granite is higher than limestone. Granite is denser than limestone but both aggregate are still in averages (neither heavy nor light). Sand has specific gravity of 2.58 and it is also categorized as averages

For specific gravity of granite, limestone and sand, apparent specific gravity is chosen as shown in the result. Since, the determination of apparent specific gravity does not involved the measurement existence of water absorption and higher compared to oven-dried basis and saturated surface basis, for the reason apparent specific gravity will used for further computation.

The base filler used throughout in this study is Ordinary Portland Cement. The specific gravity was determined using Ultra Pycnometer Test 1000 which available at Chemical Engineering Department lab in Appendix A. The weight of 3.7756g of OPC which is half of the pcynometer was used to determine the particle density. The average value of the specific gravity was taken as per result in Table 4.

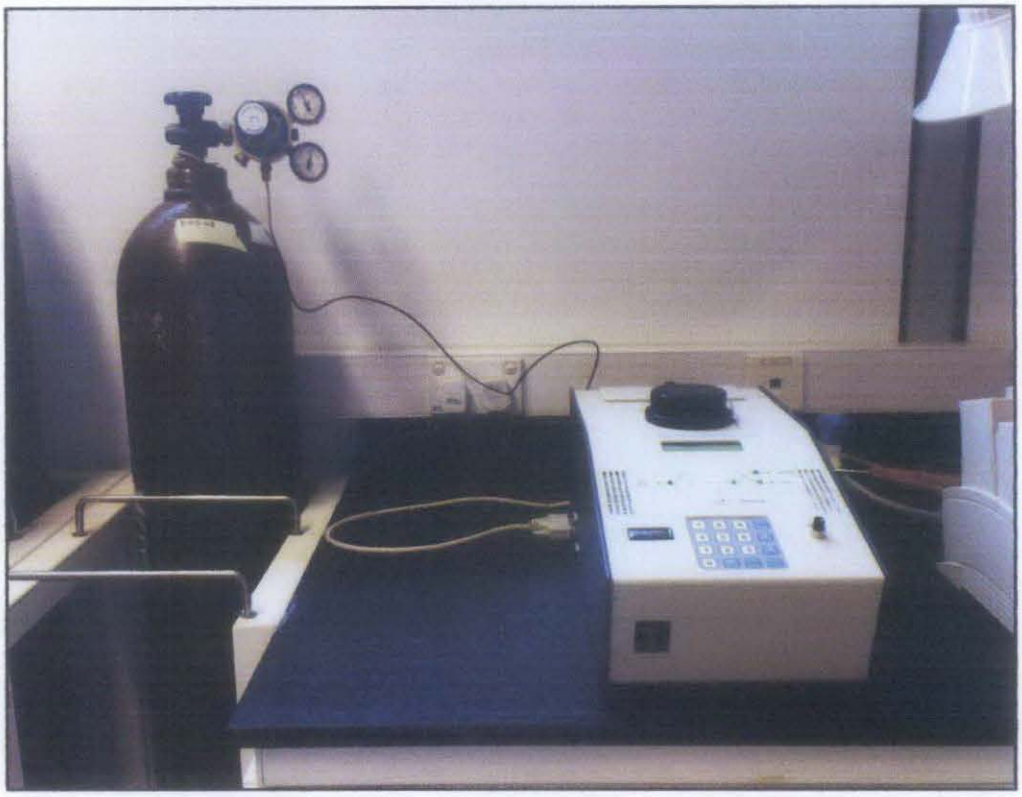

Figure 3: Ultra Pycnometer Test 1000

According to Kamaruddin (1998), to determine the porosity in designing the mixtures of bitumen and aggregate required binder specific gravity. Table 4 shows the mean result of specific gravity of bitumen.

The mean specific gravity from both results was 1.03. According to Whiteoak (2003), for bitumen with penetration grade 20/30 has specific gravity of 1.02-1.04. Although in the handbook did not mention the range of specific gravity for 80/100 grade bitumen penetration, but it must be within the same range.

4.1.2 Water Absorption

Water absorption is a percentage by weight determined by the ratio of the weight of absorbed water and the stone weight. A stone's level of porosity and permeability will determine its absorbent it is. The porosity of a stone is its ratio of pores or 'micro-voids' to its total solid volume and permeability is an ability to transmit a fluid and it is affected by the interconnectedness of the pores and capillary structures within it. A high level of fracturing in the stone or a presence of soft veining will also increase its permeability. It is possible for a stone to have a high level of permeability and also have a low porosity. This would happen if a stone develops a good network of pores while maintaining a low percentage of micro-voids.

From result in Table 4, it shows that limestone has higher water absorption than granite. Thus it means that limestone has high porosity and the porosity might be interconnected that can give water freely move in the pores. All types of aggregate are absorbent to water includes granite. Granite less water absorption compare to limestone because granite formed under high pressure that allows very little pores.

4.1.3 Aggregate Impact Value

Impact value of an aggregate is the percentage loss of weight of particles passing 2.36mm sieve by the application of load by means of 15 blows of standard hammer and drop, under specified test condition. The aggregate impact value gives a relative measure of the resistance of an aggregate to sudden shock or impact, which in some aggregates differs from their resistance to a slowly applied compressive load. This test gives an idea of toughness of the aggregate to resist fracture under the impact of moving loads.

Figure 4: Set of Aggregate Impact Value tester

Three sets of aggregates (granite and limestone) passing sieve 14 mm and retained on 10 mm sieve are used. During the test, result addition of weight B and weight C must equal to weight A.

The average Aggregate Impact Value for granite obtained from the result is 23.90%. With refer to Appendix D (Robert, 1994); in the table it shows the range of Aggregate Impact Value criteria that has to be meet in mixing the bituminous mixtures, the AIV for granite was within the range. Aggregate Impact Value for limestone was shown in Table 4. The mean of result for limestone AIV is 25.39%.

As compared the test result of granite and limestone with the typical value for road stone aggregate in Appendix D, the results obtained were within the range. Since the purpose of doing AIV test is to measure the resistance of an aggregate to sudden shock, e.g. as might occur under vibratory roller, the value of AIV greater than 25% are normally consider as being too weak and brittle to use in a pavement. The lower the AIV value the stronger the aggregate. Value for aggregate is lower than limestone means that granite is harder than limestone because granite is formed deep in the earth's mantle at extremely high pressure. It is a very hard, resistant stone made of crystallized minerals

4.1.4 Los Angeles Abrasion

Aggregate used in pavement should durable so that they can resist crushing under the roller. The aggregate abrasion test is a test to evaluate the ease (or difficulty) which aggregate particles are likely to wear under attrition from the traffic. This test is carried out in a sample of aggregate all retained in No. 4 ASTM sieve. Twelve steel ball of 44-48cm diameter are put in the steel cylinder with an internal shelf and rotated at 30-33 rpm for 500 revolutions. The typical Los Angeles abrasion for granite is 20% and below. For softer aggregate such as limestone, Los Angeles abrasion value is about 50% and above. Based on JKR pavement manual, aggregates with abrasion value over than 60% are not acceptable for road pavements.

The result that obtained from the test shows that both granite and limestone are acceptable to use for road pavements. The value for limestone is higher means that limestone has high tendency less durable compared to granite has lower value. Lower value means that the aggregate crushing during the test is less. The results that obtained are expressed as the percentage of aggregate weight passing sieve No. 12 to the original weight of aggregate retained on No.4

4.1.5 Softening Point - Bitumen

The objective of this experiment is to measure the susceptibility of blown asphalt to temperature changes by determining the temperature at which the material will be adequately softened to allow a standard ball to sink through it.

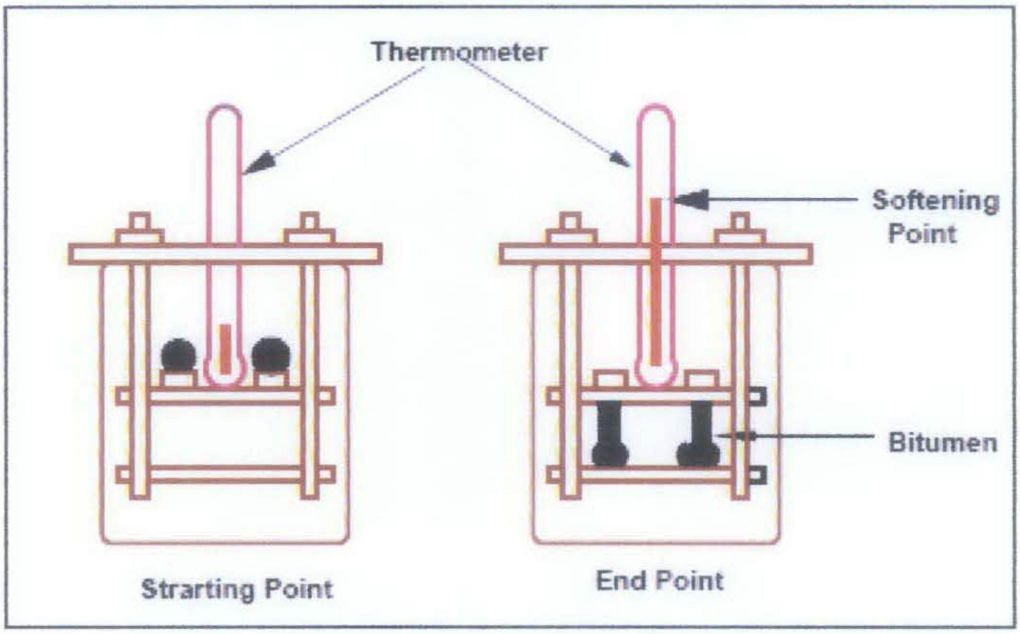

Figure 5: Softening point setup

The results that were obtained as per Table 5 below:

Table 6: Result of softening point test

SOFTENING POINT TEST BS2000: Part 58; 1983 / ASTM D36		
Ball 1	Ball 2	Mean
48.0°C	48.6°C	48.3°C

In this experiment, a steel ball (3.5g) was used and placed it on bitumen contained in a brass ring. The equipment then suspended in water. Water was used as a bath instead of glycerol because the author assumed that the softening point will be below than 80°C. If the softening point of the bitumen above than 80°C, glycerol will used as bath. The bitumen samples used were 80 penetration grades conforming to M.S. 124.

From the table, the difference between ball 1 and ball 2 for sample is accepted which is 0.02°C.

According to Manual on Pavement Design (JKR), the requirement for softening point for penetration grade 80-100 as per Table 6:

Table 7: JKR requirement for softening point

Characteristic	ASTM Test Method	Penetration Grade	
		60 - 80	80 - 100
Softening Point (°C)	D36	Not less than 48 & not more than 56	Not less than 45 & not more than 52

As compared the result with The JKR requirement, the sample is within the range for penetration grade 80-100.

4.1.6 Ductility

Ductility is the property of bitumen that permits it to undergo great deformation or elongation. Ductility is defined as the distance in cm, to which a standard sample or briquette of the material will be elongated without breaking. The objective of this experiment is to determine the cohesive strength of bitumen. Dimension of briquette thus formed is exactly 1cm square. The bitumen sample is heated and poured in the mould assembly placed on the plate. These samples with mould are cooled in the air and then in water bath at 27°C temperature. The excess bitumen is cut and the surface is leveled using hot knife. Then the mould will assembly containing sample is kept in water bath of the ductilometer for about 90 minutes. The sides of the mould removed, the clips are hooked on the ductilometer and the ductilometer is operated. One jaw is moved away from the other at standard rate; the distance it moves before the thread between the two breaks is the ductility in centimeters as shown in Figure 6. The ductility value gets affected by factors such as pouring temperature, test temperature, rate of pulling etc. A minimum ductility value of 75 cm has been specified in BIS.

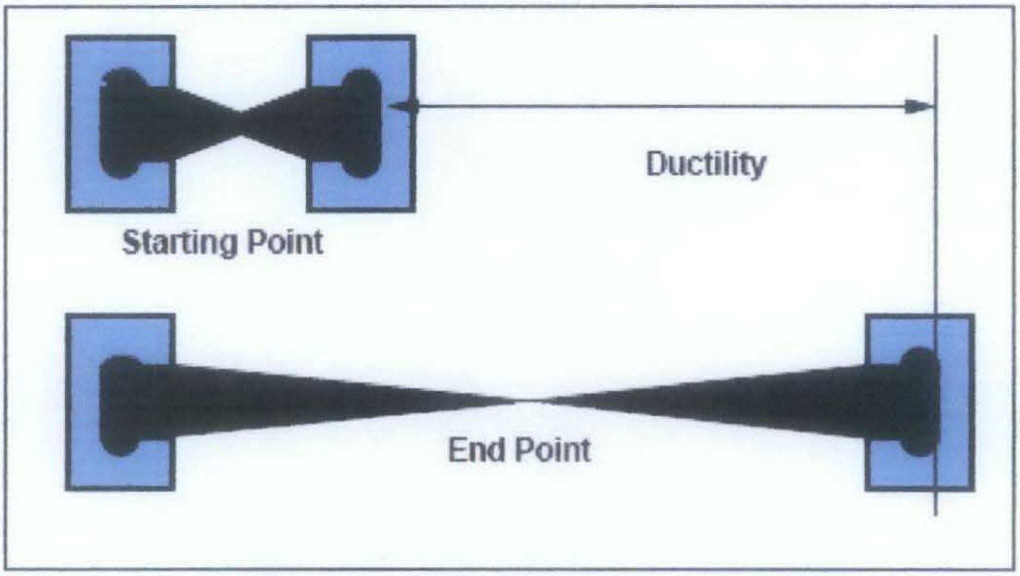

Figure 6: Ductility test

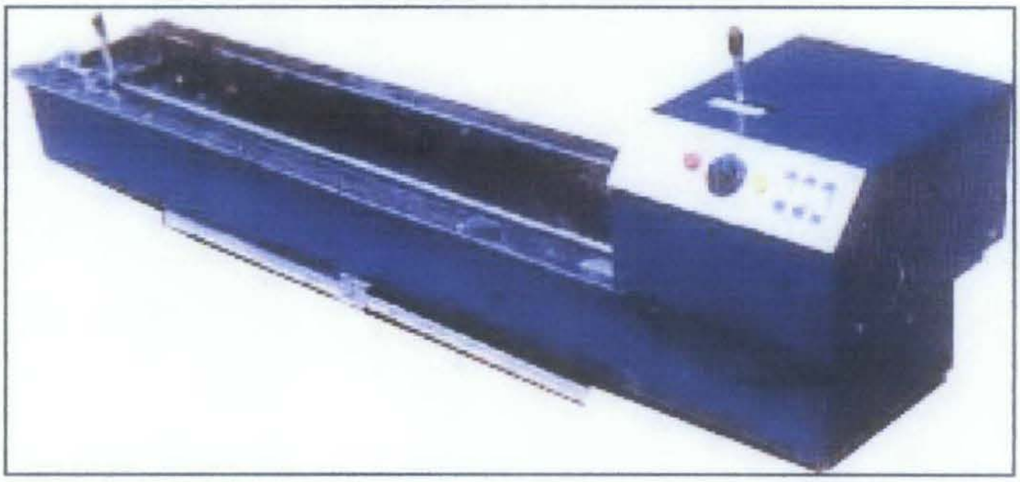

Figure 7: Ductilometer

Table 8: Result of ductility test

Ductility Test ASTM D113			
Sample No.	Mould No. 1	Mould No. 2	Mean
A	103	121.5	112.25

Table 9: JKR requirement for ductility

Characteristic	ASTM Test Method	Penetration Grade	
		60 - 80	**80 - 100**
Ductility at 25°C	D113	Not less than 100	Not less than 100

The comparison has been made between the test result and JKR requirement; it shows that the mean from three moulds did reach the requirement with ductility value more than 100. For this test, the bitumen penetration grade 80 was used and it will be standard penetration during this study.

4.1.7 Standard Penetration

The penetration is defined as the distance traveled by the needle into the bitumen. It is measured in tenths of a millimeter. The lower the value of penetration, the harder the bitumen. Contrast, the higher the value of penetration, the softer the bitumen. This test is the basis upon which the penetration grade bitumen is classified into standard penetration ranges. In JKR pavement manual has state that, the standard penetration of bitumen that should be used in making bituminous mixture is 80 standard penetrations. The result that obtained is actually acceptable for the used in making bituminous mixture.

4.2 Optimum Bitumen Content

The determination of optimum bitumen content is needed so that it will give the maximum strength to the mixture. Because of this study did not test on the variation in bitumen, so the optimum bitumen content will used throughout the study on the effect of moisture damage in bituminous mixture.

The lab test was conducted by using Marshall Stability test to determine the parameter for calculation of optimum bitumen content. The result is shown from Figure 8 until Figure 12.

The height of the each specimen was recorded for the calculation of volume. Volume of the specimen also can be obtained by

$$V = (W_a - W_w)$$

where

Wa = weight of specimen in air (kg)

Ww = weight of specimen in water (kg)

The mass was also recorded for the calculation of specific gravity (bulk density) that will be used to find the optimum bitumen content. Bulk density of specimen is given by:

$$d = M/V$$

where

M = Mass of specimen (= $M_B + M_G$)

V = Bulk volume of specimen

Voids in total mix (VTM) and voids in mineral aggregate (VMA) can be obtained by:

$$VTM = 100 \times V_A/V\ (\%) \qquad VMA = 100 \times (V_{BE} + V_A)/V\ (\%)$$

where

V = Bulk volume of specimen

V_A = Volume of air between coated aggregate particles in the mix

V_{BE}= Volume of effective binder

Stability and flow are obtained from the Marshall Stability test. All the results are being summarized into graph to obtain the optimum bitumen content.

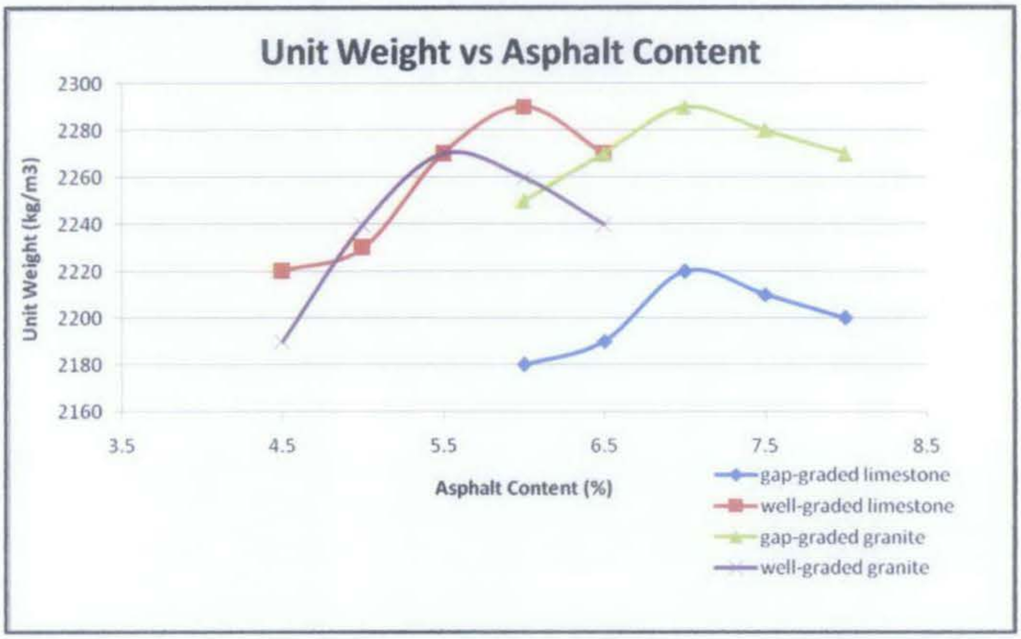

Figure 8: Unit Weight

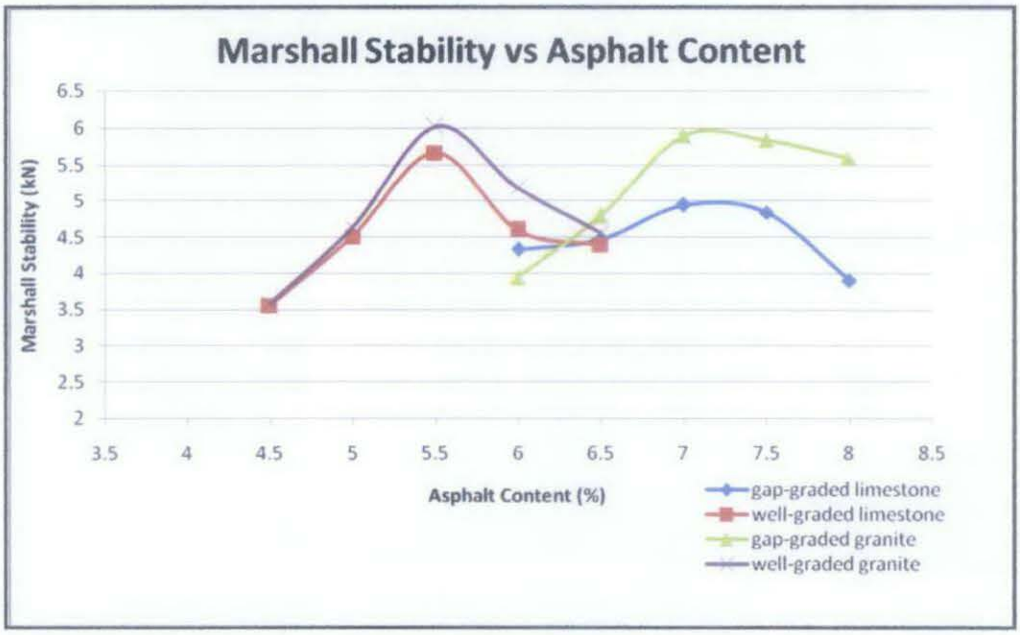

Figure 9: Marshall Stability

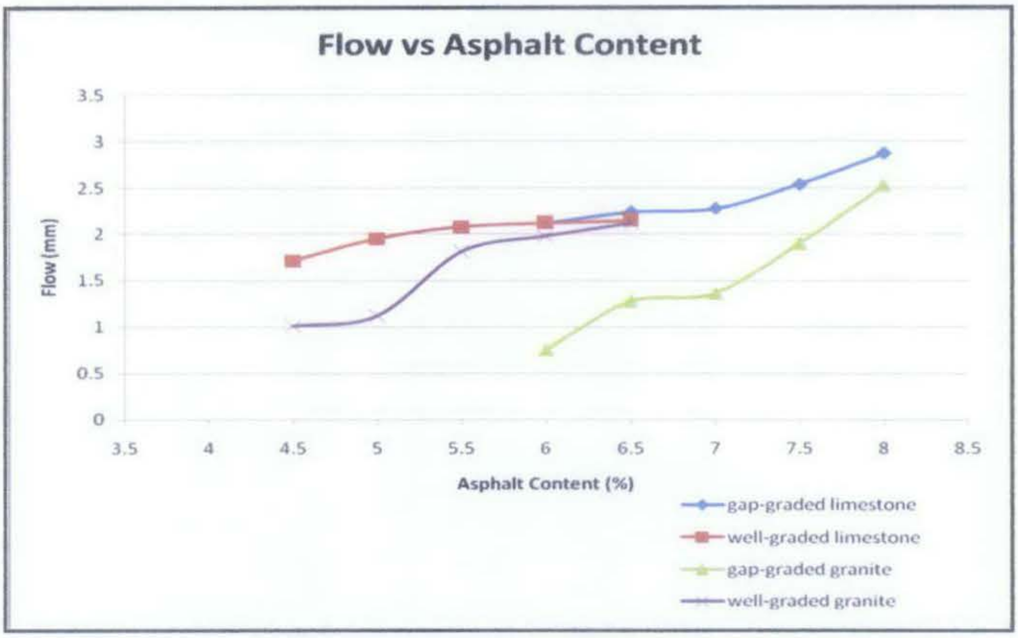

Figure 10: Flow

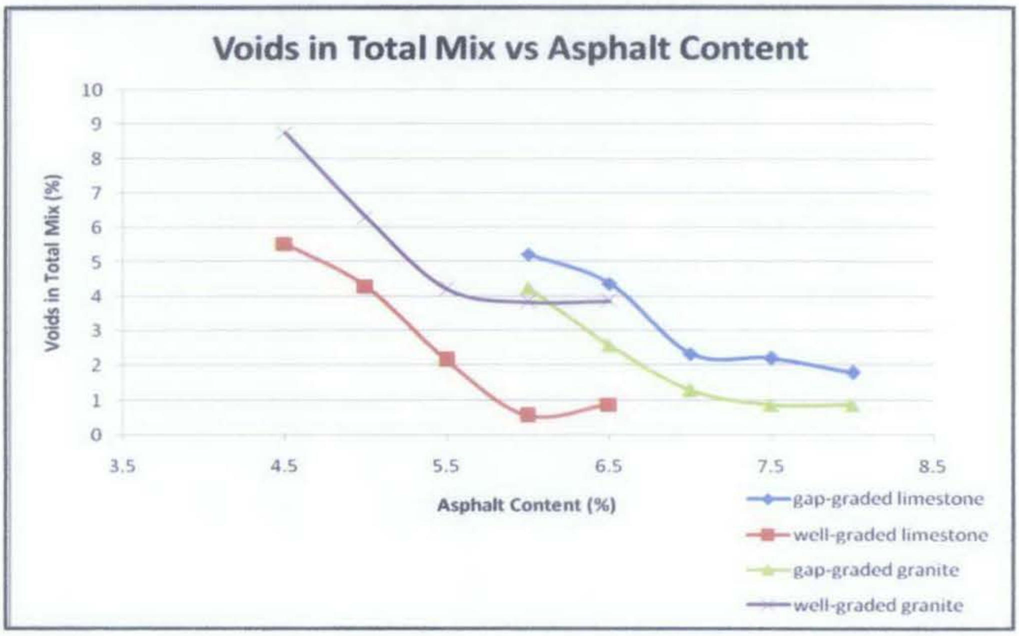

Figure 11: Voids in Total Mix

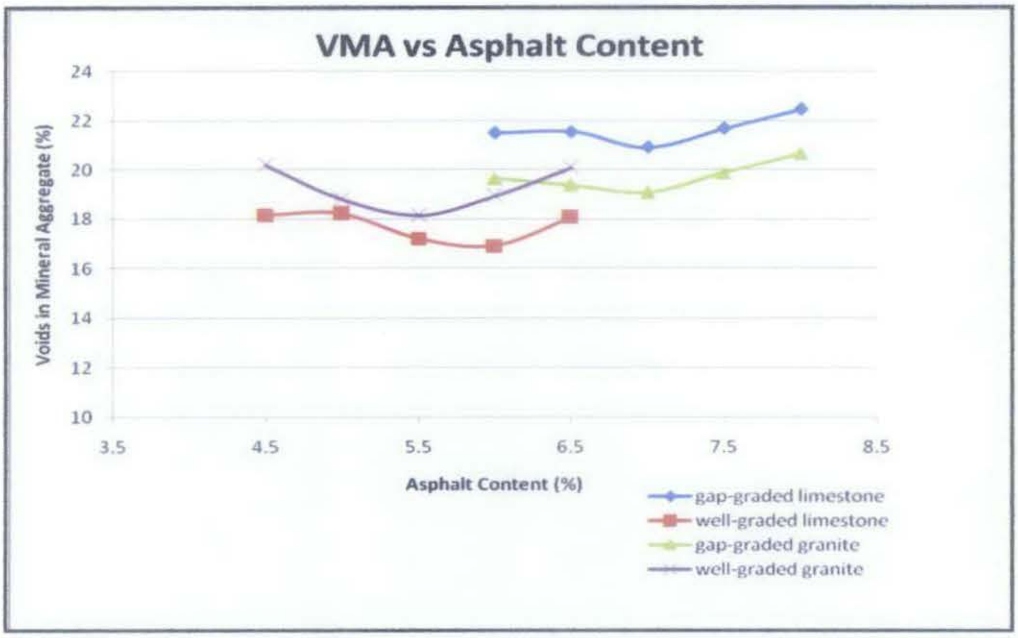

Figure 12: Voids in Mineral Aggregate

The asphalt content that meets the design requirement for unit weight, stability and VMA is then selected from the appropriate plot in Figure 8,9,10 and 11 respectively. The asphalt content having the maximum value of unit weight and stability is selected from each respective plot. The optimum asphalt content is determined as the average of the three values that obtained from the graph. The optimum bitumen content for each respective category is shown in Table 10.

Table 10: Optimum Bitumen Content

Aggregate	Gradation	Optimum Bitumen Content, %
Granite	Well Graded	5.55
Granite	Gap Graded	6.80
Limestone	Well Graded	5.63
Limestone	Gap Graded	7.00

From Table 10, it has shown that optimum bitumen content for limestone is higher than granite. From this, it is known that limestone need more bitumen for them to reach their maximum strength. If review back to result of properties, limestone has high water absorption because of high porosity and because of this property, limestone absorb more bitumen to fill up the pores inside it and bitumen to binder the aggregate (limestone) with other materials in bituminous mixture in order to gain the maximum strength.

If the comparison is made between the gradations of aggregate, it shows that gap graded aggregate need more bitumen compare to well graded aggregate. It is might be because in well graded mixture, the percentage of sand particle is less than the percentage of sand particle used in gap graded mixture (Appendix E). Sand particle is smaller in size which has greater surface area, so it needs more bitumen content to coat the surface area.

4.3 Moisture Damage Test

Two tests have been conducted to test moisture damage on bituminous mixture which is Indirect Tensile Test and Retained Marshall. The purpose conducted these two test were not to compare the result but to support each other result.

Figure 13 show the comparison of air voids and mixtures. It shows that gap graded has more air voids compare to well grade. The air voids were determined by using the bulk and maximum specific gravity. Because well graded comprise of size from large to small so the small size can fill the void between the large size. In gap graded mixture, there are some sizes that missing which result that the pore left from the bigger size not be filled (Appendix E). The voids that left will be filled with air and water. If the voids connected each other, it will form a connection and this connection between voids will then resulted in high permeability. Generally, permeability means the ease of fluid to flow through the void. In this case, if the fluid easy flow (high permeability) into the mixture, the tendency of the mixture to damage is high. The more voids in the mixture is not means the mixture has high permeability. Although in well graded mixture has little void but if that little void connect to each other it will give high permeability. High permeability happens when the voids are connected to each other. If many voids connected to each other, the mixture will has high permeability. This sometimes resulted from the method of compaction and how many blows that used for compaction.

Figure 14 shows the comparison degree of saturation for different mixture and condition. Degree of saturation is a ratio of liquid (such as water) in a porous material. Previous we had discussed about the voids in the mixture, from the result of air void and degree of saturation, it is shows that well graded mixture have little voids but has high degree of saturation. This shows that although well graded aggregate has little voids but this little voids are connected to each other and give high permeability that will eased the water to flow into it. There is some probability in well graded limestone mixture that caused this mixture has high degree of saturation but little void. This probability occurred because limestone is less harden aggregate, so when the compaction of mixture, the edge of limestone might be crushed. Because of this crushed, there are small particles of limestone which have greater surface area and because of this greater surface area so it absorb more water. As we relate the degree of saturation with the bitumen content, it shows that the less bitumen result in high degree of saturation. From the graph, the combination of well grade and rock type granite which used 5.5% of bitumen to reach the maximum strength resulted high degree of saturation.

4.3.1 Indirect Tensile Load

The tensile load (non-destructive test) of the samples was determined for both unconditioned and conditioned sample. Figure 15 and Table 11 shows the result of load imposed on the samples and the strength for dry and wet samples. The figure and table shows that in wet state, the load and strength are lower than the dry state (control). For combination mixture of granite with well graded, unconditioned mixture can sustain load 1.2N more than conditioned mixture. For granite with gap graded mixture, it shows the difference load is very significant between unconditioned and conditioned mixture by 3.3N. Conditioned gap granite is weak with the present of moisture. The same thing also happen to combination of limestone with gap graded aggregate with difference in load by 3.17N. Combination of aggregate limestone with well graded only have little difference in load. From the results of load and differences of load, it is shows that the combination of well graded with limestone aggregate in unconditioned state can sustain more load than others mixture in unconditioned state.

Each load that obtained are then be calculated to find the strength value. The bigger value indicated that the mixture has better strength. Results for wet and dry strength value are then compared. As an expected, dry condition for each of the combination give a high strength value compared to wet conditioned. The difference percentage of dry and wet strength value between combination of granite and well graded, granite and gap graded, limestone and well graded and limestone with gap graded are 6.37%, 8.62%, 6.81% and 5.21%. The percentage shows that reduction of strength for all mixtures not very high. Overall results for the strength value gives that limestone has better strength in wet state because limestone is a hydrophobic aggregate (hate water) so the attraction between limestone and bitumen was better than the attraction between limestone and water. In contrast, granite was more attract to water than bitumen because granite is water loving aggregate (hydrophilic). Gap graded granite has an ability to sustain high load might be because of the arrangement of the aggregate inside it. Although there are missing size of the aggregate but if the arrangement was good and it interlock each other it can give better performance.

Figure 16 shows the result on deformation of bituminous mixture. The graph shows that for aggregate granite mixture conditioned sample, well graded sample has high deformation compared to gap graded sample but for unconditioned sample, it is vice versa. For limestone aggregate, it shows that the deformation for unconditioned sample, well graded sample was slightly higher than gap graded sample. The same trend also happen to limestone conditioned sample. If looked at the graph, the result shows that conditioned mixture for all combinations have low deformation compare to unconditioned mixture. The difference deformation between conditioned and unconditioned sample for mixture of granite with well graded, granite with gap graded, limestone with well graded and limestone with gap graded are 0.63μm, 0.79μm, 0.67μm and 0.60μm. This might be because of the voids in the mixture have been filled with water and when load is imposed on it, the pressure of water try to resist the load and make it less deformation. For unconditioned mixture, the voids space in the mixture are only fill with air and empty, and when the load imposed on it, the mixture can easily deformed. This result also supported by the result on Marshall Test in Figure 19 which also gives the result that conditioned mixture has low deformation than unconditioned mixture.

4.3.2 Indirect Tensile Strength Ratio

The result of comparison for indirect tensile strength ratio between different mixtures has shown in Figure 17. From six samples, three samples with more air voids were choose to be soaked in the water while the other have been tested unconditioned. Values of the strength represent the mean for each set of three samples. The tensile strength ratio obtained from dividing wet strength value with dry strength value which the answer represents the amount of strength loss due to the effect of water.

From the figure it shows that the mixture with combination of well graded aggregate and limestone has high value of indirect tensile ratio with 97.43% followed by combination of well graded and granite with 94.67%. Combination of mixture for aggregate limestone with gap graded gives Indirect Tensile Strength ratio 94.19% and last combination of mixture, granite with gap graded has Indirect Tensile Strength ratio 91.38%. The required Indirect Tensile Strength ratio for bituminous mixture is above 70%. It is seems that the ratio for all combination of mixture give value above the requirement. If the results give value low, it indicates more damage to the sample. From the result, although all value give above the requirement but the lower value may has tendency to stripping problem.

4.3.3 Marshall

Figure 18 and Table 12 shows the result from Marshall Test (destructive test). Marshall Load between different mixtures is then compared and calculated to obtain retained Marshall. The Marshall stability of mix is defined as a maximum load carried by a compacted specimen at a standard test temperature of 60°C. From the graph, it can be seen that reduction in sustaining load for granite is very large and significant compared to limestone. The different load between unconditioned and conditioned sample for well graded with granite is 6.97kN and for gap graded with granite is 9.82kN. The different is very significant shows that granite is weak with the present of water. These results can be proved by lower retained Marshall that shows granite is more vulnerable to moisture damage and reveal a higher level of moisture sensitivity as indicated. The requirement for mixture to sustain moisture damage, retained Marshall must above 75% (Whiteoak, 2003). For limestone, there are also has some reduction in strength but not as much as reduction in granite mixture. As seen the result in Retained Marshall that obtained from dividing conditioned load to unconditioned load, mixture with limestone did not reach the requirement as expected with value of 74% for limestone with well graded mixture and 72.94% for limestone with gap graded mixture. This might because another factor for example air void which store water that will affect the bonding between binder and aggregate that caused the increment reduction in load sustaining. Limestone is less attraction to water so it less tendency to moisture damage.

From the result also, it shows that gap graded mixture can sustain more load compared to well graded mixture but the difference not very significant. From literature, it is expected that well graded mixture will sustained more load than gap graded because of the continuous size that will fill the voids and give a better performance. For this case, it might be because of the arrangement of aggregate in gap graded is better than well graded mixture.

Figure 19 shows the result of deformation from Marshall Test. From the result it is shows that the deformation for unconditioned is higher than conditioned sample. These results are same with Indirect Tensile Test but different in unit. The different is significant for limestone gap graded mixture with value of 0.66mm. The other combinations, the different are a little. This deformation results are still can be accepted because in JKR Manual, the deformation between 2mm to 4mm can be permitted.

4.3.4 Effect of aggregate and Gradation in Moisture Susceptibility

Water susceptibility and water absorption are two different things. Water absorption is a penetration of water into another substance while water susceptibility is a state of substance being likely or liable to water (degree of sensitivity). From the result of indirect tensile strength and retained Marshall, granite exhibit more tendencies to moisture damage rather than limestone although the result for water absorption shows that limestone is higher in water absorption. Because of granite that comprise of quartz and it is mineral that absorb and more attraction to water than asphalt. Silica and silicate in granite have high dipole moment that can attract to water which also a polar molecule. It is difference from limestone which comprise of carbonate which have non polar molecule. It has less attraction to water, so it can maintain the adhesion force with the asphalt.

Mixture that made from combination of granite with gap graded aggregate shows that it can sustain high load from both indirect tensile test and Marshall Test. From this, no doubtful that granite is the best aggregate compare to limestone for sustaining high load. This can be proved from the test of aggregate impact value. The result shows that, granite has low value compare to limestone which means that granite is harder than limestone and it can sustain more load.

Mixture with gap graded aggregate shows that this type of gradation can also exhibit strong mixture with asphalt to sustain high load as been shown by the result. Generally, gap-graded mixes are similar to dense-graded mixes in that they provide dense impervious layers when properly compacted. In conditioned samples, samples with gap graded aggregate shown better result might be because of degree of saturation was less and interconnected voids are less although there are many voids in it, so the absorption of water less. From the result, when degree saturation higher the bitumen content is low. Mixtures with gap graded aggregate consume more bitumen content compare to mixture with well graded aggregate. So, it is no doubt that gap graded aggregate also can give better result that well graded aggregate. In conditioned mixture, result from IDT test shows that, combination of well graded and limestone exhibit the higher sustained load. Because of limestone non water loving aggregate, so it can maintain adhesion force with asphalt and it can be prove by the difference value between the conditioned and unconditioned samples which small.

To assure that result in IDT strength ratio is true, retained Marshall Test also conducted. Marshall Test result will give different value but the final result (Retained Marshall) will be evaluated either these mixture can be affected with water not. From Table 10 and Figure 16, it can be said that these result supported the IDT strength ratio. Retained Marshall Result shows that the combination of well graded limestone exhibit high strength avoid moisture damage.

Bituminous mixture will be used as a road pavement. This study is important to know which combination that will have more tendencies to stripping problem and the effect from using the weak combination. From the discussion above, it is concluded that combination of granite with well graded is exhibit tendencies to stripping. The effects of used this combination of bituminous mixture for road pavement is the pavement will loss in its strength and because of this the pavement cannot take normal stress. Disintegration (separation and removal of asphalt binder and aggregate) of bituminous mixture will happen and can see the white grain of sand (no bonding) that can cause damage to the surface of pavement structure due to long contact with water and heavy traffic wheel as shown in Figure 20. The pavement will slowly deteriorate and result in less durability of structure and existing of pothole that can be danger to the user as shown in Figure 21.

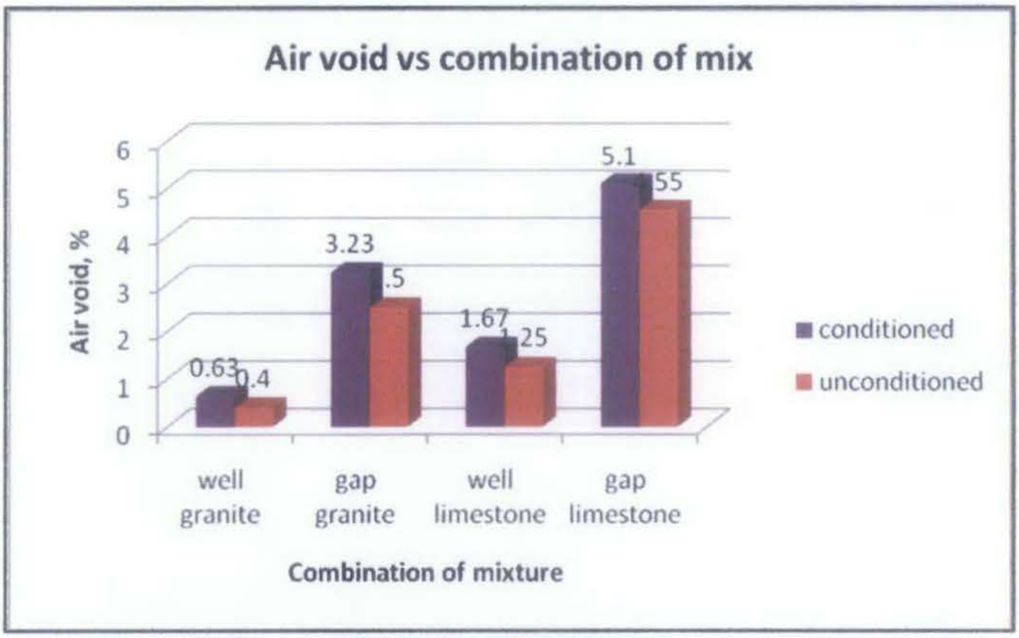

Figure 13: Air voids

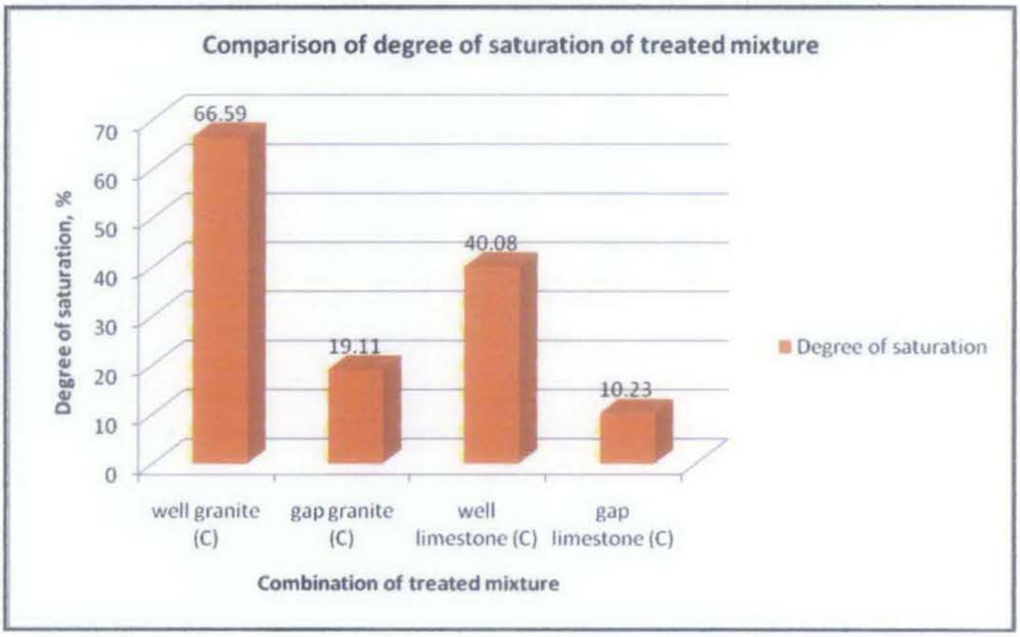

Figure 14: Comparison degree of saturation

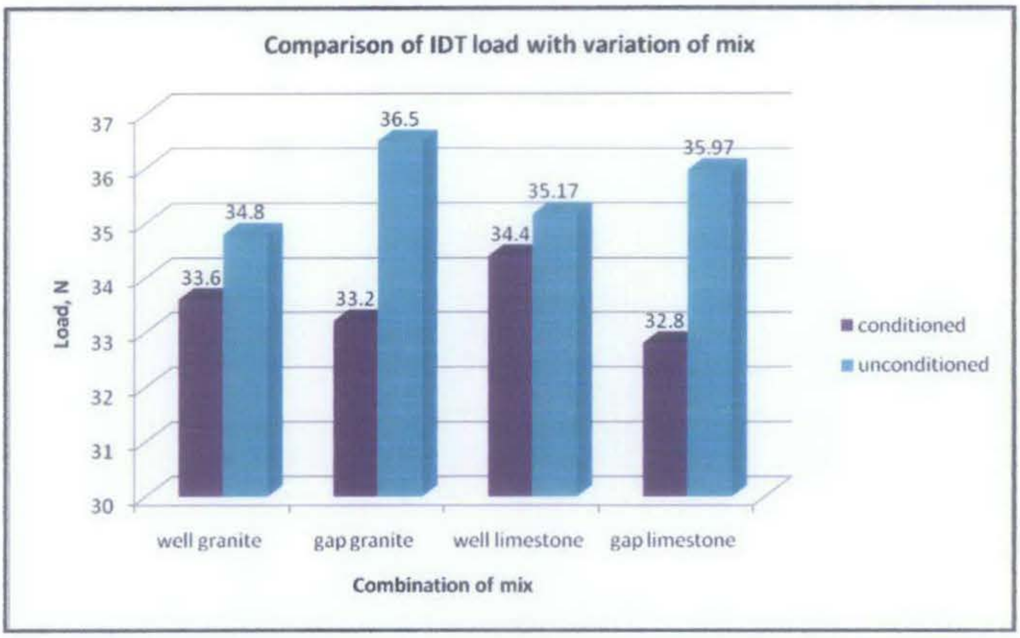

Figure 15: Comparison of IDT load

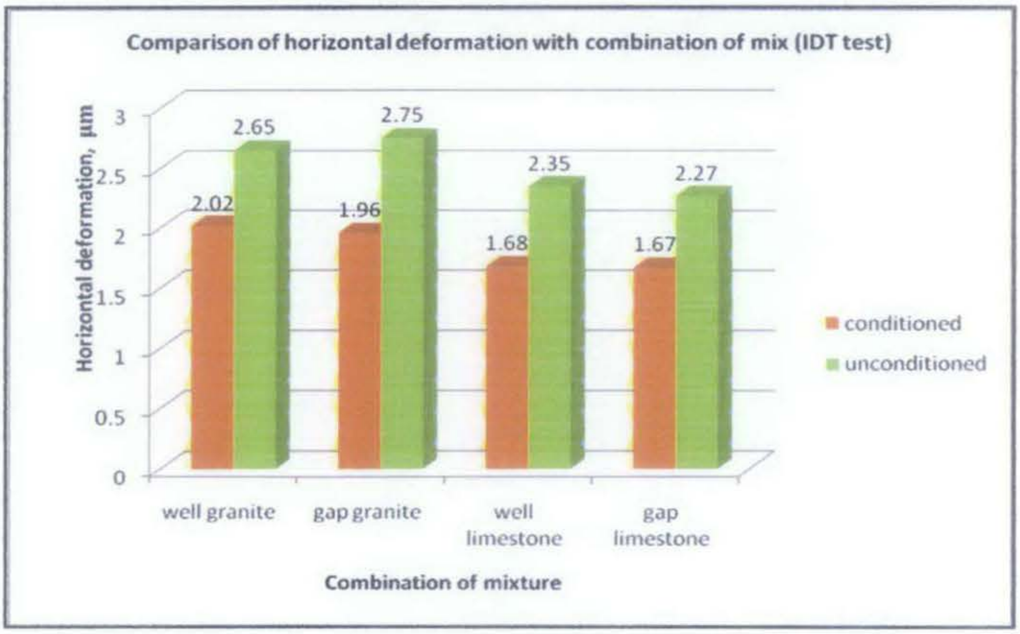

Figure 16: Comparison of horizontal deformation (IDT test)

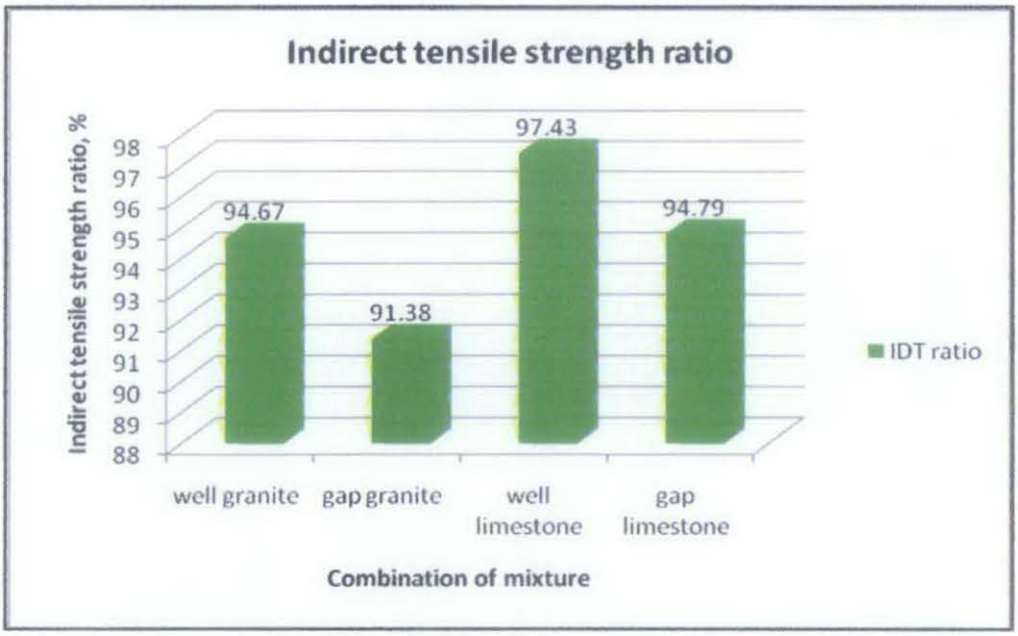

Figure 17: Indirect tensile strength ratio

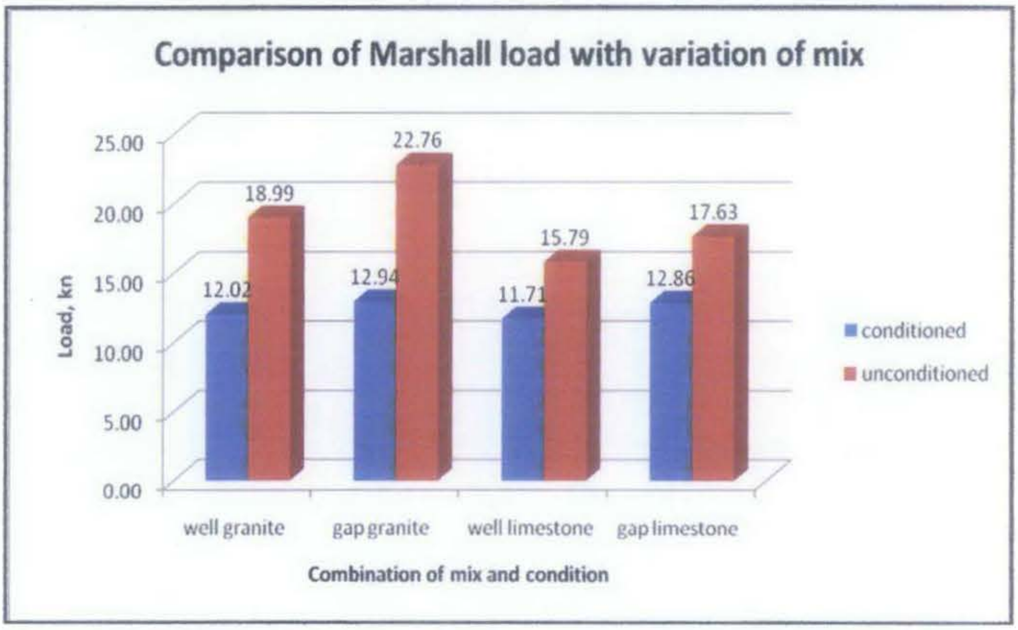

Figure 18: Comparison of Marshall Load

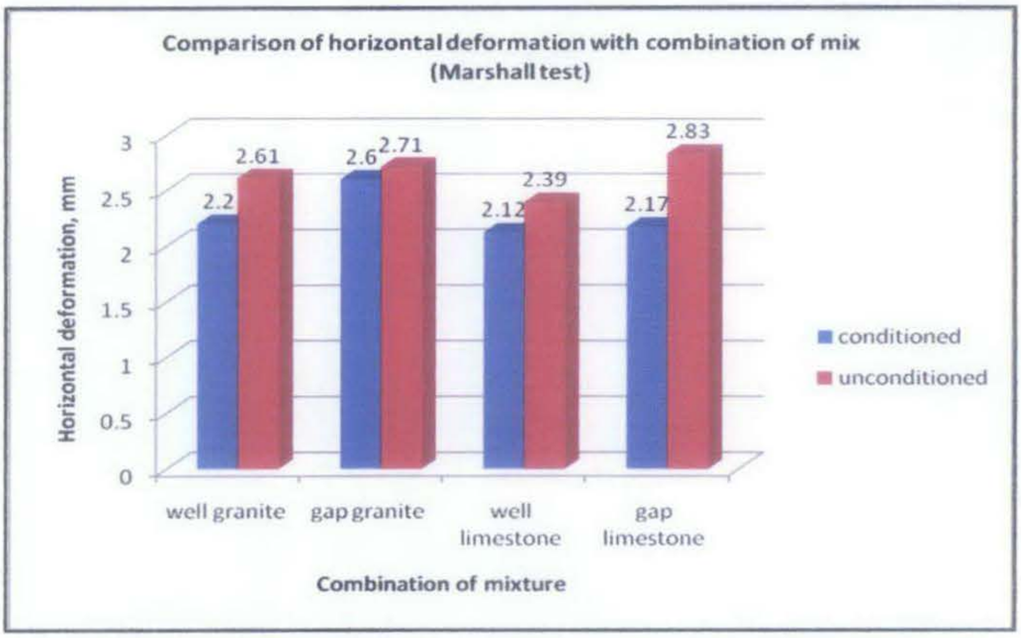

Figure 19: Comparison of horizontal deformation (Marshall Test)

Table 11: Result on dry and wet strength of IDT test

Mixture	Dry Strength	Wet strength
Well graded + Granite	0.00314	0.00294
Gap graded + Granite	0.00325	0.00297
Well graded + Limestone	0.00323	0.00301
Gap graded + Limestone	0.00326	0.00309

Table 12: Retained Marshall Result

Mixture	Unconditioned (kN)	Conditioned (kN)	Retained Marshall (%)
Well graded + Granite	18.99	12.02	63.30
Gap graded + Granite	22.76	12.94	56.85
Well graded + Limestone	15.79	11.71	74.00
Gap graded + Limestone	17.63	12.86	72.94

Figure 20: Fatigue from stripping problem and disintegration of pavement

Figure 21: Potholes

CHAPTER 5

CONCLUSION

Based on the study and lab works that have been conducted and with references in literature review, following are the conclusions that have been made:

5.1 Material physical properties

1. Specific gravity of granite is higher than specific gravity where granite is 2.56 and limestone is 2.50.
2. Limestone has higher water absorption compared to granite where limestone is 3.20 and granite 1.10 which can be concluded that limestone has higher surface porosity than granite.
3. Aggregate Impact Value for granite (23.90%) is lower than limestone (25.39%) which indicated that granite is harder than limestone.
4. Granite has lower Los Angeles Abrasion (18%) compared to limestone (52%) which indicated that granite is more durable than limestone.
5. Combination of limestone with gap graded mixture required high bitumen content where optimum bitumen content 7.00% compared to the other combinations.

5.2 Moisture damage test

1. Gap graded mixture has high air voids than well graded mixture. In term of aggregate type, limestone give higher air voids than granite.
2. Combination of granite with well graded mixture give higher degree of saturation compared to other combinations.
3. Gap graded granite has an ability to sustain high load in unconditioned state and it might be because of the arrangement of the aggregate inside it.
4. Combination of well graded with limestone only has little reduction in

ability to sustain load between dry state and wet state.

5. Dry condition for each of the combination give a high strength value compared to wet conditioned.
6. Limestone has better strength in wet state because limestone is a hydrophobic aggregate (hate water) so the attraction between limestone and bitumen was better than the attraction between limestone and water.
7. Conditioned sample for granite mixture, well graded sample has high deformation compared to gap graded sample but for unconditioned sample, it is vice versa.
8. Limestone aggregate, it shows that the deformation for unconditioned sample, well graded sample was slightly higher than gap graded sample.
9. Combination of well graded aggregate and limestone has high value of indirect tensile ratio with 97.43% compared to other combinations and it is above the requirement which is 70%. This indicated that this combination is less vulnerable to stripping problem.
10. In Marshall Test, combination of gap graded with granite give an ability to sustain high load compared to other combinations in dry and wet state but the reduction in load from dry to wet is too big.
11. Result deformation from Marshall Test shows that the deformation is within the range permitted by JKR between 2mm-4mm.
12. Conditioned mixture has low deformation than unconditioned mixture. This might be because of the voids in the mixture have been filled with water and when load is imposed on it, the pressure of water try to resist the load and make it less deformation.
13. In Retained Marshall result, combination of limestone with well graded aggregate has high value which is 74% that indicated this combination less vulnerable to stripping problem.
14. From the result of Indirect Tensile strength ratio and Retained Marshall test shows that granite and gap graded has high potential to have possibility of moisture damage.
15. The effects of used this combination (granite + gap graded) of bituminous mixture for road pavement is the pavement will loss in its strength and because of this the pavement cannot take normal stress.
16. Disintegration (separation and removal of asphalt binder and aggregate)

of bituminous mixture will happen and can see the white grain of sand (no bonding) that can cause damage to the surface of pavement structure.

17. The pavement will slowly deteriorate and result in less durability of structure and existing of pothole.

The objective of this study is achieved by the analysis of IDT strength ratio and Retained Marshall.

5.3 Recommendation

Basically, the use of granite as an aggregate in area that high water susceptibility is dangerous to the traffic but to use limestone also not suitable because it has a history of polishing under traffic that cannot make it proper material to use in surface course. So, the best solution is to use granite because of its properties that sustain more load and hard. To avoid the moisture damage that caused because of granite is hydrophilic and to reduce the voids within the mixture; there are some recommendations to minimizing or preventing the problem:

1. Use an anti-strip agent in proper amount if the amount excess, this anti-strip will turn into stripping agent in presence of water. Hydrated lime and heat-stable liquid anti-strip agents have provided acceptable field performance with selected aggregates.
2. Make sure that the aggregate particles are completely and uniformly coated with asphalt films as thick as allow the mixture to meet strength requirements.

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APPENDICE

APPENDIX A

ULTRAPYCNOMETER ANALYSIS REPORT

QUANTACHROME CORPORATION
Ultrapycnometer 1000 Version 2.2
Analysis Report

Sample & User Parameters

Sample ID: OPC
Weight: 3.7756 grams
Analysis Temperature: 34.0 degC

Date: 04-29-08
Time: 16:56:08
User ID: 6241

Analysis Parameters

Cell Size: Small
V added - Small: 12.4554 cc
V cell: 20.9726 cc
Target Pressure: 19.0 psi
Equilibrium Time: Auto
Flow Purge: 1:00 min.
Maximum Runs: 6
Number of Runs Averaged: 3

Results

Deviation Requested: 0.005 %
Average Volume: 1.1363 cc
Average Density: 3.3227 g/cc
Coefficient of Variation: 0.3330 %

Deviation Achieved: +/- 0.1469
Std. Dev. : 0.0038 cc
Std. Dev. : 0.0111 g/cc

Tabular Data

RUN	VOLUME (cc)	DENSITY (g/cc)
1	1.1372	3.3201
2	1.1390	3.3148
3	1.1306	3.3395
4	1.1322	3.3348
5	1.1354	3.3252
6	1.1413	3.3081

APPENDIX B

PROJECT MILESTONE

No	Detailed/month	1	2	3	4	5	6	7	8	9	10
1.0	Selection of topic										
1.1	propose topic										
1.2	confirmation of topic										
1.3	proposal submission	✧									
2.0	Preliminary research work										
2.1	literature review										
3.0	Submission of progress report 1		✧								
4.0	Methodology selection										
4.1	HSE analysis										
5.0	Submission of progres report 2			✧							
6.0	Preliminary test										
6.1	material physical test										
7.0	Submission of interim progress report										
8.0	Presentation										
9.0	Bituminous mixture										
9.1	bituminous testing										
10.0	Stripping testing										
10.1	indirect tensile test										
10.2	resilient modulus										

Process ✧ **Milestone**

APPENDIX C

LAB TEST

	Sieve Analysis	To determine the aggregate particle size distribution	Sieve analysis consists of shaking the aggregate sample through a set of sieves that have progressively smaller opening to bigger opening. Results are normally reported as the cumulative percentage by mass passing each appropriate test sieve and the results are plotted in the graph paper to obtain the aggregate gradation
	Particle Density & Water Absorption	To determine the specific gravity of aggregate	Particle density (specific gravity) can be expressed on an oven-dried basis, on a saturated-dry basis or as an apparent particle density. Water absorption is normally obtained at the same time as the particle density; it is the difference in mass before and after drying the sample at 105±5°C for 24 hr.
	Aggregate Impact Value (AIV)	To determine the aggregates strength	Basically the AIV is the percentage of fines produced from the aggregate sample after subjecting it to a standard amount of impact. The standard amount of impact is produced by a known weight, i.e. a steel cylinder, falling a set

			height, a prescribed number of times, onto an amount of aggregate of standard size and weight retained in a mould. Aggregate Impact Values, (AIV's), below 10 are regarded as strong, and AIV's above 35 would normally be regarded as too weak for use in road surfaces. Aggregate Impact Values and Aggregate Crushing Values are often numerically very similar, and indicate similar aggregate strength properties.
	Standard Penetration test for Bitumen	To determine the penetration (consistency) of semi-solid and solid bitumen	In the test a needle of specified dimension is allowed to penetrate into a sample of bitumen, under known load (100g), at the fixed temperature (25°C), for known time (5 seconds). The greater the penetration of needle the softer the bitumen.
	Ring and Ball Test	To determine the softening point of bituminous binder	In this test a steel ball (3.5 g) is placed on a sample of bitumen contained in a brass ring, this is suspended in a water or glycerol bath. The bath temperature is raised at 5°C per minute, the bitumen softens and eventually deforms slowly with the ball through the ring.
	Ductility Test	To determine the cohesive strength of	The cohesive strength of penetration grade bitumen is

		the bitumen	characterized by low temperature ductility. In the test three dumb-bell of bitumen are immersed in a water bath with a standard test temperature of 25°C and stretch at a constant speed of 50 mm per minute until fracture occurs.
	Specific Gravity	To determine the specific gravity of bitumen	The specific gravity obtained by fill in distilled water in a 600 ml Griffin low form beaker. The beaker is put in water bath. Label the weight the pycnometer with mass A. Remove the beaker from the water bath, fill the pycnometer with distilled water and place in the beaker and put them inside the water bath. Weight the pycnometer and water, Mass B. Pour sample inside the pycnometer about 3/4 and leave it cold. Weight the pycnometer and sample, Mass C. Add distiller water inside the pycnometer and put it inside the beaker. After 30 min, weight the pycnometer, Mass D. Then calculate the particle density of bitumen.
	Marshall Test	To determine the optimum asphalt content	The design of a bituminous mix involves the choices of aggregate type, aggregate grading and bitumen grade an the determination of bitumen content

			which will optimize the engineering properties in relation to the desired behavior in service. Test specimens of 4 in. diameter and 2 ½ in. height are used in this method. They are prepared by specified procedure of heating, mixing and compacting the mixtures of asphalt and aggregates, which is subjected to a stability-flow test and density-voids analysis.
	Lottman Test	To determine the effect of moisture on asphalt mixed concrete	Potential for Moisture Damage- The degree for susceptibility to moisture damage is determined by preparing a set of laboratory-compacted specimens conforming to the job-mix formula without an additive. The specimens are compacted to a void content corresponding to void levels expected in the field, usually in the 6 to 8% range. The set is divided into two subsets of approximately equal void content. One subset is maintained dry ("unconditioned") and used as a control, while the other subset is partially saturated with water and moisture conditioned ("conditioned"). The tensile strength of each subset is determined by the tensile

			splitting test. The potential for moisture damage is indicated by the ratio of the tensile strength of the wet subset to that of the dry subset (ASTM D4867/MN DOT MODIFIED Revised 2/19/99)

APPENDIX D

Typical value possible for road stone aggregates in relation to their geological classification (Robert, 1994)

	Rock types	Mechanical				Physical		Weathering		Stripping
	Test	ACV	AAV	AIV	PSV	RD	WA	S	FT	
Igneous	Basalt range	14	8	27	61	2.71	0.7	Low to high	Low to high	No
		(15-39)	(3-15)	(17-33)	(37-74)	(2.6-3.4)	(0.2-1.8)			
	Porphyry range	14	4	14	58	2.73	06	Medium	Low	No
		(9-29)	(2-9)	(9-23)	(45-73)	(2.6-2.9)	(0.4-41.1)			
Metamorphic	Granite range	20	5	19	55	2.69	0.4	Low	Low	Yes
		(9-35)	(3-9)	(9-35)	(47-72)	(2.6-3)	(0.2-2.9)			
	Quartzite range	16	3	21	60	2.62	0.7	Low	Low	Yes
		(9-25)	(2-6)	(11-33)	(47-69)	(2.6-2.7)	(0.3-1.3)			
Sedimentary	Gritstone range	17	7	19	74	2.69	0.6	Low to high	Medium	No
		(7-29)	(2.16)	(9-35)	(62-84)	(2.6-2.9)	(0.6-1.6)			
	Limestone range	24	14	23	45	2.66	1.0	Low to high	Low to high	No
		(11-37)	(7-26)	(17-33)	(32-77)	(2.5-2.8)	(0.2-2.9)			
Pits	Gravels range	20	7	15	50	2.65	1.5	Low to high	Low to high	Yes
		(18-25)	(5-10)	(10-20	(45-58)	(2.6-2.9)	(0.9-2.0)			
Artificial	Slag range	28	8	27	61	2.71	0.7	Low to high	Low to high	No
		(15-39)	(3-15)	(17-33)	(37-74)	(2.6-3.2)	(0.2-2.6)			

ACV = aggregate crushing value
AAV = aggregate abrasion value
F = freeze thaw
PSV = polished stone value
S = soundness
WA = water absorption
AIV = aggregate impact value
RD = relative density

APPENDIX E

Aggregate gradation

Gradation	Coarse Agg., (%)	Fine Agg., (%)	Filler
Well	42	50	8
Gap	35	55	10