THE STUDY OF THE STRIPPING PROPERTIES OF BITUMINOUS MIXTURES CONTAINING DIFFERENT AGGREGATE TYPES

by

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17729

Final report submitted in partial fulfilment of
The requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

SEPTEMBER 2016

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CERTIFICATION OF APPROVAL

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SEPTEMBER 2016

CERTIFICATION OF ORIGINALITY

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

MOHAMED SALAHELDIN HUSSEIN

ABSTRACT

This report present an experimental study to establish the properties of stripping in the bituminous mixtures by using different types of aggregates. Two types of aggregate were used with varying chemical and moisture sensitivity characteristics.

Stripping is considered as a common issue that is caused from water exposure to the highway pavement that might lead to different issues such as fatigue and traffic damages. Such issues will lead to full repair of the damaged area, which is very costly, therefore a correct material selection is vital to obtain a good quality of highway pavement that is more resistant to stripping.

The Jabatan Kerja Raya (JKR) standards (a manual of pavement design in Malaysia) were used in the bitumen mixtures, to test out the stripping properties. The phases of this investigation were to choose the types of aggregate to be used in the experiments based on the moisture sensitivity and chemical compositions and to determine the stripping properties by using the laboratory experimental tests, which were The Retain Marshall Stability Test and The Retain Indirect Tensile Strength Test.

It is expected for the mix that contain an acidic surface aggregate to be less resistant to stripping as they have the tendency to attract to water over bitumen.

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Chapter 1

Introduction

1.1 Background of the study

Recently, due to the moisture damage that appears in the form of stripping, it is detected that there is a need to replace a lot of the roadways around the world. Loss of adhesion is caused by stripping at the bitumen and aggregate interface due to actions caused by water (Fromm, 1974; Kiggundu et al., 1988; Taylor et al., 1983; Kandhal et al., 1989). The strength is compromised as the mixture ceases to act as a coherent structural unit. Loss of adhesion also renders cohesive resistance of the interstitial bitumen body useless (Kiggundu, 1988). Water may find it is way in the interface through diffusion across bitumen layers, and when that happens, the water affect the aggregate-bitumen bond which causes the bitumen to strip off from the aggregate surface. This process of stripping is shown in the figure 1.1.

Stripping is considered as a complex issue, and is not yet fully understood, however the mineralogy and chemical composition of the aggregate are important contributing factors in stripping. Some aggregates have a sort of attraction to water over asphalt, these aggregates are known as hydrophilic aggregates. On the other hand, the hydrophobic aggregates have the opposite attraction which tend to asphalt over water. The second type have a better resistance to stripping.

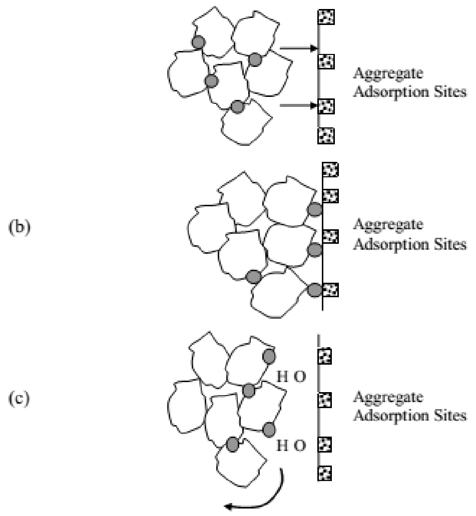


Figure 1: (a) Heteroatom Containing Bitumen Parts move towards the Aggregate sites (b) Bitumen Adsorbed onto Aggregate (c) Stripping due to Water at the Interface

In this study we are going to study the behavior of stripping when using 2 different types of aggregate, based on their resistance to stripping and moisture sensitivity.

1.2 Problem Statement

Aggregate and bitumen form a mixture which is asphalt concrete pavement. The Moisture damage to asphalt concrete pavement can occur in the form of stripping, it is considered as a common problem that can lead to expensive repair of the highway pavements. Further issues such as fatigue could appear due stripping which will lead to traffic issues and car crashing injuries. That is why a study is needed to show us how is the difference in aggregate types used in asphalt concrete pavement can give us more resistance to stripping.

As it is stated before the stripping appear due the loss of bond between aggregates and asphalt binder, therefore it is important to understand the characteristics and the properties of stripping, and to know which type of stone aggregate adhere the best to bituminous binder and result in a minimum form of stripping. This understanding will help us to know water sensitive mixtures, which we need to avoid in order to pave way to enhanced road performance.

1.3 Objective

The main objective is to study the stripping properties of bituminous mixtures containing different aggregate types. Specifically the study is aiming to achieve the following objectives:

a) Study the effect of composition of aggregate on moisture sensitivity of bituminous mixtures.
b) Determining the stripping properties of 2 different aggregate types by using the laboratory experimental tests.

1.4 Scope of Study

This study will give us a prediction of the best mix that can be used to avoid stripping, and how the aggregate chemical properties can be related to the interface of the bitumen-aggregate bond.

The first phase of this project will begin with the determination of the aggregates and bitumen properties. Then the aggregate will be selected by using the typical sampling method and gradation values of the aggregate according to the JKR (Jabatan Kerja Raya) Standards for the specification of Road Works Flexible Pavement, and this will help us to determine their degree of resistance to stripping, In addition to that, the bitumen of Penetration Grade 80-100 will be prepared as well according to the JKR specifications.

After selection of materials, number of laboratory tests will be conducted to the limestone and granite in order to determine their physical and mechanical properties in accordance with the BS and ASTM standards. Tests such as:

- Specific Gravity and Water Absorption
- Aggregate Impact Value
- Los Angeles Abrasion Test
- Flakiness and Elongation Index

In addition to that, some tests will be done to check the properties of bitumen following the standards of JKR, such as:

- Ductility Test
- Specific Gravity
- Softening Point Test
- Marshall Mix Design

The main lab tests to determine the stripping properties of the bituminous mixtures containing limestone and granite will be, Marshall Stability Test and Indirect Tensile Strength Test.

Chapter 2

Literature Review

2.1. Stripping Properties

Stripping occurs when there is a breakdown of the adhesive bond that connect the bitumen with the aggregate. This usually happens when the bitumen–aggregate bond is weakened. Water contacts the aggregate surface and displaces the bitumen coating. Therefore the important aspects of the stripping are bitumen–aggregate adhesion, the susceptibility to water of the bitumen–aggregate bond, and the loss of binder and/or mastic in the asphalt.

There are 4 principal means of asphalt binder-aggregate adhesion:

Mechanical: A mechanical lock is created when the asphalt binder gets into the pores and loopholes of the aggregate and hardens. Susceptibility to stripping is increased when moisture on the aggregate interfere with asphalt binder penetration into the aggregate and reduce the mechanical lock.

Chemical: A chemical reaction between the asphalt binder and aggregate surface occurs causing chemical adhesion. This weaker reaction may not be strong enough to counter other moisture damage factors.

Adhesion tension: The tension between the asphalt binder and aggregate at the wetting line (as a drop spreads over a surface, the edge of the drop is the “wetting line”) is generally less than the tension between water and aggregate.

Molecular orientation: When in contact with aggregate, asphalt molecules tend to orient themselves in relation to the ions on the aggregate surface essentially creating a weak attraction between the asphalt binder and aggregate surface.

All of these principles are further explained through this research.

2.2 Aggregate Gradation

The particle gradation or size distribution, of an aggregate is considered to be the most significant aggregate characteristics because it will help to show how it will act as a pavement material. In HMA, gradation supports determining almost every important property including, stability, workability, permeability, durability, stiffness, frictional resistance, moisture susceptibility and fatigue resistance (Roberts et al., 1996[1]). Because of this, gradation is a main apprehension in HMA mix design and that is why most organisations require suitable aggregate gradations.

In this project, JKR Standards of Road Works Flexible Pavement is to be used to select the gradation of the aggregate as below:

Table 1: Gradation foe Asphaltic Concrete (JKR Standard, 2008)

Sieve Size (mm)	Percentage by weight passing	
	Binder Coarse	Wearing Coarse
28	100	-
20	72-100	100
14	58-76	90-100
10	48-64	76-86
5	30-46	50-62
3.35	24-40	40-54
1.18	14-28	18-34
0.425	8-20	12-24
0.15	4-10	6-14
0.075	3-7	4-8

2.3 Aggregate Properties

The characteristic of the aggregates has an important role in a bituminous mixture. After all it is the main factor behind the strength of the pavement. Properties such as shape and size of the aggregates, surface area, volume, alkalinity and acidity, polarity or surface charge, chemical elements at the surface and as well as the surface density are considered to be some of the commonly cited characteristics that perform a major role in contribution of good engineering properties of the bituminous mixture.

A lot of studies have been conducted of the properties of aggregates that are related to the stripping, covering aspects such as mineralogy, surface morphology and chemistry

(Kiggundu, 1986; Dukatz, 1989, Kandhal, 1998). The stated properties have a major effect on the surface energy and chemical reactivity, hence the positions of ponding locations. However, generally aggregates that are hydrophilic (attract water) are expected to strip over aggregates that are hydrophobic (repulse water). The main factors that determine the aggregate is either hydrophobic or hydrophilic are, (a) Porosity and pore size, (b) Surface chemistry.

As the scope of study for this research is being constricted to aggregate that is widely used in the local country, only granite and limestone will be take into consideration.

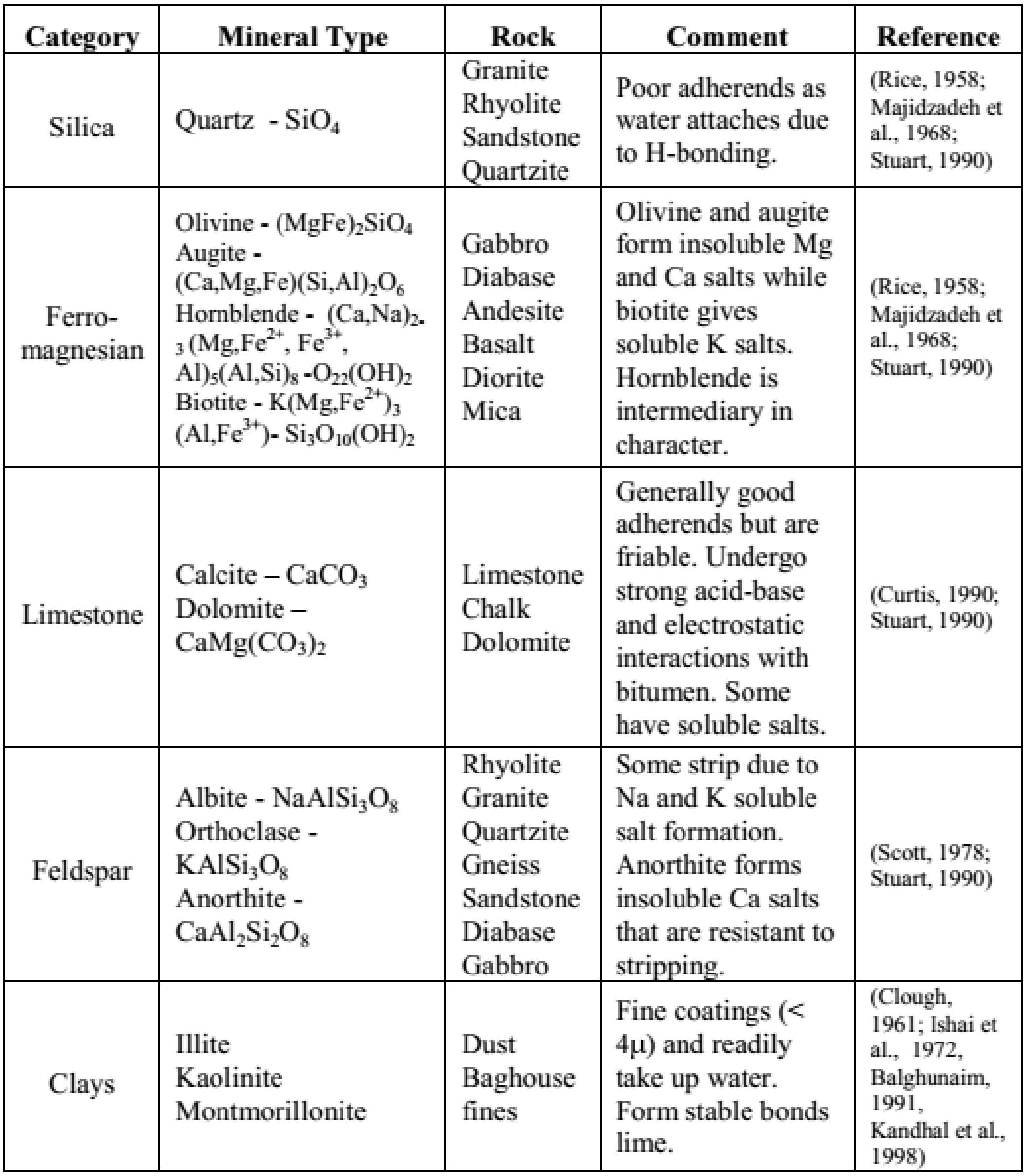
2.3.1 Porosity and Pore Size

Pore size of the aggregate is a critical aspect, as large pore size might lead to the entry of asphalt binder, which may be a contributor to moisture vulnerability. High absorption will occur due to high porosity, meaning that more asphalt binder must be used to reach the anticipated effective asphalt binder content. On the contrary, if high porosity is not considered, for a given amount of asphalt binder, more will be absorbed and less will be obtainable to create the asphalt binder film around aggregate particles producing stripping and faster aging.

2.3.2 Surface Chemistry

The chemical properties of the aggregate surface can be a factor of stripping, for example stripping is less likely to happen for the surfaces that can form a bond with the asphalt binder. Overall, an acidic surface is more vulnerable to stripping. Calcium, iron and perhaps magnesium are considered favorable, however potassium and sodium are not.

Table 2.1: Mineral Types and Their Relation to Stripping (Bagampadde, U. ON INVESTIGATION OF STRIPPING PROPENSITY OF BITUMINOUS MIXTURES (PhD). KTH Royal Institute of Technology.)



Category	Mineral Type	Rock	Comment	Reference
Silica	Quartz - SiO_4	Granite Rhyolite Sandstone Quartzite	Poor adherends as water attaches due to H-bonding.	(Rice, 1958; Majidzadeh et al., 1968; Stuart, 1990)
Ferro-magnesian	Olivine - $(MgFe)_2SiO_4$ Augite - $(Ca,Mg,Fe)(Si,Al)_2O_6$ Hornblende - $(Ca,Na)_{2\text{-}3}(Mg,Fe^{2+},Fe^{3+},Al)_5(Al,Si)_8\text{-}O_{22}(OH)_2$ Biotite - $K(Mg,Fe^{2+})_3(Al,Fe^{3+})\text{-}Si_3O_{10}(OH)_2$	Gabbro Diabase Andesite Basalt Diorite Mica	Olivine and augite form insoluble Mg and Ca salts while biotite gives soluble K salts. Hornblende is intermediary in character.	(Rice, 1958; Majidzadeh et al., 1968; Stuart, 1990)
Limestone	Calcite – $CaCO_3$ Dolomite – $CaMg(CO_3)_2$	Limestone Chalk Dolomite	Generally good adherends but are friable. Undergo strong acid-base and electrostatic interactions with bitumen. Some have soluble salts.	(Curtis, 1990; Stuart, 1990)
Feldspar	Albite - $NaAlSi_3O_8$ Orthoclase - $KAlSi_3O_8$ Anorthite - $CaAl_2Si_2O_8$	Rhyolite Granite Quartzite Gneiss Sandstone Diabase Gabbro	Some strip due to Na and K soluble salt formation. Anorthite forms insoluble Ca salts that are resistant to stripping.	(Scott, 1978; Stuart, 1990)
Clays	Illite Kaolinite Montmorillonite	Dust Baghouse fines	Fine coatings (< 4μ) and readily take up water. Form stable bonds lime.	(Clough, 1961; Ishai et al., 1972, Balghunaim, 1991, Kandhal et al., 1998)

2.3.3 Physical Properties of Limestone

The limestone colour can vary from shades of grey and tan. Due to the carbonaceous impurities, the limestone is appearing to be greyish, while the presence of iron caused the existence of the tan. Depending on the formation, limestone can take on a number of different structural shapes, including clastic, crystalline, massive or granular. They will re-crystallize as marble when undergo a process of metamorphism. This is due to the reaction of calcium carbonate and hydrochloric acid to produce bubbles. Limestone will have relatively flat surfaces.

In general, limestone is defined as a soft rock that it is surface can be easily scratched and fine-grained. According to Moh's scale, the hardness of limestone vary within the ranges from 3 to 4 with dolomitic lime being marginally harder when it is compared to the high calcium diversities. Compared to chalk limestone has the higher compressive strength (Blyth, 2002).

Due to the change in the porosity, the density of the limestone varies from the ranges of 2.5 to 2.7 kg/cubic meter. The specific gravities of the limestone varies from the range of 2.65-2.75 for high calcium and 2.75-2.9 for the dolomitic limestone. The compressive strength of the limestone is between the range of 1.8-2.1 kg/cubic meter.

2.3.4 Physical Properties of Granite

Granite is an acidic crystalline and igneous rock with a relative density of 2.65-2.75 kg/cubic meter. The hardness of the granite vary accordingly to the composition and as well as with the proportion and type of feldspar present in the granite

Due to the development of slow and complete crystallization of the molten magma, the permeability and porosity of granite are typically low. The porosity of granite is consistently low with the values only on the order of 0.1 to 1.2 percent being characteristics. The compressive strength of the granite is between the ranges of 140 to 210 N/mm^2. Even though weathered rocks are usually much more permeable. As a crystalline, granite has low permeability when fresh.

2.4 Water Properties

Stripping is a form of adhesion. Adhesion affects capillarity while cohesion affects the surface tension. Water displays the hydrogen bonds that marks its cohesive and adhesive characteristics. As most surfaces in the aggregates have electrostatics charges, water molecules will be more attached to them than bitumen polars in order to satisfy unstable surface charges. The pH of contact water is one of the factors that affects adhesion, which changes with temperature (Covington et al., 1977). The wetting properties of bitumen are affected by the pH as it is responsible in the shift in angle of contact. At pH values that are up to 9 the interfacial tension is considered to be the highest, while it drops with increase of pH to 14 (Kiggundu et al., 1986). The effect of water at the interface is dependent on the aggregate type.

2.4.1 Wetting and Adsorption

The stripping potential of a bituminous mixture is determined by the proper wetting and adsorption of bitumen onto aggregate. Hot bitumen spreads on an aggregate depending on the contact angle θ. The attraction forces between aggregate and bitumen direct the wetting. The wetting phenomena was offered by Thomas Young in 1805, by relating the surface tension (γ) to contact angle for non-deformable, insoluble homogenous and smooth solids. Wenzel Improved Young's work as he studied equilibrium on rough surfaces culminating in following equation 2.1 (Asthana et al., 2000).

$$\gamma_{SV} = \gamma_{SL} + \gamma_{LV} Cos\theta_{w} (1/r) \quad \text{…………… (2.1)}$$

Where S= solid, L= liquid, V=vapor and r is the ratio of true ridged area to the apparent flat area and θ_w is Wenzel contact angle. Work of adhesion is used to determine the wetting, by using Dupre formula that was developed in 1869, which is given in equation 2.2

$$W_{a} = \gamma_{LV} [1 + Cos\theta_{w} (1/r)] \quad \text{……………. (2.2)}$$

Low W_a shows that there is a good tendency for the bitumen to wet the aggregate (Taylor et al., 1952, Cheng et al., 2002).

If we considered a system that is made of bitumen (a), infinitesimal interface (s) and aggregate (b). Once the aggregate is coated by bitumen, both are considered to be in equilibrium and the total free energy of the system is given thru $F = F_a + F_b + F_s$. However if any small change took place in the pressure (p), temperature (T), composition of the material n_i, the system energy change to $dF = dF_a + dF_b + dF_s$ (Majidzadeh et al., 1968).

Lytton, (2002) displays that interfacial surface free energy (SFE) is divided into an acid-base and an apolar component. London dispersion forces, Keesom orientation forces and Debye induction forces are considered to be as a sub-division of the apolar part.

$$\Gamma_{Total} = \Gamma^{LW} + 2\sqrt{\Gamma^{-}\Gamma^{+}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(2.3)}$$

Where total SFE (Γ_{Total}) is linked with acid (Γ^{-}) and apolar (Γ^{LW}) – base (Γ^{+}) and if these values are compared with the ones of bitumen under investigation, there is a possibility to tell if the bitumen has low or high stripping vulnerability.

2.5 Traffic Effects:

While service of the road, there is a constant contact between the pavement and the vehicle wheel, this interaction will increase the pore water pressure in the void pocket of the mixture. The thin bitumen films can be broken due to the traffic stresses, especially nearby sharp aggregate corners, which will create a path for moistures to enter the interface. Stripping that occur around the outer traffic lanes support the theory of traffic effect (Kandhal, 1992).

2.6 Mechanisms of Stripping Process

Even though stripping is a complex issue that is not fully understood, numerous mechanisms have been proposed to further clarify its occurrence, in all the mechanisms, there has to be initiation and progression of stripping (Mcglashan et al., 1984; Tarrer et al., 1991). According to Graf, (1986) stripping begins usually at the bottom bituminous layer, where the moisture content is high and works its way up. An analysis of few of the formulated mechanisms is given in Table 2.2.

Table 2.2: Mechanisms of Stripping at the Bitumen-Aggregate Interface

Process	Mechanism	References
Detachment	Water with higher dipole moment and lower surface energy detaches it from the aggregate surface	(Fromm, 1974; Terrel et al., 1989; Mcgennis et al., 1995)
Pore Pressure	a bitumen film is broken due to the high pore water pressure in undrained conditions, allowing water to enter the interface	(Hallberg, 1950; Taylor et al., 1983; Kiggundu, 1988; Kandhal, 1994)
Displacement	Water with higher dipole moment and lower surface energy displaces it from the aggregate surface	(Fromm, 1974; Mcglashan, 1984; Terrel et al., 1989; Mcgennis et al., 1995)
Chemical dis-bonding	electrostatic and chemical interaction between water and some aggregates favour removal of bitumen from them	(Scott, 1978; Edwards et al., 2000)

2.7 Moisture Sensitivity Test Methods

Generally, moisture sensitivity tests do not measure individual factors but fairly attempt to measure the HMA (Hot Mix Asphalt) mixture's capability to resist stripping or the moisture damage, no matter what the source is. They are characteristically capable of providing gross results or comparative results and are not able to predict the degree of stripping exactly. However, due to the limitation of time, only three main tests will be performed, which are aggregate stripping value test, Marshall stability test and indirect tensile ratio test, a brief description of the other major tests for moisture sensitivity follows:

- *Boiling test (ASTM D 3625):* Add loose HMA to boiling water and measure the percentage of total visible area of aggregate surface that retains its asphalt binder coating. The test is simple but is subjective, does not involve any strength determination and examining the fine aggregate is difficult.
- *Hamburg wheel-tracking device*: Compacted HMA samples are tested underwater. Results give a relative indication of moisture susceptibility.

- *Static-immersion test (AASHTO T 182)*: Which is a very similar test to aggregate stripping value, however the difference is that this test use HMA sample rather than the aggregate, this test is done by immersing the sample of HMA in water for 16 to 18 hours, and then the sample is observed through the water to measure the percentage of total visible area of aggregate surface that retains its asphalt binder coating. This test is also simple but subjective and does not involve any strength determination.
- *Lottman test*: Tests 3 sets of compacted samples. Group 1, the control group, is not conditioned. Group 2, representing field performance at 4 years, is subjected to vacuum saturation with water. Group 3, representing field performance at 4 to 12 years, is subjected to vacuum saturation and a freeze-thaw cycle. A split tensile test is performed on each sample and the ratio of the indirect tensile strength of the conditioned samples is compared to the control group as a ratio. A minimum tensile strength ratio (TSR) of 0.70 to 0.80 is often used as a standard.

Chapter 3

Methodology

3.1 Introduction:

The main objective of this research is to study the stripping properties of bituminous mixtures with different aggregate types, based in all of the information shared in the literature review, the two aggregate types that will be used for this study are Granite and Limestone, as they have different chemical characteristics, so they will give us a wider idea on the stripping properties. Another reason to choose these types of aggregate is because they are the most used aggregates in Malaysia.

Stripping properties for the bituminous mixtures using the two types of aggregates are to be determined by using the laboratory experimental tests, the first test was The Retain Marshall Stability Test. The second test is The Retain Indirect Tensile Strength Test.

The approach used to reach the objectives of this study is shown in the following Figure 2.

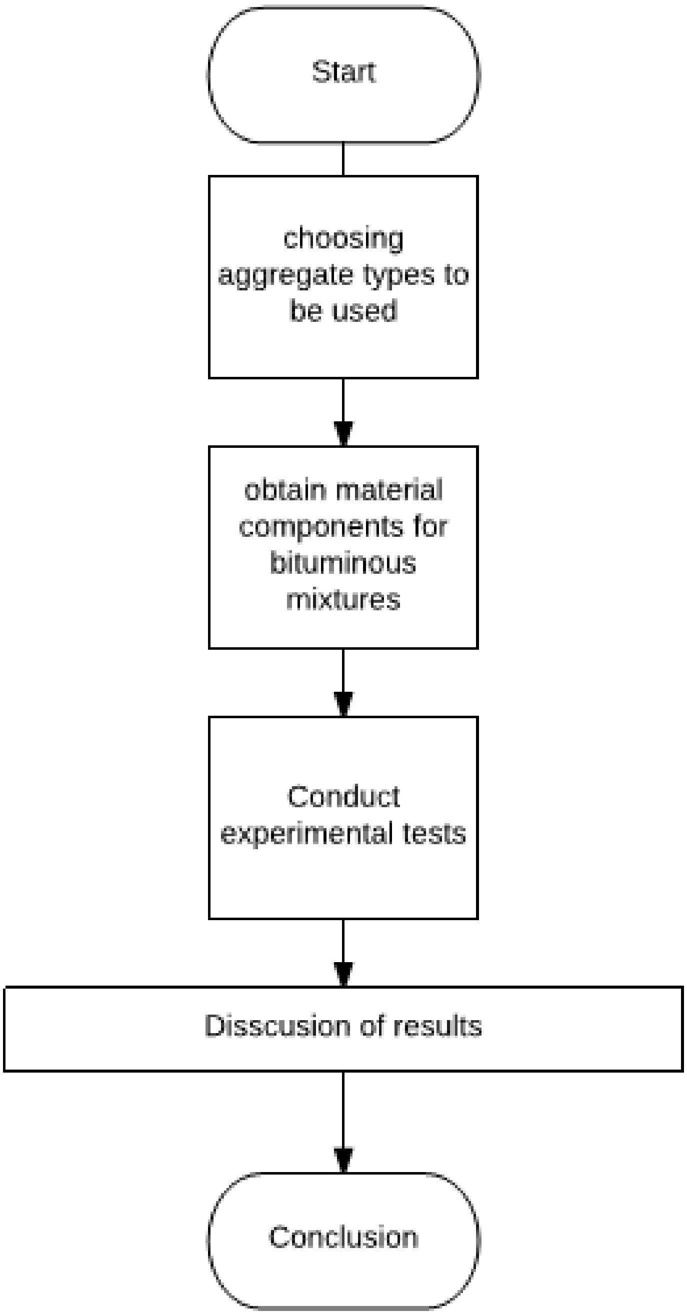


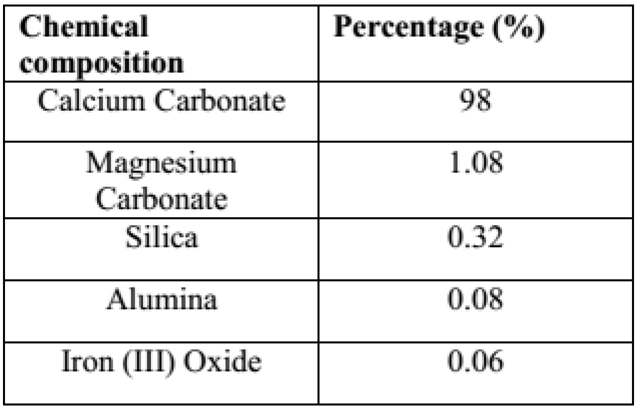
Figure 2: Flow chart of the research steps

3.2 Experiment Materials

3.2.1 Limestone

Limestone is a sedimentary rock. The two major chemical components of Limestone are magnesium carbonate and calcium, the other chemical components are shown in the following Table 2.

Table 3: Composition of Limestone



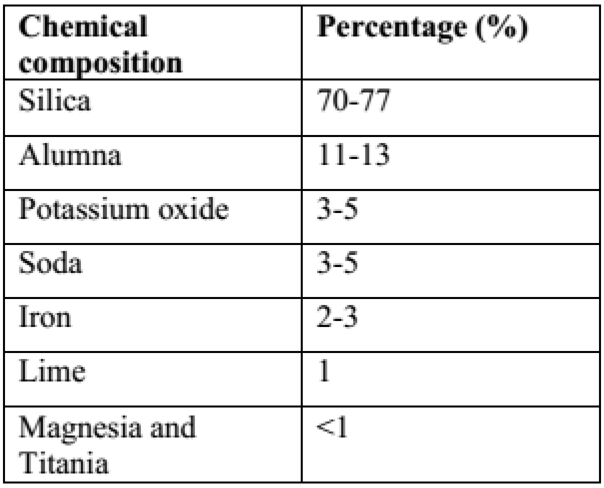
Chemical composition	Percentage (%)
Calcium Carbonate	98
Magnesium Carbonate	1.08
Silica	0.32
Alumina	0.08
Iron (III) Oxide	0.06

Figure 3: Limestone

3.2.2 Granite

Granite is an igneous rock that consists a lot of minerals such as feldspar, potassium, micas and quartz.

Table 4: Composition of Granite



Chemical composition	Percentage (%)
Silica	70-77
Alumna	11-13
Potassium oxide	3-5
Soda	3-5
Iron	2-3
Lime	1
Magnesia and Titania	<1

Figure 4: Granite

3.2.3 Bitumen

Bitumen is used for road surface, it is a black viscous mixture made of hydrocarbons that is obtained naturally or as a residue from petroleum distillation. Bitumen Penetration Grade 80/100 is a standard penetration grade Bitumen usually used as a Paving Grade Bitumen suitable for road construction and for the production of asphalt pavements with superior properties. This grade of Bitumen is mainly used in the manufacture of hot mix asphalt for bases and wearing courses

Figure 5: Bitumen

3.3 Experimentation Testing

Some tests will be conducted to determine the stripping properties, which are as following:

3.3.1 Sieve Analysis

The test was done determine determines the relative proportions of different grain sizes as they are distributed among certain size ranges. The grain size analysis is widely used in classification of soils. The data obtained from grain size distribution curves is used in the design of filters for earth dams and to determine suitability of soil for road construction, air field etc. Information obtained from grain size analysis can be used to predict soil water movement although permeability tests are more generally used. The apparatus for the experiment are:

- Stack of Sieves including pan and cover

- Rifle Box
- Mechanical sieve shaker
- Oven

3.3.2 Specific Gravity and Water Absorption Test

The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. The specific gravity test helps in the identification of stone.

Water absorption gives an idea of strength of aggregate. Aggregates having more water absorption are more porous in nature and are generally considered unsuitable unless they are found to be acceptable based on strength, impact and hardness tests. The test will be carried out according to ASTM designation: C 127-88.

Several method of obtaining the particle density of the aggregates are specified which include the measurements of the mass of the sample in air and in water. Particle density of also known as specific gravity can be defined on an oven-dried basis, on saturated surface-dry basis or as an apparent particle density. The oven dried is the most commonly used for road engineering construction.

The amount of water absorption is normally measured at the same time as the particle density. The value can be obtained through the difference in mass of before and after drying the sample at 105± 5ºC for 24 hours.

3.3.3 Aggregate Impact Value Test

Toughness is the property of a material to easiest impact. Due to movie ng loads the aggregates are subjected to pounding action or impact and there is possibility of stones breaking into smaller pieces. Therefore a test designed to evaluate the toughness of stones i.e. the resistance of the stones to fracture under repeated impacts may be called Impact test on aggregates. The test can also be carried on cylindrical stone specimen known as Page Impact test. The aggregate Impact test has been standardized by Indian Standard Institution. The aggregate impact test is conducted as per IS-2386 Part IV.

The aggregate Impact value indicates a relative measure of resistance of aggregate to a sudden shock or an impact, which in some aggregates differs from its resistance to a slope compressive load in crushing test.

3.3.4 Los Angeles Abrasion Test

In the experiment, the standard L.A abrasion test subjects a coarse aggregates sample to abrasion, impact and grinding which occur in a rotation steel drum containing specified number of steel spheres. The percentage wear of the aggregates due to rubbing with the steel balls will be determined and also known as Los Angeles Abrasion Value.

3.3.5 Aggregate Stripping Value Test

Bitumen and tar adhere well to all normal types of aggregates provided they are dry and are not exceptionally dusty. This problem of stripping is experienced only with bituminous mixtures, which are permeable to water. This test gives us a determination of the stripping value of aggregates by static immersion method, when bitumen and tar binders are used.

200 g of clean and dry aggregate were used after passing 20 mm IS sieve and retaining on 12.5 mm sieve, then they are heated up to 150°C to be mixed with bitumen. Bitumen binder amounting to five percent by weight of aggregate is heated to 160°C. Both the aggregate and the bitumen are well mixed until the aggregates are fully coated with the bitumen, and after letting the aggregate rest in room temperature for about 2 hours, the aggregate are immersed with distilled water inside a 500 mm beaker, and left inside a 40^{o} C water bath for 24 hours. Finally a percentage of the stripping value can be taken visually.

Some types of aggregates have a lesser affinity with bitumen in comparison with water and hence stripping value of the bituminous binder is done when the mix is immersed in water. The problem of stripping in coated aggregate is not so amenable to theoretical treatment. Thus an adhesion test such as the simple stripping test would be suitable to assess whether the binder would adhere to the aggregate when immersed in water.

Several anti-stripping agents are available, which when used with the bituminous mix reduce the stripping.

3.3.6 Retain Marshall Stability Test

The method described determines the retained Marshall stability on Marshall Compaction specimens after curing for 24 hours in a water bath at 60^o C.

The purpose of Marshall Test is to obtain the Optimum Bitumen Contain of Asphalt Concrete Mixtures. There are two procedures in it. First is the preparation of the Asphalt Specimens and second is testing the Asphalt specimens. After conducting the test and getting the data from the machine, the following relationships need to be plotted:

- Density vs. bitumen content
- Stability vs. bitumen content
- Porosity vs. bitumen content
- Flow vs. bitumen content

3.3.7 Retain Indirect Tensile Strength Test

This test is used to determine moisture sensitivity, by getting the resilient modulus and indirect tensile strength ratios, MRR and TSR.

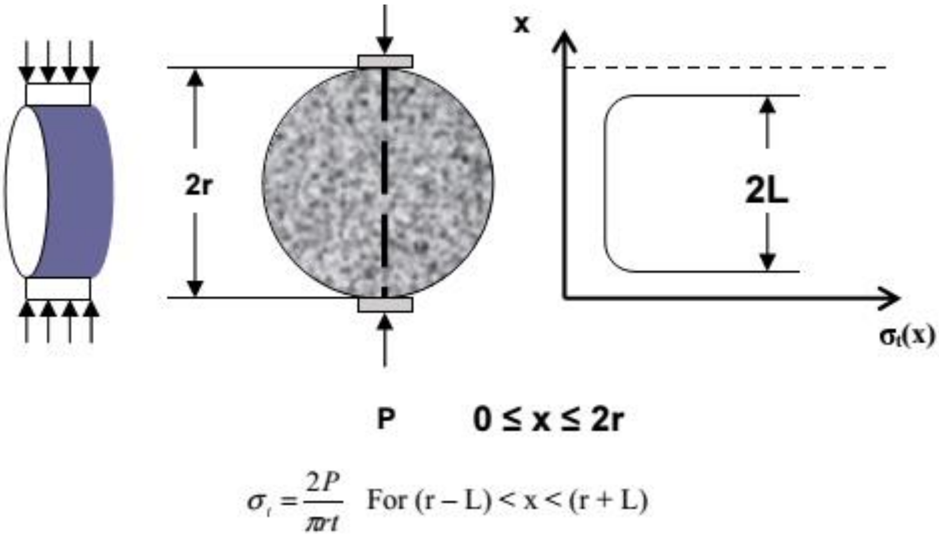


Figure 6: Stress Field in the Indirect Tensile Strength Test (Kennedy, 1977)

$$\text{TSR} = \frac{\textit{Conditioned Tensile Strength}}{\textit{Unconditioned Tensile Strength}} \times 100$$

$$\text{MRR} = \frac{\textit{Conditioned Resilient Modulus}}{\textit{Unconditioned Resilient Modulus}} \times 100$$

A threshold value of 70% for mixes is recommended by Lottman, (1978) to be stripping resistant.

3.4 Gantt Chart

Table 5: Gantt chart FYP I

	Week													
Detail	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Topic Selection	🟩													
Research Work/ Litrature Review	🟩	🟩	🟩	🟩	🟩	🟩								
FYP seminar	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩		🟩		
Preparation of Extended Proposal Report			🟩	🟩	🟩	🟩								
Submission of Extended Proposal Report						🟩								
Proposal Defense Presentation											🟩			
Continue Research Work							🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Submission of 1st Draft Interim Report													🟩	
Submission of Interim Report Final draft														🟩

Table 5.1: Gantt chart FYP II

	Week													
Detail	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Preparing samples	🟩	🟩												
Proceed with lab work (aggregates)			🟩	🟩	🟩	🟩								
Proceed with lab work (Sample testing)							🟩	🟩	🟩	🟩	🟩			
Progress report submission										🟩				
Pre-SEDEX poster presentation											🟩			
Final report submission												🟩		
Final viva														🟩

Chapter4

Results & Discussion

4.1 Sieve Analysis

Table 6: Sieve Analysis

BS Sieve Size	Weight Retained (g)	Percentage Retained (%)	Total Passing (%)
20.00 mm	0	0	100
14.00 mm	60	5	95
10.00 mm	180	15	80
5.00 mm	360	30	50
3.35 mm	48	4	46
1.18 mm	288	24	22
0.425 mm	72	6	16
0.150 mm	96	8	8
0.075 mm	36	3	5
Total	1200	100	100

By using the data from the table above, a graph of Total Passing (%) versus Sieve Size (mm) is plotted as shown below:

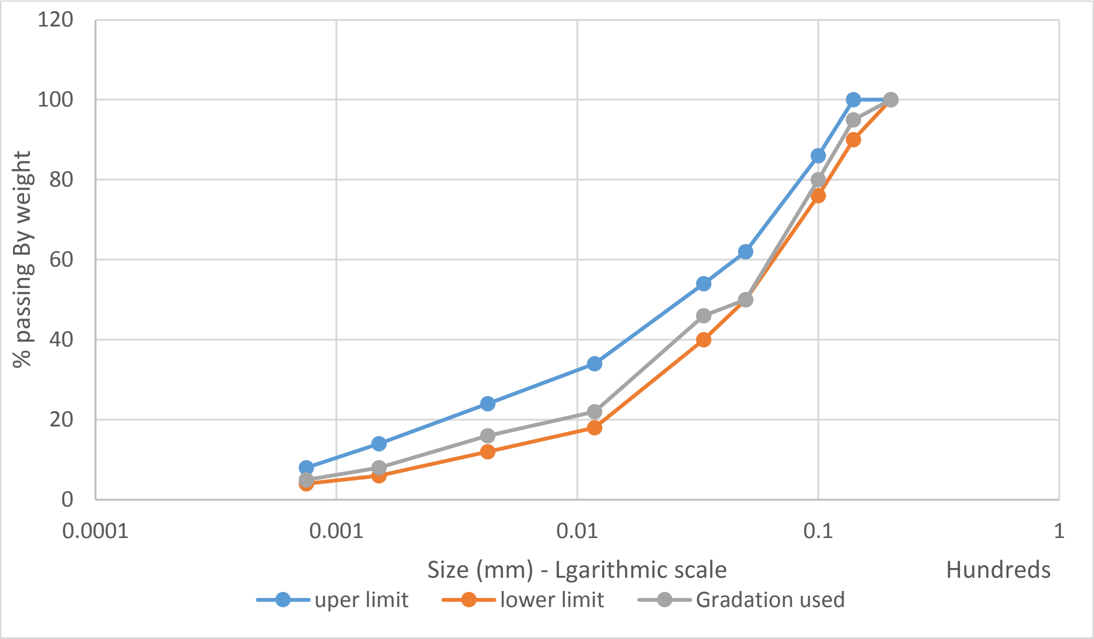


Figure 7: Gradation Graph

4.2 Aggregate Stripping Value Test

The stripping value of aggregates is determined as the ratio of the uncovered area observed visually to the total area of aggregates, expressed as a percentage.

After immersing the two samples of Granite and Limestone that are fully coated with bitumen in the water bath for 24 hours. It was clear that the Limestone have more stripping resistance than the Granite, as the results were as follow:

❖ Limestone	10%
❖ Granite	20%

Figure 8: Limestone stripping value

Figure 9: Granite Stripping Value

4.3 Specific Gravity and Water Absorption

Specific gravity is defined as ration of the unit weight of aggregate to the unit weight of water. It is used in calculating air voids, voids in mineral (VMA), and voids filled by asphalt (VFA). Water absorption can be a display of asphalt absorption and may also give hints of the frost susceptibility or other weakness of an aggregate. A highly absorptive aggregate could lead to a low durability asphalt mix. The water absorption test will reflect the strength of the aggregate as high water absorption tell that the aggregate is more porous and thus considered to be weaker in terms of strength. Granite and Limestone aggregates were used in this test, and there values are shown in the graph below:

Table 7: Specific Gravity & Water Absorption Results

Properties	Coarse Aggregate		Fine Aggregate
	Limestone	Granite	Sand
Specific Gravity	2.5	2.61	2.79
Water Absorption (% Of Dry Mass)	3.17	1.15	0.55

In Table 5 above, the results shows that the water absorption of Granite is 1.15% which meets the standards of the JKR, as the manual requires the water absorption value aggregate to be less than 2%. Same goes to the fine aggregate used in the HMA samples of this project (Sand), which have a value of 0.55%. On the other hand the Limestone used in this project have a water absorption of 3.17% which exceed the maximum 2% value required by the JKR manual. As the samples immersed in water bath, water will fill the pore spaces within the rock. It is concluded that the aggregate with higher value are porous and thus considered to be weak. So from the table above it can be concluded that the Limestone has higher porosity and weaker than Granite.

The reason behind this is that the Granite has less porosity compared to Limestone. The same table shows that the specific gravity of Granite is 2.61 which is higher than the Limestone which is 2.5. This might be due to the structure of the aggregate itself.

4.4 Aggregate Impact Value

The impact value test is done as it helps to give an indication of aggregate toughness property and their suitability in the pavement construction. The aggregate impact value that is used to classify the stone aggregates with respect to toughness properties is given as below:

Table 8: Aggregate Impact Value Specification (Suryakanta, 2014)

Aggregate impact value (%)	**Toughness Properties**
<10	Exceptionally tough / Strong
10 – 20	Very tough / Strong
20 – 30	Good for pavement surface course
>35	Weal for pavement surface course

The values obtained for the Limestone and Granite are as below:

Table 9: Aggregate Impact Value for Granite

	Unit	1	2
Net Weight of aggregate (A)	g	797	801
Weight of sample coarser than 2.36mm sieve (B)	g	606	610
Weight of sample retained in pan (C)	g	190	194
Aggregate Impact Value (AIV)	(%)	23.81	23.98
Average		23.89%	

Table 10: Aggregate Impact Value for Limestone

	Unit	1	2
Net Weight of aggregate (A)	g	930.6	900.8
Weight of sample coarser than 2.36mm sieve (B)	g	689.4	678
Weight of sample retained in pan (C)	g	244.6	235
Aggregate Impact Value (AIV)	(%)	26.3	25.94
Average		26.12%	

Two samples of each aggregate type were prepared to implement the impact value test. Due to the mineral properties of the limestone, it is clear from the results above that the impact value of it is higher than the Granite. The test has proved that the Granite is stronger and more durable than the Limestone, as it was easier to be crushed.

4.5 Los Angeles Abrasion Test

The Los Angeles (L.A.) abrasion test is a test method that is commonly known to get the characteristics of abrasion and toughness of the aggregate. As the essential aggregate in HMA must overcome crushing, disintegration and degradation. It is very important to know the aggregate abrasion characteristics, in spite of producing an extreme quality of HMA. Shown below are the Los Angeles values for limestone and granite for this research:

Table 11: Los Angeles Abrasion Result for Granite

		1	2
Mass of aggregates retained on No.4 ASTM sieve	(kg)	5.0	5.051
Mass of material passing No. 12 ASTM sieve	(kg)	0.714	0.776
Los Angeles Abrasion Value	$\frac{M1}{M2} \times 100$	14.28%	15.36%

Table 12: Los Angeles Abrasion Result for Limestone

		1	2
Mass of aggregates retained on No.4 ASTM sieve	(kg)	5.0	5.028
Mass of material passing No. 12 ASTM sieve	(kg)	2.66	2.74
Los Angeles Abrasion Value	$\frac{M1}{M2} \times 100$	53.20%	54.49%

The aggregate resistance to abrasion is measured by conducting this test. Looking at the tables above, it is clear that the granite has a lower L.A. abrasion value when it is compared to limestone. This shows that the limestone resistance to abrasion is lower than granite. It is not desirable to use aggregates with higher abrasion value in the road works, because they deliver less resistance against skidding. According to JKR specifications, the L.A. value of an aggregate to be used in road construction should be less than 60%, which means that both of the aggregates above meet the requirements.

4.6 Marshall Stability

24 samples were prepared from both limestone and granite aggregates, contributing 12 samples from each aggregate. The porosity of the samples and the percentage of voids in mineral aggregate (VMA) were determined. Following that, the samples were tested in Marshall machine, in order to calculate the optimum Bitumen content, which is calculated by taking average value of the highest bitumen content point at the stability and density graph, in addition to the bitumen content at 4% of the porosity graph.

Table 13: Optimum Bitumen Content (OBC)

Mixtures	Optimum Bitumen Content (OBC)
Granite	5.06
Limestone	5.3

According to the results that is shown in the table above, it is clear that the limestone has the highest OBC value. The reason behind this is that the limestone has higher water absorption when it is compared to granite. Moreover, this mixture is a well graded mix, so the amount of sand used is less than the amount of sand in a gab graded mixture. Sand is known for it is big surface area, and that is why more amount of bitumen is needed to fully coat it. When compared to granite, limestone is an aggregate with high porosity and voids, thus it requires more bitumen for it to be coated, which fully explain the main reason behind the high OBC value of limestone compared to granite.

4.6.1 Density and Bitumen Content

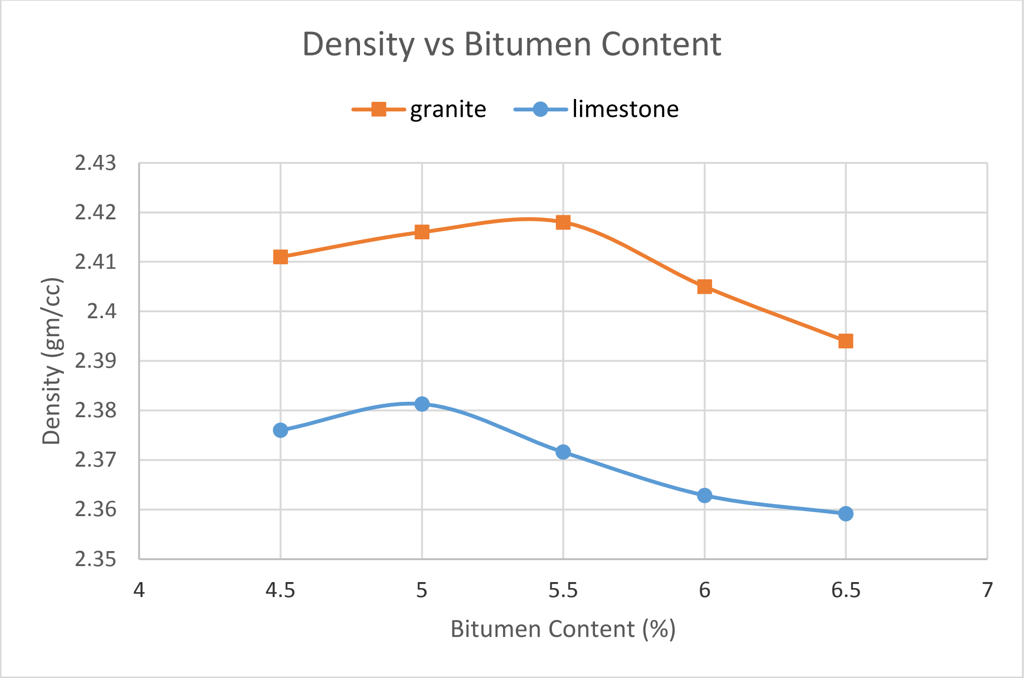


Figure 10: Density vs Bitumen Content Graph

By taking a look into the graph above, it shows us the comparison of the density between limestone and granite, and according to it the limestone has lesser density when it is compared to granite. Unit weigh (Density) is calculated by determining the mass of the HMA sample for each aggregate in water and in air. Each value in the graph above is calculated by getting the average density of the sample at each bitumen content. The following formula is used to obtain this value:

$$\text{Density} = \frac{Wa - Ww}{Wa}$$

While preparing the samples for the mixture. The Gyratory Compaction Machine was used to compact the sample. As soon as the aggregates are crushed, they became finer, and these fine particles can fill up some the voids in the aggregate, which leads to decreasing the porosity. Even though this progress helps to decrease the porosity, the limestone is still higher in terms of porosity, which is the reason why, when we measured the sample in water, the mass of the limestone sample is higher than granite, which explains the graph shown above, with the granite having more density than limestone.

4.6.2 Porosity and Bitumen Content

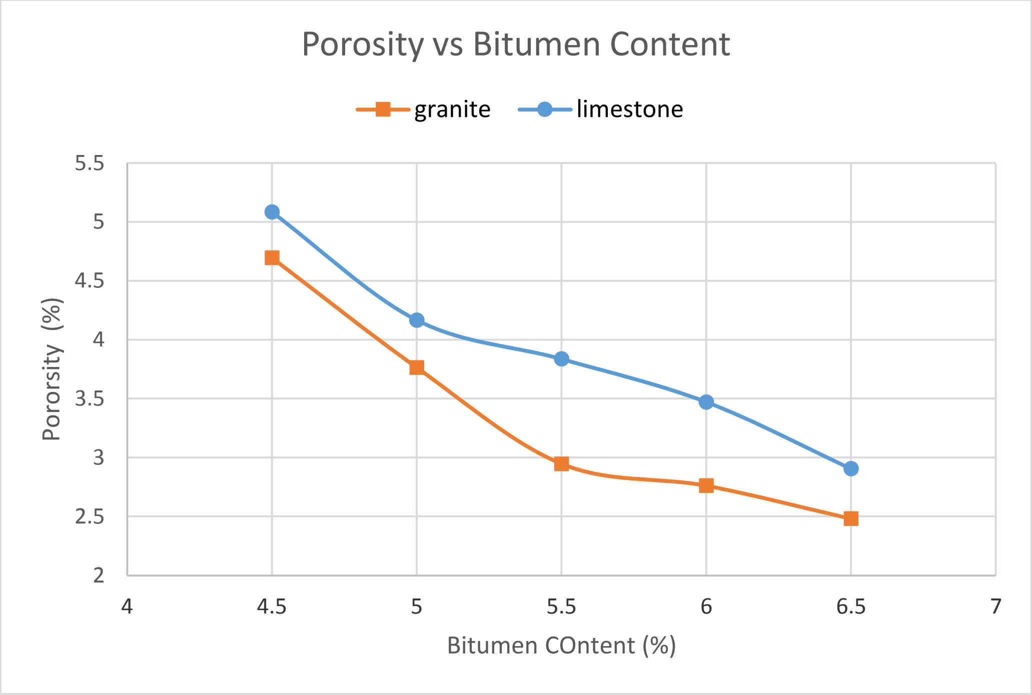


Figure 11: Porosity vs Bitumen Content Graph

As stated many times in the report, the limestone is well known for it is higher porosity when it is compared to the granite, these statements are backed up by the results shown in the graph above. Likewise it is aligned with the results of the density graph, where higher density will produce lesser porosity. It is concluded that the granite has low pore size which means less bitumen will be obtainable to create the asphalt binder film around aggregate particles producing stripping and faster aging.

A percentage of 4% is chosen while calculating the optimum bitumen content, because high air voids in the mixture may lead to cracking in the mixture, and if it is too low there would not be enough room to contain the bitumen, which will lead to bleeding. Voids is known as a parameter which reflect the porosity in the HMA sample. Thus, it is recommended to limit the air voids into 3-5%.

4.6.3 Flow and Bitumen Content

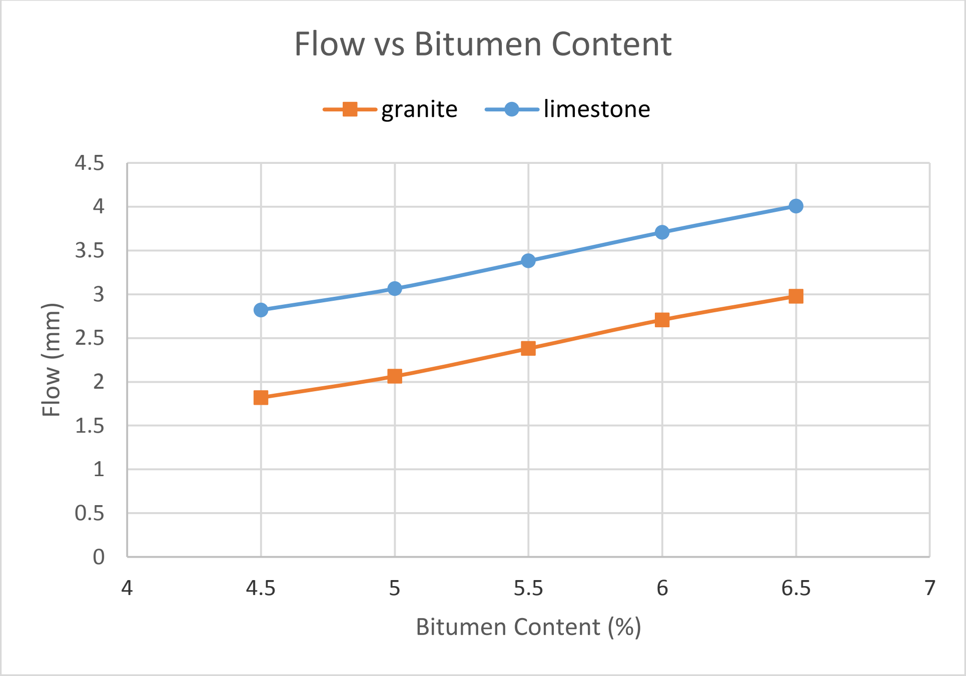


Figure 12: Flow vs Bitumen Content Graph

The flow graph above describe the deformation of different mixtures, by stating the values in where the sample deform up to the point where the load start decreasing. These values are strongly correlated with the amount bitumen used in the HMA sample, which ranges from 4.5% up to 6.5%.

The graph shows that with the increment of bitumen content, the values of flow increase as well in both mixtures, containing the granite and limestone, also it shows that the limestone aggregate HMA sample have higher flow rates.

4.6.4 Stability and Bitumen Content

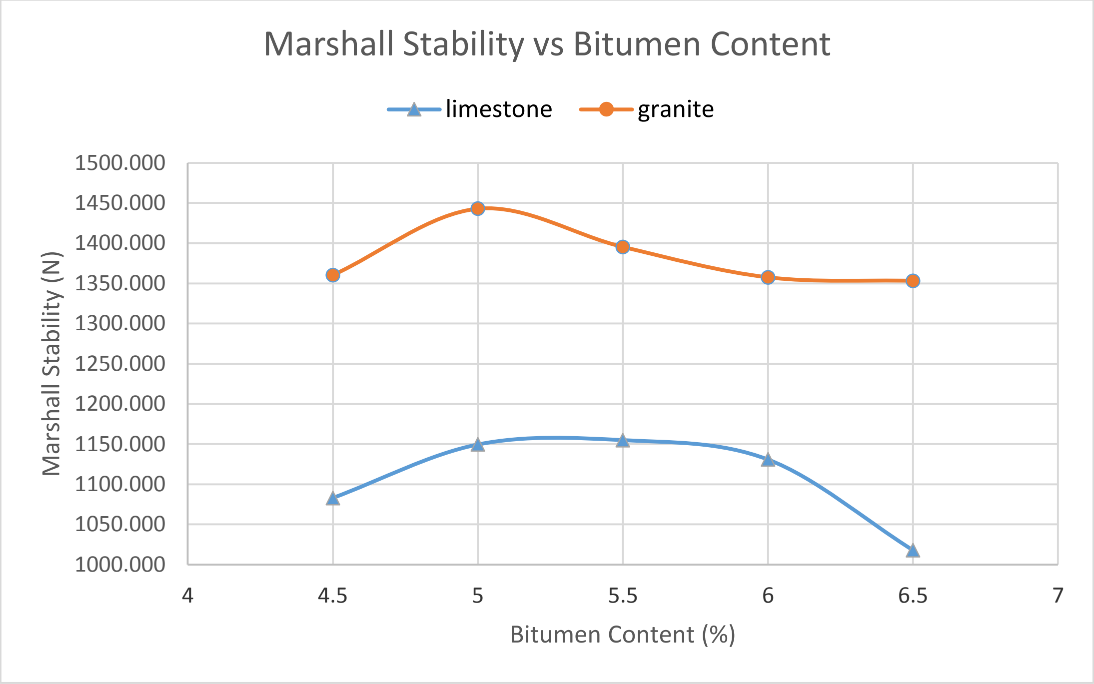


Figure 13: Stability vs Bitumen Content Graph

The stability is last graph for Marshall Analysis, which displays the maximum load that the HMA sample can withstand before it fails or break. The results obtained is proportional with the expected results, where the HMA sample containing granite aggregate takes higher load before it fails, and that because the granite is well known for it is high durability and strength.

4.7 Retained Marshall Stability

Table 14: Retained Marshall Stability Load Results

Mixture	Unconditioned (kN)	Conditioned (kN)	Retained Marshall (%)
Limestone	17.86	13.26	74.24
Granite	22.31	15.12	67.77

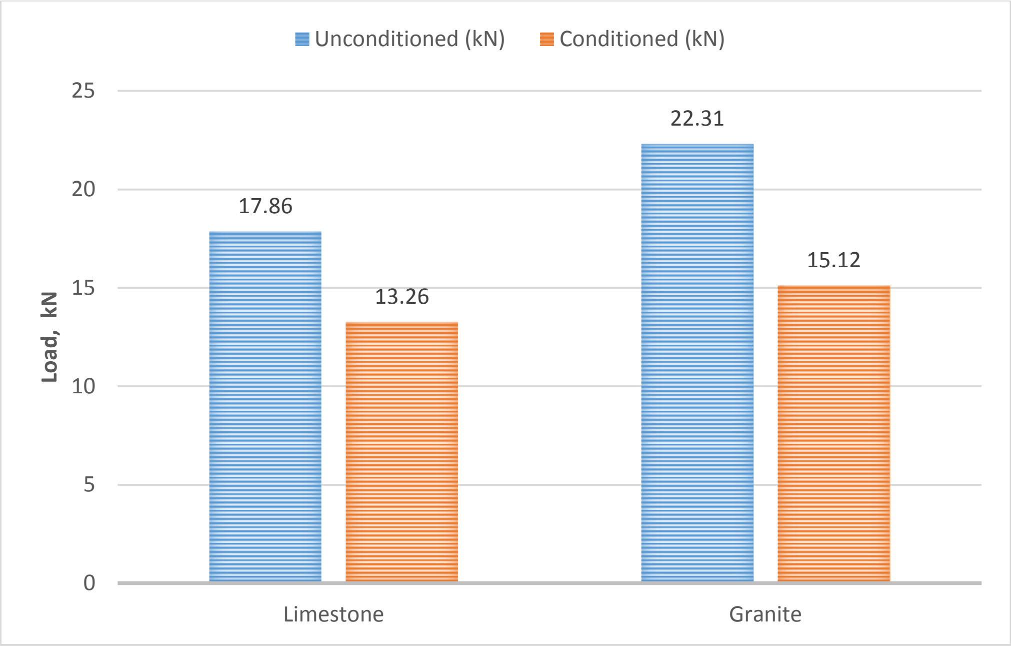


Figure 14: Comparison of Retained Marshall Load

Table 15: Retained Marshall Stability Deformation Results

Mixture	Unconditioned (mm)	Conditioned (mm)
Limestone	2.28	2.09
Granite	2.56	2.18

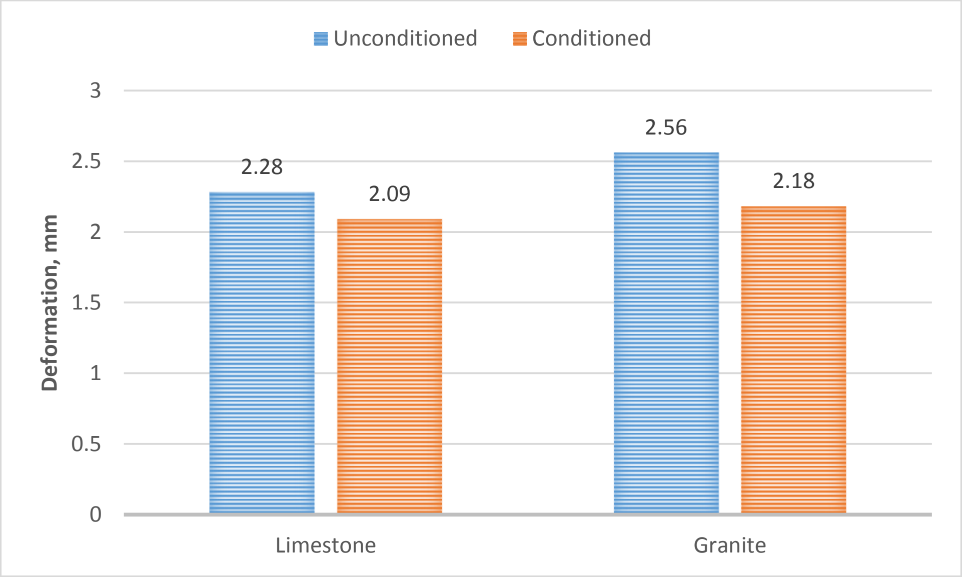


Figure 15: Comparison of Retained Marshall Deformation

Marshall Stability is known as the maximum load that a compacted specimen (HMA sample) can carry under a standard test of 60ºC. Observed at the graphs above that when we compare the granite and limestone in terms of load, we can see that there is a very high reduction in sustaining load for granite. The difference of load between conditioned and unconditioned for limestone is 4.6kN and for granite is 7.19kN. This difference shows us that the limestone is stronger in presence of water, meaning that the mixture containing granite is more exposed to water and less resistant to stripping. The Retained Marshall percentage must be above 75% to sustain moisture damage (Whiteoak, 2003). However both of the aggregates did not reach the requirement, with the limestone being the closest with a value of 74.24%.

These results are allied, with results of Aggregate Stripping Value Test which stated that the limestone is more resistant to stripping by having a lesser percentage of stripped bitumen coating in the aggregate.

Figure 14 contains the same samples, both conditioned and unconditioned, however it compares both of the aggregate in terms of deformation rather than load. The results shows that the deformation of unconditioned sample is higher than the conditioned, with a higher difference of deformation in the samples that contain the granite.

4.8 Indirect Tensile Strength Ratio Test

Table 16: Indirect Tensile Test Results

Mixture	Dry Strength	Wet Strength
Limestone	0.00334	0.00321
Granite	0.00321	0.00298

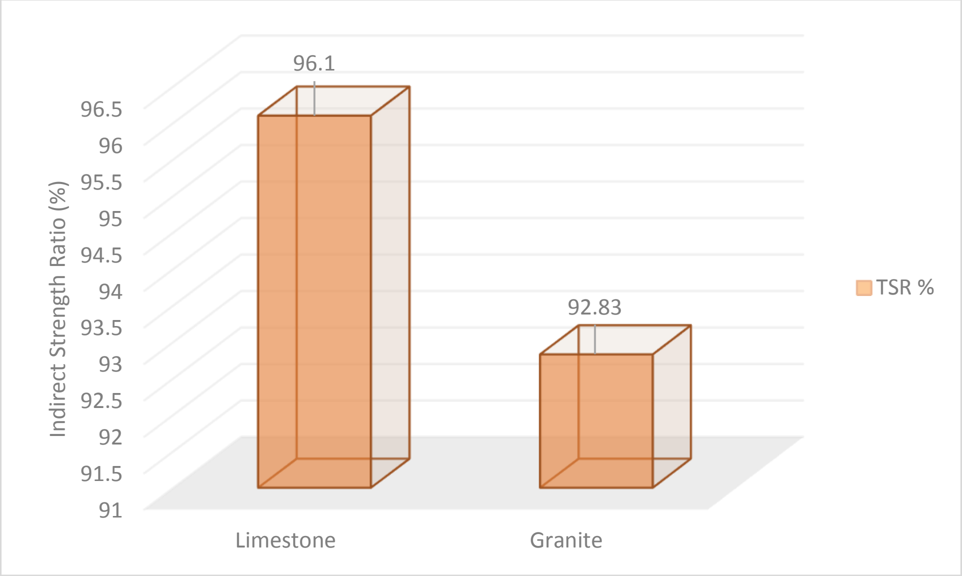


Figure 16: Indirect Tensile Strength Ratio

This test was determined using conditioned and unconditioned samples, and the values of indirect strength ratio were calculated by dividing the wet strength over the dry strength, which reflect the amount of strength lost with the presence of water.

According to the graph above the mixture which contains limestone has higher value of indirect tensile strength ratio with 96.1%, followed by a relatively high value of 92.83% of the granite HMA sample, knowing that the recommended indirect tensile strength ratio value should be above 70% to avoid stripping (Lottman, 1978).

Even though both of the bituminous mixtures containing granite and limestone give values above the requirement, but the lower value of the granite mixture may have the tendency to be less resistant to stripping.

4.9 Aggregate Type Effect in Stripping

Based on the results of retained Marshall and indirect tensile strength ratio, that granite is more exposed to moisture damage, even though limestone water absorption is higher. This might be explained by the mineral composition of granite, as one of it is many minerals is quartz, which is known as a mineral that is more attracted to water than asphalt. Also other minerals such as silica and silicate have high dipole moment that attract to water as it is a polar molecule. However the limestone minerals, such as carbonate have non polar molecule, which is why it can maintain the adhesion force with the bitumen binder.

This study is important to know which combination will be more resistant to stripping. From the discussion above, it is concluded that bituminous mixture that contains granite exhibit tendencies to stripping more than limestone. On the other hand using the bituminous mixture that contains limestone, has appeared to be weak in terms of strength and cannot sustain load. Thus it is recommended to use other types of aggregates in further researches to find out the best aggregate to resist stripping and in the same time withstand high load. Aggregates that are more porous than granite and stronger than limestone, such as basalt, diabase, gabbro or sandstone.

Chapter 5

Conclusion

Several tests has been carried out in order to conclude the properties of each material used to produce bituminous mixtures. In addition, this research ideally shows how the properties of the materials control the engineering properties of the bituminous mixture and build up a legitimate plan and create a decent resistance bituminous mix in light of choice of materials which can last for a long period of time to be used in the future.

This study is important to know which combination will be more resistant to stripping. From the discussion above, it is concluded that bituminous mixture that contains granite exhibit tendencies to stripping more than limestone. On the other hand using the bituminous mixture that contains limestone, has appeared to be weak in terms of strength and cannot sustain load. Thus it is recommended to use other types of aggregates in further researches to find out the best aggregate to resist stripping and in the same time withstand high load. Aggregates that are more porous than granite and stronger than limestone, such as basalt, diabase, gabbro or sandstone.

5.1 Stripping Preventive Measures

Various measures can be taken to prevent, or at least minimize, moisture damage. These measures range from material selection, to construction practice, pavement design and HMA additives:

- Aggregate selection: Choose low porosity aggregate with rough, clean surfaces.
- Prevent moisture penetration into the HMA pavement: Reduce the permeability of the pavement structure by manipulating air void content, lift thickness and gradation. Additionally, surface treatments such as fog seals, slurry seals or bituminous surface treatments (BSTs) can essentially waterproof the HMA surface.

- Pre-treat aggregate: Modify aggregate surface properties to replace ions that are likely to contribute to poor asphalt binder-aggregate adhesion.
- Anti-strip additives: Add chemicals or lime to the asphalt binder or HMA to prevent moisture damage.

  Chemicals: Generally work to reduce surface tension in the asphalt binder, which promotes better wetting, as well as impart an electrical charge to the asphalt binder that is opposite that of the aggregate surface charge. Most chemical additives contain amines and are added at about 0.1 to 1.0 percent by weight of asphalt binder. Chemical additives are generally added to asphalt binder prior to mixing with aggregate but this can cause some waste as not all the additive is guaranteed to reach the critical asphalt binder-aggregate interface. Some additives can be added to the aggregate before mixing with asphalt binder so that all the additive is on the aggregate surface.

  Lime: Works by replacing negative ions on an aggregate surface with positive calcium ions, resulting in better asphalt binder-aggregate adhesion. Also reacts with molecules in both the asphalt binder (carboxylic acid) and aggregate (acidic OH groups) that results in molecules that are more readily absorbed on the aggregate surface or molecules that are less likely to be dissociate and associate with water molecules. Lime is usually added at about 1.0 to 1.5 percent by total aggregate weight. Moisture is needed to activate the lime, so lime is usually added as a slurry or added to slightly moist aggregate.

Chapter 6

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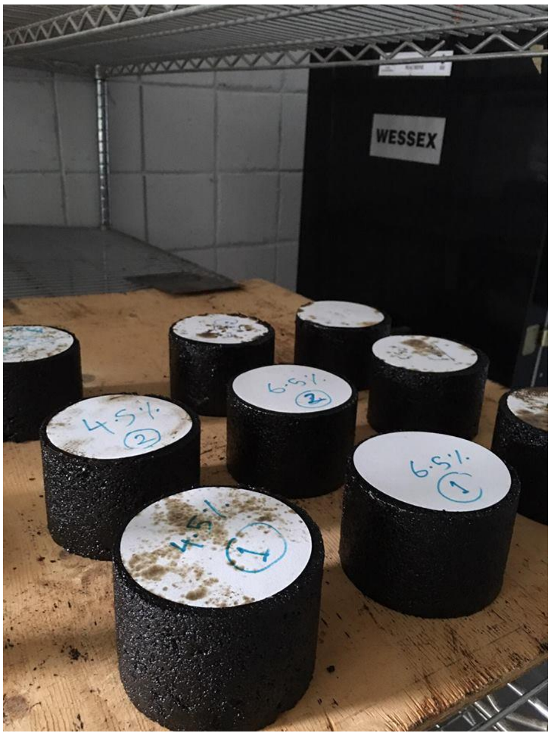
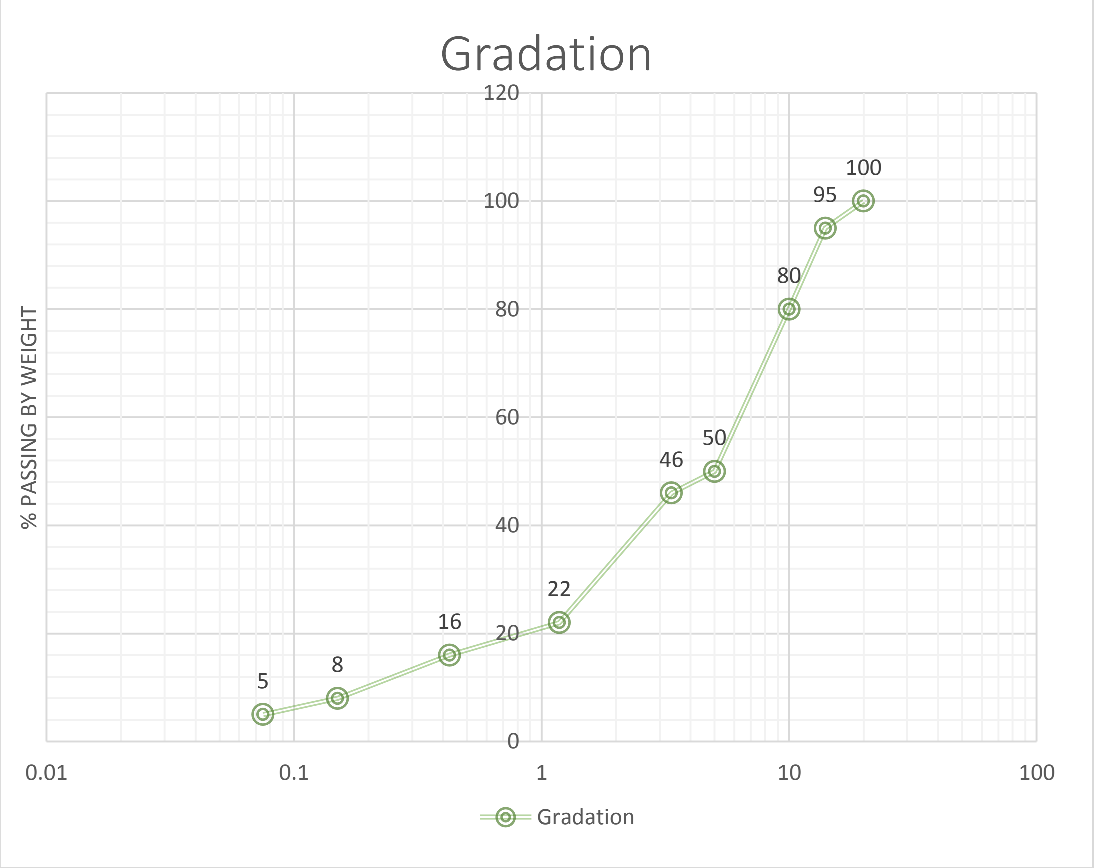
Appendix




Gradation
% PASSING BY WEIGHT
120
100
80
60
40
20
0
0.01
0.1
1
10
100
5
8
16
22
46
50
80
95
100
Gradation

LIMESTONE SAMPLES

% BIT. SPEC. NO.	% BIT. SPEC. NO.	SPEC. HGT. mm	WEIGHT - gm		BULK VOL. cc	SPEC. GRAV		VOLUME - % TOTAL			VOIDS - %				STABILITY - KG		FLOW mm	stiffness
			IN AIR	IN WATER		BULK	MAX. THEOR.	BIT	AGG	VOIDS	AGG	FILLED (BIT)	TOTAL MIX		MEAS.	CORR		
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s
% Bit by wt. of Agg.	% Bit by wt. of Mix				d-e	d/f		(bXg)/Gbit	(100-b)g/Gag	100-i-j	100-j	100(i/l)	100-(100g/h)	CORR FACTOR		pXo		q/r
	4.500	64.400	1202.300	696.500	505.800	2.377								1.040	1331.000	1384.240	1.880	
		64.600	1200.400	695.300	505.100	2.377								1.040	1352.000	1406.080	1.780	
		64.500	1199.800	694.800	505.000	2.376								1.040	1342.000	1395.680	1.800	
AVG.		64.500				2.376	2.504	10.484	84.432	5.083	15.568	67.347	5.083		1341.667	1395.333	1.820	766.667
	5.000	64.100	1203.700	696.800	506.900	2.375								1.040	1300.000	1352.000	2.010	
		65.400	1204.000	698.800	505.200	2.383								1.040	1311.000	1363.440	2.080	
		65.300	1200.900	697.600	503.300	2.386								1.040	1305.000	1357.200	2.100	
AVG.		64.933				2.381	2.485	11.673	84.160	4.166	15.840	73.696	4.166		1305.333	1357.547	2.063	657.939
	5.500	65.000	1202.300	692.500	509.800	2.358								1.040	1325.000	1378.000	2.330	
		65.200	1201.400	697.300	504.100	2.383								1.040	1318.000	1370.720	2.410	
		65.100	1200.800	694.800	506.000	2.373								1.000	1332.000	1332.000	2.400	
AVG.		64.821				2.372	2.466	12.788	83.376	3.836	16.624	76.925	3.836		1325.000	1360.240	2.380	571.529
	6.000	64.100	1203.200	692.500	510.700	2.356								1.040	1397.000	1452.880	2.680	
		64.250	1204.400	694.400	510.000	2.362								1.040	1390.000	1445.600	2.740	
		64.550	1205.900	697.300	508.600	2.371								1.040	1375.000	1430.000	2.700	
AVG.		64.300				2.363	2.448	13.899	82.630	3.471	17.370	80.017	3.471		1387.333	1442.827	2.707	533.064
	6.500	64.650	1199.900	690.700	509.200	2.356								1.000	1304.000	1304.000	2.980	
		64.200	1200.900	692.600	508.300	2.363								1.040	1313.000	1365.520	2.940	
		65.900	1199.500	690.900	508.600	2.358								1.000	1390.000	1390.000	3.010	
AVG.		64.917				2.359	2.430	15.034	82.061	2.905	17.939	83.807	2.905		1335.667	1353.173	2.977	454.594

GRANITE SAMPLES

% BIT. SPEC. NO.	% BIT. SPEC. NO.	SPEC. HGT. mm	WEIGHT - gm		BULK VOL. cc	SPEC. GRAV		VOLUME - % TOTAL			VOIDS - %				STABILITY - KG		FLOW mm	stiffness
			IN AIR	IN WATER		BULK	MAX. THEOR.	BIT	AGG	VOIDS	AGG	FILLED (BIT)	TOTAL MIX		MEAS.	CORR		
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s
% Bit by wt. of Agg.	% Bit by wt. of Mix				d-e	d/f		(bXg)/Gbit	(100-b)g/Gag	100-i-j	100-j	100(i/l)	100-(100g/h)	CORR FACTOR		pXo		q/r
	4.500	74.400	1222.300	715.900	506.400	2.414								1.040	1031.000	1072.240	2.880	
		74.600	1227.400	718.300	509.100	2.411								1.040	1052.000	1094.080	2.780	
		74.500	1220.700	714.000	506.700	2.409								1.040	1042.000	1083.680	2.800	
AVG.		74.500				2.411	2.504	10.638	85.667	3.695	14.333	74.222	3.695		1041.667	1083.333	2.820	384.161
	5.000	74.100	1229.700	720.100	509.600	2.413								1.040	1100.000	1144.000	3.010	
		75.400	1231.200	722.700	508.500	2.421								1.040	1111.000	1155.440	3.080	
		75.300	1228.800	719.800	509.000	2.414								1.040	1105.000	1149.200	3.100	
AVG.		74.933				2.416	2.485	11.844	85.392	2.764	14.608	81.079	2.764		1105.333	1149.547	3.063	375.260
	5.500	75.000	1235.300	723.500	511.800	2.414								1.040	1125.000	1170.000	3.330	
		75.200	1231.200	722.800	508.400	2.422								1.040	1118.000	1162.720	3.410	
		75.100	1229.900	721.500	508.400	2.419								1.000	1132.000	1132.000	3.400	
AVG.		74.821				2.418	2.466	13.039	85.014	1.947	14.986	87.008	1.947		1125.000	1154.907	3.380	341.688
	6.000	74.100	1228.300	718.000	510.300	2.407								1.040	1097.000	1140.880	3.680	
		74.250	1225.900	715.900	510.000	2.404								1.040	1090.000	1133.600	3.740	
		74.550	1226.700	716.300	510.400	2.403								1.040	1075.000	1118.000	3.700	
AVG.		74.300				2.405	2.448	14.145	84.094	1.761	15.906	88.928	1.761		1087.333	1130.827	3.707	305.079
	6.500	74.650	1229.900	717.600	512.300	2.401								1.000	1004.000	1004.000	3.980	
		74.200	1228.100	715.900	512.200	2.398								1.040	1013.000	1053.520	4.030	
		75.900	1226.900	712.000	514.900	2.383								1.000	998.000	998.000	4.010	
AVG.		74.917				2.394	2.430	15.254	83.265	1.481	16.735	91.149	1.481		1005.000	1018.507	4.007	254.203