Volume 5 No. 1
June 2008
ISSN 1675-7009

Scientific Research Journal

Research Management Institute

SCIENTIFIC RESEARCH JOURNAL

Scientific Research Journal is jointly published by Research Management Institute (RMI) and University Publication Centre (UPENA), Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.

SCIENTIFIC RESEARCH JOURNAL

Vol. 5 No. 1 June 2008 ISSN 1675-7009

Scientific Research Journal *Vol. 5 No. 1, 53-66, 2008*

Consensus and Source Properties of Malaysian Aggregates for Superior Performing Asphalt Pavements

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ABSTRACT

Aggregates and binder are the two main constituents that make up hot mix asphalt (HMA). Since a wide variety of mineral aggregate is used to produce Hot Mix Asphalt (HMA), proper evaluation of the mineral aggregate properties is important to ensure good performance of asphalt mixture. Unlike Superpave system, Marshall and Hveem method do not incorporate aggregate criteria into their procedures. The Superpave Highway Research Programme (SHRP) modified the Delphi process to include aggregate properties which are divided into two categories; consensus and source. The consensus properties include aggregate angularity, flat and elongated particles and sand equivalent to ensure aggregate quality is sufficient to provide satisfactory HMA performance for all design traffic levels. The source properties are often used to qualify local source of aggregate which include abrasion, deleterious materials and soundness test. In this study, granite aggregates were collected from northern, central and southern region of Peninsular Malaysia. Results of the aggregate testing showed that Malaysian aggregates are durable and of good quality. These aggregates conformed to the criteria as required in the Superpave system, hence suitable for use in the mix design.

***Keywords**: Consensus and Source Aggregate Properties, Superpave system*

ISSN 1675-7009

Introduction

Malaysia is blessed with good aggregates for use in pavement construction. Nevertheless, not all aggregates are suitable for use in road construction as wearing course. Although generally, most of the granite aggregates performs well in construction, the quality of these aggregates may vary due to vulnerability to weathering and mineralogy content. Currently in Malaysia, the Marshall method adopted to develop a mix design does not specify both consensus and source properties. A detailed study on the suitability, quality and aggregate properties must be carried out to ensure that these aggregates conform to the criteria set by the Superior Performing Asphalt Pavement (Superpave) System. Since aggregate properties play a vital role in the performance of asphalt concrete, the Superpave System places strict controls on the characteristics of aggregates to ensure the aggregates are compatible with the performance objectives. This is important because aggregate properties played the central role in overcoming permanent deformation and constitute up to up 90 to 95 percent by weight of the hot mix asphalt (HMA) mixtures and between 80 to 85 percent of the volume of the mixture.

Processed aggregate has been quarried, crushed, separated into distinct size fractions, washed, or otherwise processed to achieve certain performance characteristics of the finished HMA. Proper evaluation of the aggregate physical properties such as cleanliness, toughness and shape is important for the pavement to adequately withstand the high traffic loadings. Aggregates should also have low porosity and be hydrophobic to give it an affinity for the asphalt binder [1]. Often pavement distress, such as stripping and rutting, can be traced directly to the aggregates used. Rutting for example can be reduced by the use of large aggregates and angular rough coarse and fine aggregates and the choice of surface characteristics and shape qualities can significantly enhance skid resistance [2].

From the engineering characteristics aspect, aggregate must provide enough shear strength to resist repeated load applications regardless of the source, processing method or mineralogy content. The aggregate properties have great effect on the strength and durability of pavement mixtures and it is primarily responsible for the load supporting capacity of asphalt mixtures. When a mass of aggregate is overloaded, a shear plane develops, and aggregate particles slide or “shear” with respect to each other, resulting in permanent deformation. Along this plane the “shear stress” exceeds the “shear strength” of the aggregate mass as depicted in Figure 1.

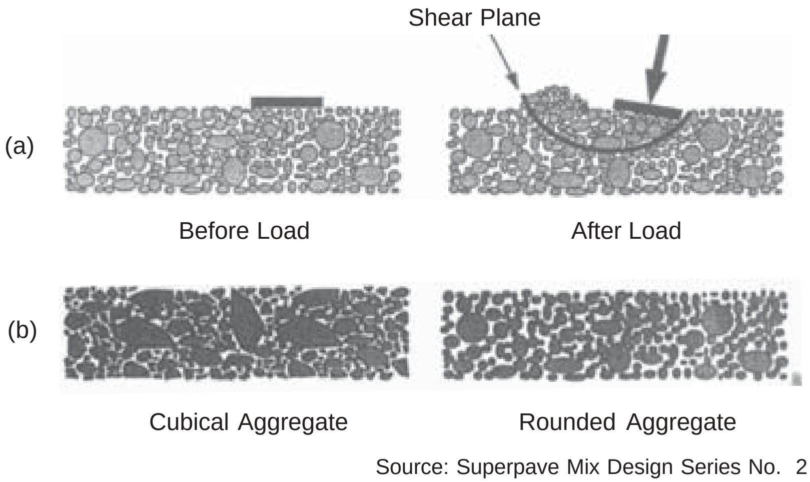

Figure 1: (a) Shear Loading Behavior of Aggregate;
(b) Aggregate Stone Skeleton

The Superior Performing Asphalt Pavement (Superpave) mix design method is one of the research project conducted by the Strategic Highway Research Programme (SHRP) of the Federal Highway Administration between 1987 and 1993 in the United States. This effort was undertaken to develop better tools for designing longer lasting asphalt pavements. Under this programme, performance graded are specified to be critical in achieving high performance in HMA based on two types of aggregate properties needed to be used in Superpave system; consensus and source aggregate properties. These properties are important to meet the various levels of traffic volume and position within the pavement. Marshall and Hveem mix design methods do not incorporate aggregate criteria into their procedures unlike the Superpave mix design procedures. However, no new aggregate procedures were developed instead existing procedures were refined to fit within the Superpave system [3].

The goal of this study is to address the suitability and evaluate the quality of Malaysian granite aggregates for use in the new Superpave system. Apart from that, database acquired from the study by presenting consensus and source aggregate properties test results from variety of aggregate source within Peninsular Malaysia is useful for further evaluation of volumetric mix design in the new Superpave system.

Aggregate Selection

Ten Granite aggregate sources were selected from various parts of Peninsular Malaysia covering northern, southern and central region in this study. The basis for selection was to provide a wide range of performance levels of the aggregate properties at different locality although these aggregates are of the same origin. The quarries involved in this study are Cabaran Minetech Park, Granite Indah, PW Mix, Kuad and Pendang located in the northern region, Hanson, Bt. 3 and Sg. Buloh in middle region and Melaka and Port Dickson in the southern region of the country. This study emphasized on laboratory investigations to evaluate the properties of aggregates that conforms to the criteria set by Superpave system.

Methodology

Initially, the aggregates are classified by size to specify distribution of particle sizes to be used in hot mix asphalt (HMA). Aggregates for HMA are required to be hard, tough, strong, durable and properly graded. Specifications for coarse aggregate, fine aggregate and mineral filler are given in ASTM D692, D1073 and D242 respectively. The American Standard of Testing Materials (ASTM) defines coarse aggregate as particles retained on No. 4 (4.75 mm) sieve, fine aggregate as that passing No. 4 (4.75 mm) sieve and mineral filler as material with at least 70 percent passing the No. 200 (75 microns) sieve. Apart from size classification of aggregate, another important factor to be considered in this study is the traffic loadings which specify different criteria of aggregate test values at different equivalent single axial loads (ESAL).

Consensus Aggregate Properties

The criteria for these consensus aggregate properties are based on traffic level and position within the pavement structure. Materials near the pavement surface subjected to high traffic levels require more stringent consensus properties. The criteria are intended to be applied to a proposed aggregate blend rather than individual components [4]. The aggregate angularity are designed to ensure adequate surface texture while flat and elongated specification relates to aggregate shape and clay content in aggregate deals with mineralogy.

Flat and elongated particles are determined in accordance to BS 812 [1989] using an elongated and thickness gauge. The flakiness and elongated (F & E) test is conducted for coarse aggregate which is retained and weighed on sieve size fractions of 20 mm, 14 mm, 10 mm and 6.3 mm. The total flat, elongated, or flat and elongated particles are measured. This characteristic is the percentage by weight of coarse aggregates that have a maximum to minimum dimension of greater than five. The required maximum values for flat, elongated particles in coarse aggregate are a function of traffic level.

The fine aggregate angularity test determines the loose uncompacted void content of sample of fine aggregate material of known standard grading. This measurement provides an indication of particles shape. The material angularity, roundness or surface texture relative to other materials of the same standard grading is indicated by the percent of voids determined by this test. The Superpave asphalt mix design method sets minimum requirements for void content that vary depending on traffic loads and depth from the surface of the asphaltic concrete pavement. The specimen is allowed to free-fall through funnel of specified diameter and height into small cylinder of known volume.

Reducing undesirable foreign matter is important in HMA. Clay content in aggregate may be harmful and affect durability and cause debond of asphalt binder and aggregate in the presence of moisture. Sand equivalent or clay content test was originally developed in 1952 by Francis Hveem. The sand equivalent is the ratio of the height of sand to height of sand plus clay × 100. Higher sand equivalent values indicate more sand and less clay and silt. This test is quick to perform and requires simple equipment.

Source Aggregate Properties

In addition to the consensus aggregate properties, pavement experts believed that certain other aggregate characteristics were critical. However, critical values of these properties could not be reached by consensus because needed values were source specific. Consequently, a set of “source properties” was recommended. While these properties are relevant during the mix design process, they may also be used as source acceptance control. In HMA, the wheel load transmitted to the underlying layers must be able to resist abrasion and polishing through internal friction of the aggregates. This is also true during compaction, placing and manufacturing stage of the HMA. The L.A Abrasion machine is often used to evaluate the desired toughness and abrasion characteristics of the aggregates. ASTM C131 and C535 are methods used for coarse aggregate smaller than 38 mm (1.5 inch) and aggregates larger than 19 mm (0.75 inch) respectively. Aggregates with high L.A. Abrasion will generate dust during handling of aggregates and production of HMA. High dust content will likely produce environmental problems as well as mixture control problems. Aggregates must be tough and abrasion resistant to prevent crushing, degradation, and disintegration when stockpiled, fed through an asphalt plant, placed with a paver, compacted with rollers, and subjected to traffic loadings. These properties are especially critical for open or gap graded asphalt concrete mixtures (such as open-graded friction courses and stone mastic asphalt) which do not benefit from the cushioning effect of the fine aggregate and where coarse particles are subjected to high contact stresses. Aggregates which lack adequate toughness and abrasion resistance may cause construction and performance problems. Degradation occurring during production can affect the overall gradation and, thus, widen the gap between properties of the laboratory designed mix and field produced mix.

Another empirical test known as soundness test [ASTM C88] provides an indication of durability to weathering and useful for evaluating new source aggregate. This test is to determine loss of material from an aggregate during the immersion. It furnishes information helpful in judging the soundness of aggregates subjected to weathering. Samples retained on 4.75 mm to 150 microns were immersed in prepared solution of magnesium sulfate at 210 °C not less than 16 hours and nor more than 18 hours. The process of immersion and drying were repeated until 5 cycles. Finally the samples are washed, dried, sieved and weighed to determine percentage losses based on grading of original samples. Maximum allowable sodium sulfate soundness loss ranges from 5 to 25 percent with an average of about 14 percent. Range and average for magnesium sulfate soundness are 10 to 20 percent.

Results and Discussion

Consensus Aggregate Properties

The consensus properties showed desirable aggregate properties of Malaysian granite aggregates for use in Superpave system of mix design. Currently the Superpave mix design system specify that no more than a maximum limit of 10 percent of the coarse aggregate retained on sieve 4.75 mm sieve be flat and elongated (F & E) at a 5:1 ratio for the design aggregate blend. Table 1 tabulates the suitability of F & E index of various aggregate quarried for all levels of traffic calculated based on the Equivalent Single Axle Loads (ESALs).

Table 1: Flat and Elongation Criteria for Aggregates

Quarry Location	Flakiness Index (%)	Elongation Index (%)	Superpave Flat, Elongated Requirements (Percent, maximum)				
			Traffic Million ESALs				
			<0.3	0.3 to <3	3 to <10	10 to <30	>30
Hanson, Semenyih	ok	ok	-	10	10	10	10
Hanson, Cheras	ok	ok	-	10	10	10	10
Bt. 3, Semenyih	ok	ok	-	10	10	10	10
Melaka	ok	ok	-	10	10	10	10
Port Dickson	ok	ok	-	10	10	10	10
Sg. Buloh	ok	ok	-	10	10	10	10
Cabaran Minetech Park	ok	ok	-	10	10	10	10
Granite Indah, Perak	ok	ok	-	10	10	10	10
PW Mix Penang	ok	ok	-	10	10	10	10
Kuad Penang	Not ok	ok	-	10	10	10	10
Pendang Kedah	ok	ok	-	10	10	10	10

Results in Figure 1 shows that F&E for aggregates from Kuad Quarry exceeded the maximum allowable limit of 10 % and therefore are not suitable for use in the Superpave system. Otherwise, aggregates from other sources are desirable for use and conformed to the set criteria. Aggregate with high index of F & E tends to break easily causing problems during compaction process.

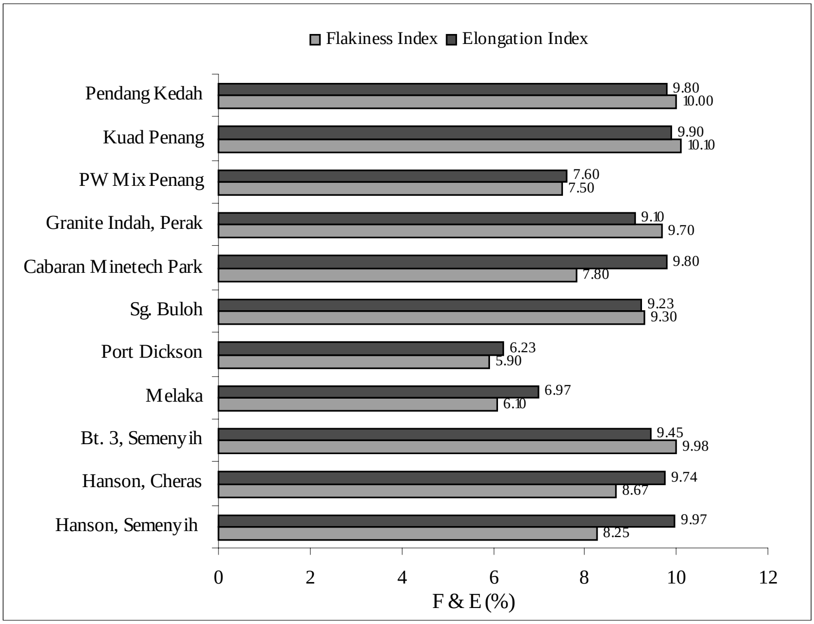

Figure 1: Flat and Elongation Test Results

In the Superpave system, the sand equivalent test is a rapid field test to show the relative proportions of fine dust or claylike materials in aggregate (or soils). The clay-like content identified in the sand equivalent test is more related to moisture damage of the pavement. Clay-like materials minimum requirement of 45 is most common but limit is rated at 50 for traffic ESALs above 30 million as shown in Table 2. The important aspect of achieving the clay content indicates how clean the fine aggregates are. Cleaner aggregates will have higher sand equivalent values. Results in Figure 2 shows that aggregate from Melaka quarry has the highest clay content values followed by aggregates from most part of the northern region, which indicates that the aggregate is cleaner. Aggregates from Hanson and Bt. 3, Semenyih having low clay content values are suitable for use for traffic level from <0.3 to <30 million ESAL except for traffic above 30 million ESALs.

Another important consensus property test is the uncompacted void content test recommended by Superpave to give some indication of fine aggregate particle shape and surface texture since aggregate with greater angularity should have greater uncompacted void content values. Angularity is one of the important aggregate properties contributing to

Table 2: Sand Equivalent Test Criteria for Aggregates

Quarry	Clay Content (%)	Superpave Clay Content Particle Requirements (Percent, maximum)				
		Traffic Million ESALs				
		<0.3	0 to <0.3	3 to <10	10 to <30	>30
Hanson, Semenyih	Not ok	40	40	45	45	50
Hanson, Cheras	Ok	40	40	45	45	50
Bt. 3, Semenyih	Not ok	40	40	45	45	50
Melaka	Ok	40	40	45	45	50
Port Dickson	Ok	40	40	45	45	50
Sg. Buloh	Ok	40	40	45	45	50
Cabaran Minetech Park	Ok	40	40	45	45	50
Granite Indah, Perak	Ok	40	40	45	45	50
PW Mix Penang	Ok	40	40	45	45	50
Kuad Penang	Ok	40	40	45	45	50
Pendang Kedah	Ok	40	40	45	45	50

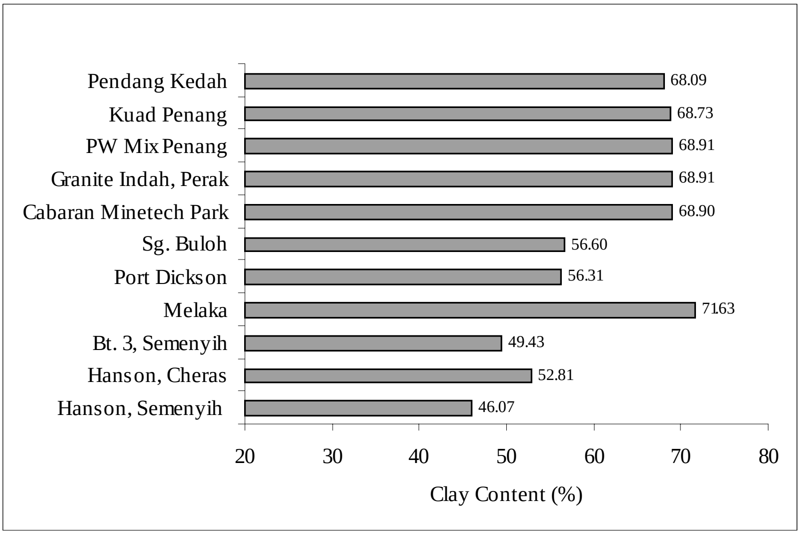

Figure 2: Clay Content Test Results

the permanent deformation resistance of asphalt mixtures. Results tabulated in Table 3 showed that all fine aggregates from the quarries are above the allowable minimum percentage of fine aggregate angularity. Figure 3 shows that Pendang Kedah aggregates have the highest FAA values and Cabaran Minetech aggregates exhibit the lowest FAA values. All aggregates are suitable for use for pavement more or less than 100 mm depth from surface for all levels of traffic.

Table 3: Fine Aggregate Angularity Test Criteria for Aggregate

Quarry Location	Fine Aggregate Angularity (FAA) (%)	Superpave Fine Aggregate Angularity Requirements (Percent, maximum)				
		Traffic Million ESALs				
		<0.3	0 to <0.3	3 to <10	10 to <30	>30
		Depth from surface (<100 mm / > 100 mm)				
Hanson, Semenyih	ok	-	40 / 40	45 / 40	45 / 40	45 / 45
Hanson, Cheras	ok	-	40 / 40	45 / 40	45 / 40	45 / 45
Bt. 3, Semenyih	ok	-	40 / 40	45 / 40	45 / 40	45 / 45
Melaka	ok	-	40 / 40	45 / 40	45 / 40	45 / 45
Port Dickson	ok	-	40 / 40	45 / 40	45 / 40	45 / 45
Sg. Buloh	ok	-	40 / 40	45 / 40	45 / 40	45 / 45
Cabaran Minetech Park	ok	-	40 / 40	45 / 40	45 / 40	45 / 45
Granite Indah, Perak	ok	-	40 / 40	45 / 40	45 / 40	45 / 45
PW Mix Penang	ok	-	40 / 40	45 / 40	45 / 40	45 / 45
Kuad Penang	ok	-	40 / 40	45 / 40	45 / 40	45 / 45
Pendang Kedah	ok	-	40 / 40	45 / 40	45 / 40	45 / 45

Source Aggregate Properties

The source aggregate properties consider the Los Angeles Abrasion test or also known as toughness test of aggregates with maximum allowable loss of 40 or 45 percent. Loss criteria become more restrictive as exposure and loading conditions increase in severity. Results of the Los Angeles degradation values are as tabulated in Figure 4. All aggregates showed acceptable abrasion values, which indicate that local granite aggregate is very durable, and resistant to abrasion. The most resistant and toughest

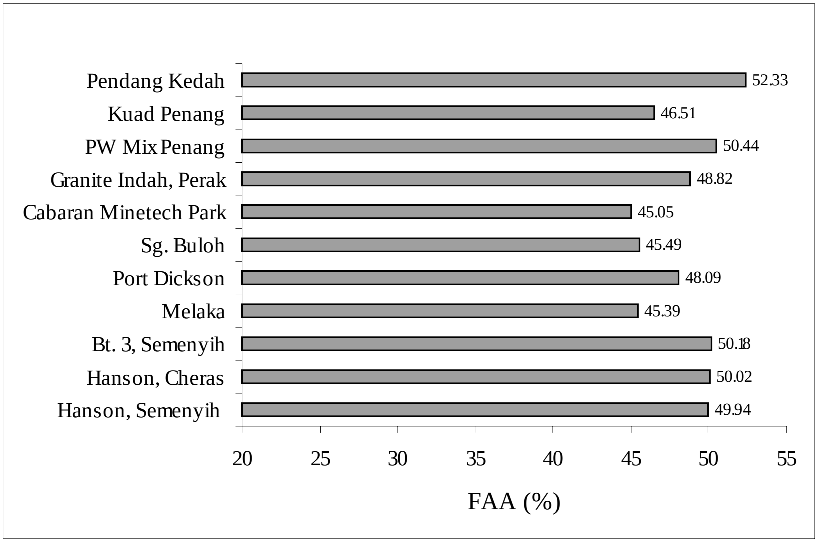

Figure 3: Fine Aggregate Angularity Test Results

aggregate is Hanson Semenyih and the least resistant to abrasion is Granite Indah aggregate. However, all aggregates are considered tough and resistant to abrasion effect and suitable for use as road aggregates.

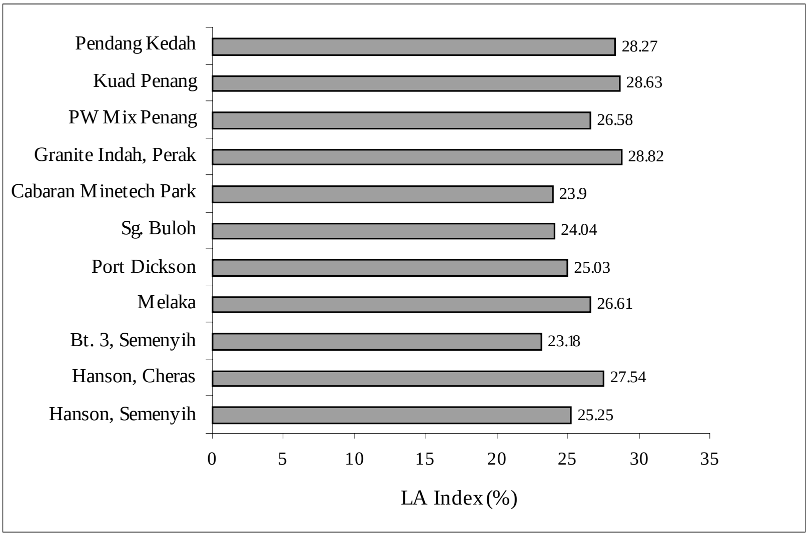

Figure 4: Los Angeles Abrasion Results of Aggregates

The aggregate soundness test is an empirical screening test conducted to indicate durability and determine the resistance of aggregate to in-serving weathering. The test is carried out by exposing the aggregate samples to repeated immersions in saturated solutions of sodium sulfate and later oven dried for 16 to 18 hours at 21°C. The acceptable percentage loss of weight for these aggregates according to ASTM C88 when using magnesium sulfate solution is 18 percent. The soundness level of aggregates in this test showed that all aggregates are resistant to breakdown or disintegration as shown in Figure 5.

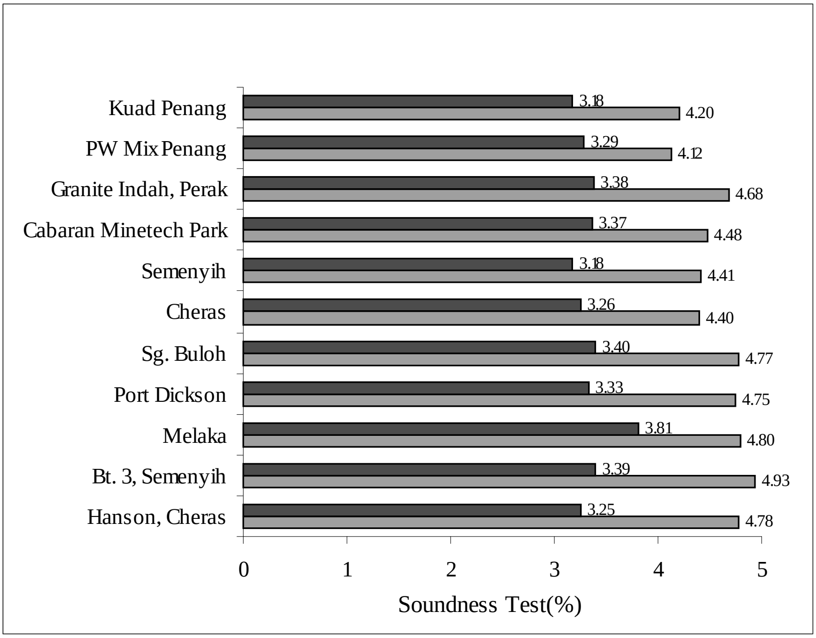

Figure 5: Soundness Test Results of Aggregates

Conclusions

This study emphasised on the importance of relating the aggregate properties to meet the requirements for use in HMA. Laboratory investigations on these aggregates are important and proper aggregate selection is necessary for attaining desired performance of HMA. It can be concluded in this study that:

- Aggregates from Kuad Quarry showed an extreme flakiness index which is undesirable in HMA because this will result in aggregate breakdown during handling, mixing and placement of the HMA. Otherwise, aggregates from other sources are desirable for use in the Superpave system
- The fine aggregate angularity of these aggregates is above the allowable limits and suitable for use for pavement less or more than 100mm depth from surface for all traffic levels. The fine aggregate angularity contributes to the rutting performance of Superpave-designed HMA.
- The presence of plastic fines in the fine aggregate portion of HMA may induce stripping in the mix when exposed to water or moisture. Aggregates from Hanson, Semenyih and Bt.3, Semenyih are not suitable for use in HMA for traffic ESALs more than 30 million, but desirable for lower traffic ESALs. Excessive clay-like particle content may cause the asphalt binder to debond from the aggregate in the mix.
- Aggregates from all quarries in this study showed excellent performance in terms of the abrasiveness to withstand handling during stockpiling, shipping, mixing at the HMA plant, laydown and compaction. This test is one of the most important aggregate property tests to measure durability in the Superpave system.
- The high resistance to severe condition or weathering in the soundness test is evident for all the granite aggregates which showed very low soundness sulfate loss. This indicates that the mineralogy of these aggregates is not easily susceptible to degradation and performs well in HMA. Geologically, granite is strong, durable and has good bonding matrix which relates to the intrusive formation of this rock types.

Acknowledgements

The authors would like to acknowledge Research Management Institute, Universiti Teknologi MARA for funding this research study.

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