# Investigation of Physical and Mechanical Properties of Locally Available Aggregates with Different Combinations for Pavement

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## 1 Introduction

The growing shortage of quality quarried materials and natural gravel for road construction and maintenance is a major challenge facing road agencies. These are finite resources, and the current resources are being exhausted. Gravel quarry products are transported over longer distances, resulting in increased costs for road construction and maintenance. This problem has been exacerbated by the trend towards stricter environmental legislation, legislation on the operation of quarries and requirements for land access, which add to the cost and limit the opportunity to initiate new quarries and to open new gravel pits.

The aggregates are an important structural component of the pavement, and their properties govern the performance and serviceability of the pavement over its service life. As a result, many researchers have stressed the significant impact of Unbound Granular Materials (UGMs) on the engineering performance of pavements [3, 4, 6, 7, 11, 18, 20]. The use of long-lasting, tough, and durable aggregates is, therefore, a primary goal in the development of long-lasting pavements [2, 5, 8, 13]. There are several types of aggregate that can be used for road construction in Malaysia such as granite, sandstone, microtonolite, basalt and limestone. The most common type of aggregate used in Malaysia for road construction is granite. In Sarawak, owing to the increasing road construction projects, the need for quality aggregate for pavement wearing courses has increased drastically. However, due to the geological structure of Sarawak, the production of granite aggregates is low due to the limited resources.

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Standard practice for road construction in Malaysia is Standard Specification for Road Work (SSRW) Sect. 4: Flexible Pavement [12] provided by Public Work Department, Malaysia. According to this standard, aggregates for asphalt concrete must be a mixture of coarse and fine aggregates as well as a mineral filler such as cement. This aggregate must also comply with the physical and mechanical quality requirements of the Public Work Department standard specification. The limestone aggregate, on the other hand, is not permitted to be used as a wearing course in accordance with this specification's requirements. Tan [19] mentioned that due to its low polished stone coefficient, limestone aggregate is not recommended for wearing courses since it is well known that many skidding incidents have occurred on polished limestone road surfaces.

Aggregates used in road construction can be divided into two categories, that is, standard and non-standard. A non-standard aggregate is described as any aggregate, that is, usually unusable due to a lack of conformity with the current specification [1]. According to Toole et al. [21], natural gravel and weathered rocks are marginal and non-standard road building materials. Even though they do not meet the required standards; however, for some roads, these materials are known to perform well as granular base and sub-base materials. Compared to the original materials, the non-standard aggregates are likely to be susceptible to faults because they are weak and unable to withstand the current specified capacity [22].

Besides that, the amount of aggregate required for a mega road project is enormous, and aggregates are often left unprotected from harsh weather, leaving aggregate quality unobserved. Furthermore, some of the aggregates are not protected because the contractor does not have sufficient covered storage, leaving the aggregates exposed to the weathering process on sunny and rainy days. As such, the quality of the aggregate can be significantly affected by the weathering process. In general, both wear resistance (degradation of particles as crushing loads) and decay resistance (i.e. weather resistance under the complex environmental conditions encountered by UGMs) affect the durability characteristics of the materials [5, 10, 16, 18]. The purpose of this research is to examine the effect of wetting and drying cycles, the mechanical properties of aggregates on the various aggregate combinations of granite, limestone, and microtonalite in order to evaluate the potential use of these materials for road construction in Sarawak, particularly locally available non-standard materials.

## 2 Aggregates in Sarawak

Malaysia's quarrying industry has consistently contributed to the country's economic development. According to Kei [14], more than 80 million tonnes of construction aggregate are produced in Malaysia with the quarrying industry contributed RM 7,119.6 million to the Malaysian economy in 2015 [15]. This emphasises how important it is for Malaysia's construction industry to obtain high-quality aggregate. Peninsular Malaysia (also known as West Malaysia) is situated in the southern part

**Table 1** Location and classification of aggregates found in Sarawak

| Site | Group classification of aggregates |
|---|---|
| Bau, Kuching Division | Limestone |
| Bau/Lundu, Kuching Division | Sandstone |
| Sebuyau, Samarahan Division | Granite |
| Santubong, Kuching Division | Granite |
| Muara Tuang, Samarahan Division | Microtonalite |
| Batu Kawa, Kuching Division | Microtonalite |
| Kakad Quarry, Mile 16, Kuching Division | Microtonalite |
| Ex. Pendu Quarry, Mile 29, Kuching Division | Limestone |
| Mile 22, Btu/Miri Road, Bintulu Division (Ex. JKR Quarry) | Sandstone |
| Mile 21, Kuching Division | Limestone |
| Mile 7, Kuching Division | Microtonalite |
| Mile 9, Kuching | Microtonalite |
| Sebuyau/Simunjan Division | Granite |

*(Source JKR Sarawak, Central Material Lab)*

of Asia, while the Eastern part of Malaysia (Sabah and Sarawak) is located on the Island of Borneo. The rocks from Peninsular Malaysia were known to be much older as compared to the rocks in Sabah and Sarawak and have been exposed for a long time to tropical tropic conditions and the earth's atmosphere, which may lead to the formation of deep weathering profiles and laterite over various types of bedrock [9]. In Sarawak's construction industries, aggregates such as microtonalite, limestone, granite, quartz, sandstone, slag, dolomite, and others are commonly available and used, particularly for road construction. Additionally, granite, limestone, and microtonalite are the three types of coarse aggregates widely used in Sarawak for road construction. The location and classification of local aggregates found in Sarawak are shown in (Table 1 and Fig. 4). Locally available aggregates such as sandstone, granite, limestone and microtonalite as shown in (Figs. 1, 2 and 3) are generally quarried and utilised in Sarawak.

## 3 Materials and Methodology

Three (3) different types of aggregate known as granite aggregate (GA), limestone aggregate (LA) and microtonalite aggregate (MA) were used in this research. Granite aggregate is used as a standard aggregate, while limestone and microtonalite aggregates are known as a low-quality/non-standard aggregate. Non-standard aggregate

**Fig. 1** Limestone

**Fig. 2** Sandstone

is classified as any aggregate that is not commonly used because it lacks the specifications' requirements nonetheless may possibly be successfully used by modifying standards for construction procedures and pavement design [1]. The general definition of non-standard or substandard aggregate is "any aggregate that is not normally used because it does not have the characteristics required by the specification but could be used successfully by modifying normal pavement design and construction procedures". The methodology used are in accordance with standard practice for road construction in Malaysia as specified in Standard Specification for Road

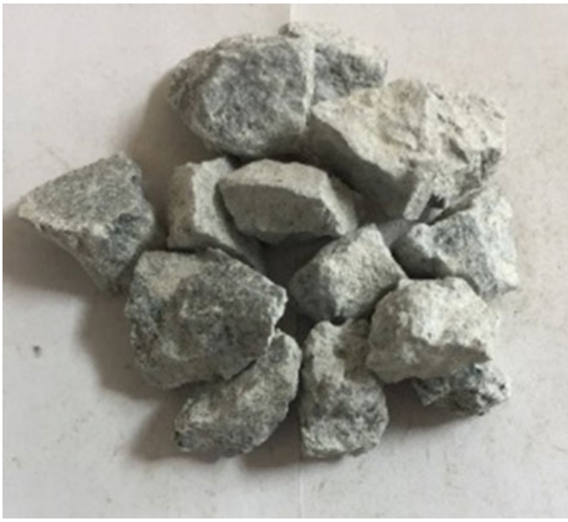

**Fig. 3** Granite

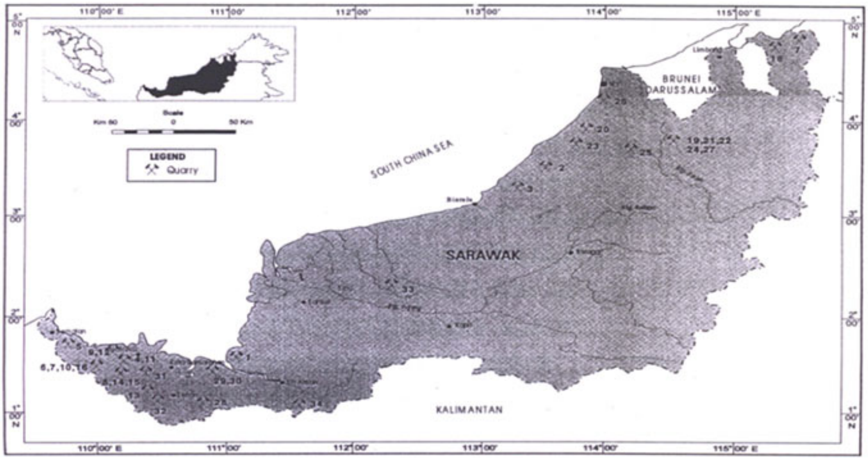


**Fig. 4** Quarries locations in Sarawak. *(Source Industrial Mineral Production Statistic & Directory of Producers in Malaysia 2002)*

Work (SSRW) Sect. 4: Flexible Pavement [12] provided by Public Work Department, Malaysia. For the purpose of this research, three types of aggregates were selected namely granite as standard aggregate, while limestone and microtonalite areconsider as non-standard aggregate. These materials are sourced locally from nearby quarries by sampling method as specified in ASTM D75.

**Table 2** Standard specification for physical and mechanical properties

| Property | Test | Standard specification |
|---|---|---|
| Physical | Specific gravity | ASTM C127-07 |
| | Water absorption | |
| | Flakiness Index | BS 812-105.1:1989 |
| | Elongation Index | BS 812-105.2:1990 |
| Mechanical | Aggregate Crushing Value (ACV) | BS 812-110:1990 |
| | Aggregate Impact Value (AIV) | BS 812-112:1990 |
| | Los Angeles Abrasion (LAA) | ASTM C 131-06 |

**Table 3** Aggregate combination percentage

| Testing | Aggregate | Percentage of combination (%) |
|---|---|---|
| 1. Aggregate Crushing Value<br>2. Aggregate Impact Value<br>3. Los Angeles Abrasion | GA | 100 |
| | LA | 100 |
| | MA | 100 |
| | GA: MA | 50–50 |
| | GA: LA | 50–50 |
| | GA: MA | 75–25 |
| | GA: LA | 75–25 |

The physical and mechanical standard specifications used for testing of aggregates are shown in Table 2. All the used aggregates were tested for physical properties and followed by mechanical properties. Different combination ratios of granite, limestone and microtonalite aggregates for mechanical tests are described in Table 3. For ACV and AIV, the size for the used aggregate passed the 5 mm sieve and was retained on the 3.35 mm sieve. The aggregate size for LAA passed the 5 mm sieve and was retained on 2.36 mm. There were two testing conditions to test the mechanical properties of aggregates known as controlled condition and wetting and drying condition. The purpose of performing wetting and drying is to investigate how well the aggregate can resist the weathering effect since, in most construction projects, the aggregate stockpiles are not fully protected and are exposed. Controlled condition means the mechanical tests were conducted in accordance with the referred standard specifications using aggregate from Table 2. Wetting and drying condition means the aggregates went through 5 cycles of wetting and drying before being tested for mechanical properties using aggregates from Table 3. For each application, the aggregate is exposed to a different set of physical and chemical degrading forces. Some of the forces that an aggregate may be exposed throughout its service life are abrasive, tensile, shear, and compressive forces, sulphate exposure, wetting and drying cycles, and freezing and thawing cycles [17]. One (1) wetting and drying cycle means 1 day of full water immersion and 1-day of ambient temperature air drying. After 5 cycles of wetting and drying, the aggregates were oven-dried for 1 day before being used for mechanical tests. After the tests, the results were compared to standard specifications. The aim of combining various types of aggregate is to determine the mechanical properties of the two aggregates when they are combined. As a result, the potential use of limestone and microtonalite in pavement wearing courses can be explored.

# 4 Result and Discussion

## *4.1 Physical Properties of Aggregate*

The physical properties of granite, limestone and microtonalite aggregates used in this research are shown in Table 4.

## *4.2 Aggregate Under Controlled Condition*

The mechanical performance of different types of aggregate and different combination ratios of aggregates is shown in Table 5. It was observed that MA 100% had better performance than GA 100% and LA 100%. From the result, ACV, AIV and LAA for GA 100%, LA 100% and MA 100%, only LAA for GA 100% did not achieve the requirement. For different combination ratios, the combination ratio consisted of MA had better performance than other types of combination. For example, the ACV, AIV and LAA of GA 50%: MA 50% were better than GA 50%: LA 50%. In addition, the ACV, AIV and LAA of GA 75%: MA 25% were better than GA 75%: LA 25%. Only GA 50%: LA 50%, GA 75%: LA 25% and GA 50%: MA 50% did not achieve the requirement for LAA. Overall, controlled conditions for different combination ratios, GA 50%: MA 50% and GA 75%: MA 25% can be selected.

**Table 4** Physical properties of aggregates

| Tests | Experimental value | | | Public work department standard specification (1988) |
|---|---|---|---|---|
| | GA | LA | MA | |
| Specific Gravity | 2.44 | 2.45 | 2.52 | – |
| Water Absorption, % | 0.74–9.04 | 0.48–8.11 | 0.58–14.36 | <2% |
| Flakiness Index, % | 10.86 | 20.13 | 10.20 | <25% |
| Elongation Index, % | 29.31 | 40.06 | 16.51 | – |

**Table 5** Controlled and wetting and drying conditions—mechanical properties of aggregate

| Condition | Test | Experimental value | | | | | | | Public work department standard specification | BS 812-112 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | GA 100% | LA 100% | MA 100% | GA: LA 50%: 50% | GA: MA 50%: 50% | GA: LA 75%: 25% | GA: MA 75%: 25% | | |
| Controlled | ACV | 17.38 | 14.96 | 11.54 | 16.36 | 14.56 | 15.25 | 14.74 | <30% Note 1 | |
| | AIV | 8.64 | 6.42 | 5.56 | 7.29 | 5.87 | 7.66 | 6.84 | | <30% |
| | LAA | 30.96 | 19.17 | 21.49 | 26.22 | 25.69 | 29.41 | 24.86 | <25% Note 2 | |
| Wetting and drying | ACV | 16.71 | 12.44 | 10.77 | 14.77 | 13.46 | 15.41 | 15.03 | <30% Note 1 | |
| | AIV | 13.02 | 9.77 | 5.23 | 10.00 | 6.56 | 11.78 | 8.23 | | <30% |
| | LAA | 36.10 | 25.70 | 19.71 | 27.45 | 24.03 | 27.71 | 26.85 | <25% Note 2 | |

*Note 1 Public Work Department, 2008*
*Note 2 Pubic Work Department, 1988*

### 4.3 Aggregate Under Wetting and Drying Condition

For aggregate that went through 5 cycles of wetting and drying before being tested for mechanical performance, the result is shown in Table 5. From Table 5, for ACV, AIV and LAA, it can be observed that only GA 100% did not achieve the LAA requirement compared to LA 100% and MA 100%. MA 100% had the highest performance than LA 100% and MA 100%.

For different combination ratios, same as controlled conditions, combination ratios consisted of MA had better performance than other types of combination. For example, GA 50%: MA 50% had better performance in terms of ACV, AIV and LAA than GA 50%: LA 50%. Same as GA 75%: MA 25% were better than GA 75%: LA 25%. Only GA 75%: MA 25%, GA 50%: LA 50% and GA 75%: LA 25% did not achieve the requirement for LAA. Overall, wetting and drying conditions for different combination ratios, GA 50%: MA 50% and GA 75%: MA 25% can be selected. By comparing the result of controlled conditions and wetting and drying conditions, wetting and drying cycles do have an effect on the mechanical properties of aggregate.

For AIV, wetting and drying show a higher value compared to the controlled samples. This shows that aggregates that have been exposed to wetting and drying conditions may reduce the impact value of aggregates. For the Aggregate Crushing Value, the sample shows a higher value for the 100% aggregate sample which varies from 11.54 to 17.38 for the controlled sample while for the wetting and drying sample it varies from 10.77 to 16.71 which is slightly lower compared to the controlled sample. However, the 50%: 50% result combination samples shows a lower value compared to 75%: 25% combination aggregates with a higher value. The Granite and Limestone combination on 75% and 50% shows that there is no significant difference in the result. Conversely, the result of Granite and Microtonalite with a 50% and 75% Granite combination showed wide gap result for both controlled, wetting and drying effects. The difference in value between the 50-percent and the 75-percent mix is roughly 50-percent different. While for the Los Angeles Abrasion, the wetting and drying samples for the 100% aggregates show a higher value for both Limestone and Microtonalite except for Granite with values varies from 30.96 to 36.10 which are the above-average result. For the 50%: 50% and 75%: 25% aggregates combination, Microtonalite shows a higher value compared to Limestone with different of $\pm 1$ in 50%: 50% combination whereas 75 per cent: 25% combination shows the highest value of 24.86 for controlled samples. The significant different findings obtained from the results are highly due to the wetting and drying effect which made the aggregate less durable mainly in the Aggregate Impact Value testing.

## 5 Conclusion

From the overall test result and significant findings, it was observed that the aggregates tested for AIV and LAA are highly affected due to wetting and drying conditions, making the value for AIV and LAA higher but still meeting the standard requirement. However, the wetting and drying effect does not show any effect under the compressive condition as shown in the ACV result which still meets the standard requirement of less than $<25\%$. According to the results of the laboratory work, the following conclusions can be drawn:

- The different combination ratio of different types of aggregates has the potential to be used as alternative materials for road construction.
- The different combination ratios can have the potential of cost saving for road construction.
- Further research needs to be carried out such as polishing stone value to evaluate the polishing resistance of the aggregate.

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