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Testing of Physical-Mechanical Properties of Blue Limestone Used in Pavements in Trinidad and Tobago: A Preliminary Study

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Abstract: *Aggregates used in pavement construction need greater strength to withstand the load of crushing, degradation and disintegration. It is of high importance to analyse the toughness and abrasion resistance of the aggregate prior to its usage. In Trinidad and Tobago, blue limestone is mainly used as source for these aggregates. This blue limestone has two varieties, namely layered limestone and massive limestone. The layered variety contains soft mica rich layers, which are sandwiched between hard calcite rich layers. Micro-structure (fabric) and other geological features play important role in defining the resistance and abrasion resistance of these aggregates. In present study, it was found that aggregate crushing and aggregate impact values were nearly two times lower in the massive limestone than the layered limestone. Whereas, the loads required for the 10% fines were more than two times lower in the layered limestone than the massive quality. However, it was found that the specific gravity values were different in layered and massive limestones (2.3 and 2.5 respectively). Moreover, these measured mechanical properties were combined into a single characteristic, Toughness Index (TI), as performance indicator of overall quality of aggregates. The TI values also suggested that the layered limestones were weaker than the massive limestone. The layered limestones did not satisfy the needs to be aggregates of international quality for pavement construction. However, the massive limestones were found suitable for this purpose.*

Keywords: *Aggregates, pavement construction, mechanical properties, toughness index*

1. Introduction

Aggregate, which is the physical framework material for pavement and road construction (Hill et al., 2001; Kamal et al., 2006; Mohajerani et al., 2017 amongst others), can contain a crushed stone content in excess of 50% of the coarse aggregate particles (FHWA, 1993). It is important to note that these granular aggregates are subjected to significant amount of wear and tear through the span of their service life. Therefore, aggregates with low resistance to abrasion should be avoided for construction of pavements (Wu et al., 2001; Ozcelik, 2011). It is also well-known that different asphalt-mix strength can be expected from different types of aggregates with different petrology, strength and grain shape (Hill et al., 2001; FHWA, 1993). As a result, the quality of aggregates (especially long-term durability, aggregate impact value and crushing value) can determine the mechanical properties of asphalt-mix (Kamal et al., 2006; Kahraman and Toraman, 2008; Ugur et al., 2010; Mohajerani et al., 2017). These geological properties are widely recognised and accepted to have strong control due to their contrasting mineral assemblage and different characteristics (e.g., shape, orientation and arrangement of grains) (Tuğrul and Zarif, 1999; Tandon and Gupta, 2013, Banerjee and Melville, 2015).

Globally numerous studies have been conducted on the influence of these geological properties in aggregates (Tuğrul and Zarif, 1999; Tandon and Gupta, 2013, Banerjee and Melville, 2015). Searches conducted so far have found negligible amount of available research on these controlling factors in the aggregates used in Trinidad and Tobago road and pavement industry. In Trinidad and Tobago, blue limestone is one of the major type of aggregate used in this sector (Lalla and Mwasha, 2014). In a previous study, one of the present author has indicated a strong control of some of the geological properties on the aggregates commonly used in Trinidad and Tobago construction sector (Banerjee and Melville, 2015). Present study is designed to investigate the suitability of aggregates commonly used for pavement construction in Trinidad and Tobago, and to other regions, where these aggregates are being exported. To establish the suitability, the aggregates were examined particularly to satisfy their resistance to abrasion produced by static, dynamic, permanent and cyclic loads.

Therefore, the objectives of the present study are to: (a) examine some important mechanical properties of the blue limestone, (b) calculate the Toughness Index (TI) of these aggregates and (c) finally to provide information on suitability of the blue limestone in local road and transportation sector.

2. Methodology

2.1 Sample Collection

Northern Range blue limestones have two verities, massive limestone and layered limestone. Present study was carried out on both types of metamorphosed blue limestone samples, collected from the Northern Range of Trinidad. A total of 30 fresh rock samples (15 from each verities) were collected from a local quarry in La Pastore district along Cutucupano (i.e., 10°43'15.15" N and 61°28'41.40"W).

2.2 Mechanical Analysis of Aggregates

Quality assessment of rock samples for the suitability to be used as aggregates for pavement construction was done by examining some important and relevant mechanical properties. These properties include porosity, specific gravity (SG), Los Angeles Abrasion (LAV), Aggregate Impact Value (AIV), Aggregate Crushing Value (ACV), and the 10% Fines Value (TFV). All these properties were tested in the Department of Civil and Environmental Engineering, University of West Indies, St. Augustine Campus, Trinidad and Tobago. Porosity and SG were measured following ASTM standard (ASTM, 2014). LAV, AIV, ACV and TFV tests were performed according to the standards of ASTM C131 (ASTM, 2003), BS: 812-110 (BSI, 1990a) and BS: 812-111 (BSI, 1990b) and BS: 812-112 (BSI, 1990c), respectively. Aggregates for this test were crushed into 1 inch to 3/8 inch fractions before LAV tests were performed, while aggregate fractions above 3/8 inch size were selected for AIV and ACV tests. Aggregates, which pass through a 2.36 mm sieve are defined as fine aggregates, and in TFV test the aim is to determine the load required to produce 10% of the fine fraction of the aggregate. Each value was obtained by averaging vigilant test results from individual sample in order to minimise possible experimental errors particularly in volume measurement (ISRM, 1981; Banerjee and Melville, 2015).

2.3 Toughness Index of aggregates

For a better representation of these mechanical properties of the aggregates, Kamal et al. (2006) have developed a classification of aggregates on the basis of a mechanical index, which is unified from measured LA, AI, AC, TF and SG values (see Table 1).

Table 1. Range of TI for Aggregates Specification

TI range	Rating	Use
>97	Very good	Road Surfacing and Base
95–97	Good	Base and Subbase
90–95	Fair	Subbase only
<90	Poor	Use with caution

Source: Based on Kamal et al. (2006)

This index has been termed as Toughness Index by these researchers. They also indicated that this index would not preclude the importance of initial testing, rather it could represent a unified, weighted and comprehensive value or index for any routine quality control or assessment of the source materials.

In this study, TI was calculated using the following equation (after Kamal et al., 2006):

$$TI = \frac{(A+B+C+D+E)}{5} \quad (1)$$

Where,

$$A = \frac{\left[1.1 \times \left(\frac{SG}{2.9}\right)\right]}{100}$$

$$B = 100, if\ ACV \leq 30;\ or$$

$$B = \frac{(100 - ACV)}{(100 - 30)} \times 100\ if\ ACV > 30$$

$$C = 100\ if\ TFV \geq 100;\ or$$

$$C = \frac{TFV}{50} \times 100\ if\ TFV\ < 50$$

$$D = \frac{(100 - LA)}{(100 - 15)} \times 100$$

$$E = 0.9 \times 100\ if\ AIV \leq 30\ or$$

$$E = \frac{0.9 \times (100 - AIV)}{100 - 30} \times 100\ if\ AIV > 30$$

3. Results

The results obtained from the selected analyses of both the verities of limestones are summarised in Table 2. This table also provides the range of values for each test conducted and the international standard values for these tests. Samples from the layered limestone showed higher porosity values (with the average of 2.18%) than the massive varieties (with the average porosity of 0.44%). The specific gravity values were also found different for both layered and massive limestones, with the average values of 2.3 and 2.5, respectively.

LA values obtained from the layered limestone samples were higher (with average of 42.3 ± 2.6%) than the LA values observed in the massive limestones (with average of 34.8 ± 2.3%). AIV and ACV test results also showed similar trends, with higher values in the layered limestones (with average of values of 50.0 ± 2.8% and 46.4 ± 2.5%, respectively) than those of the massive varieties (with average of values of 23.2 ± 2.1% and 28.2 ± 2.0 %, respectively). The loads required to produce 10% fines from the aggregates were higher in the massive limestones (with the average load of 93.7 ± 5.1 kN) than the layered varieties (with the average load of 38.0 ± 2.8 kN).

Based on Equation (1), TI values for each aggregate samples in the present study have been calculated and are presented in Table 2. The layered limestone samples showed lowered TI values (with average of values of 74.7) than the TI values calculated for the massive limestones (with average of values of 92.6).

Table 2. LA, AIV, ACV, Load to TFV, SG and TI of Analysed Blue Limestone

	Samples	LA	AIV	ACV	Load for TFV	SG	TI
Layered Limestone	SK L1	43.7 ± 2.2	37.4 ± 1.9	42.6 ± 3.2	35.5 ± 1.8	2.4	78.3
	SK L2	39.2 ± 1.8	43.5 ± 3.2	39.5 ± 2.0	33.5 ± 3.5	2.3	77.1
	SK L3	40.1 ± 2.0	44.2 ± 2.2	46.5 ± 2.8	36.1 ± 1.8	2.2	75.0
	SK L4	43.2 ± 2.2	42.6 ± 2.9	45.4 ± 2.3	35.2 ± 1.8	2.5	76.7
	SK L5	44.0 ± 2.9	55.8 ± 2.8	48.4 ± 2.6	43.6 ± 2.8	2.3	74.3
	SK L6	42.8 ± 2.1	51.4 ± 3.7	45.2 ± 2.3	38.5 ± 1.9	2.0	72.5
	SK L7	43.5 ± 2.2	49.6 ± 2.5	48.6 ± 2.4	41.6 ± 2.8	2.4	75.8
	SK L8	41.6 ± 3.1	53.2 ± 4.1	43.8 ± 2.2	41.8 ± 2.1	2.5	77.9
	SK L9	46.3 ± 2.3	55.2 ± 2.8	44.6 ± 2.7	42.8 ± 3.5	2.0	72.2
	SK L10	40.8 ± 4.2	61.5 ± 2.6	50.4 ± 2.5	39.1 ± 2.0	1.9	76.1
	SK L11	40.9 ± 2.0	53.7 ± 2.7	44.8 ± 2.8	37.2 ± 6.4	2.7	77.3
	SK L12	39.7 ± 1.9	60.4 ± 2.7	46.2 ± 2.3	35.8 ± 1.8	2.7	74.6
	SK L13	41.6 ± 2.1	42.9 ± 2.1	51.7 ± 3.1	31.9 ± 4.7	2.5	74.3
	SK L14	42.9 ± 5.1	50.1 ± 3.8	46.6 ± 2.3	36.8 ± 1.8	2.0	71.7
	SK L15	43.5 ± 2.2	49.2 ± 2.5	51.9 ± 2.6	40.2 ± 3.8	2.5	75.0
	AVG	**42.3 ± 2.6**	**50.0 ± 2.8**	**46.4 ± 2.5**	**38.0 ± 2.8**	**2.3**	**74.7**
Range of values for each of the test:		**39.2 to 43.7**	**37.4 to 61.5**	**39.5 to 51.9**	**33.5 to 43.6**	**1.9 to 2.7**	**-**
Massive Limestone	SK M1	34.5 ± 1.7	23.1 ± 1.2	28.6 ± 1.4	93.1 ± 4.7	2.3	90.9
	SK M2	35.1 ± 2.4	22.5 ± 2.5	30.1 ± 3.1	89.5 ± 4.5	2.6	92.7
	SK M3	33.5 ± 1.7	26.8 ± 1.3	29.5 ± 1.5	84.3 ± 5.5	2.3	91.2
	SK M4	36.4 ± 3.1	24.1 ± 3.6	27.5 ± 2.5	98.5 ± 4.9	2.4	91.7
	SK M5	37.2 ± 1.9	23.2 ± 1.2	28.4 ± 1.4	85.8 ± 5.3	2.2	89.7
	SK M6	35.7 ± 4.2	21.4 ± 4.5	28.0 ± 3.8	87.6 ± 4.4	2.3	91.2
	SK M7	36.5 ± 1.8	21.1 ± 1.1	28.5 ± 1.4	88.3 ± 4.4	2.6	92.8
	SK M8	31.6 ±3.6	25.2 ± 2.8	28.7 ± 2.1	85.6 ± 6.5	2.7	94.9
	SK M9	36.4 ± 1.8	23.8 ± 1.2	26.5 ± 1.3	89.9 ± 4.5	2.8	95.0
	SK M10	33.9 ±1.7	22.9 ± 3.1	24.8 ± 1.9	97.9 ± 4.9	2.6	95.1
	SK M11	33.5 ± 2.8	21.8 ± 1.1	30.2 ± 1.5	96.5 ± 5.2	2.5	92.3
	SK M12	33.9 ± 1.7	19.6 ± 2.5	29.1 ± 2.7	94.3 ± 4.7	2.5	93.0
	SK M13	35.2 ± 2.5	23.5 ± 1.2	26.5 ± 1.3	89.6 ± 5.7	2.5	93.1
	SK M14	32.8 ± 1.6	25.6 ± 2.8	28.8 ± 2.6	90.7 ± 4.5	2.3	91.9
	SK M15	35.1 ± 1.8	23.8 ± 1.7	27.5 ± 1.4	95.5 ± 6.5	2.6	93.7
	AVG	**34.8 ± 2.3**	**23.2 ± 2.1**	**28.2 ± 2.0**	**91.1 ± 5.1**	**2.5**	**92.6**
Range of values for each of the test:		**32.8 to 36.4**	**19.6 to 26.8**	**24.8 to 30.2**	**85.6 to 98.5**	**2.2 to 2.8**	**-**
International standards:		**19-30***	**< 30****	**< 35****	**> 50*****		

* LA values for limestone (Mohajerani et al., 2017)
** European Standards for Aggregates (Mitchel, 2015)
*** Specification for Highway Works, Clause 803 (HMSO, 1986)

4. Discussion

The two varieties of limestones selected in this present study showed a strong difference in their mechanical properties. It is important to note that lower values for LA, AIV and ACV are required in a standard pavement aggregate, while higher values are required in case of TFV. LAV is a standard method to determine the abrasion resistance of any aggregate (Kahraman et al., 2010; Mohajerani et al., 2017). In this present study, LA values were higher in the layered limestones than the other variety (nearly 1.2 times). This indicates that the layered limestones can break easily upon impact and degradation, which occur during handling, batching and lay-down operations in pavement construction (Meininger, 2004; Mohajerani et al., 2017).

The average values found in both layered and massive limestones were higher than the internationally recommended LA values (with the range value of 19-30%, Mohajerani et al., 2017). However, in the massive variety these values (with the average value of 34.8%) were closer to the indicated international range than that of the layered counterpart (with the average value of 42.3%). AIV represents the aggregate toughness to resist fragmentation (Mildard, 1993; Stalheim, 2014). Present study found that the aggregate impact values were more than 2 times higher in the layered limestone than the massive limestones. This indicates that massive variety of limestone is more suitable for pavement construction, while the layered limestone, with the AI values of 50%, may be of poor technical values and therefore, may be non-desirable for pavement construction (Mildard, 1993; Stalheim, 2014).

According to the European Standards, an AIV with less than 30% value is usually required for pavement aggregates (Mitchel, 2015). In present study, this was achieved only by the massive limestones. The aggregate crushing values correspond to the aggregate resistance to crushing under compression applied by gradual loading (Mildard, 1993; Stalheim, 2014). This work showed that the layered limestones had nearly two times higher AC values than the massive variety. This indicates that the massive limestone is more resistant to compression and thus, can be a higher quality pavement aggregate (Mildard, 1993; Stalheim, 2014).

Similar to AIV, the massive limestone samples had only satisfied the need of the European Standards ACV criteria (less than 35%; Mitchell, 2015). TFV test determines the load required to produce 10% fines from the aggregates (Kamal et al., 2006). In this study, it was observed that the layered limestones needed less than 40 kN load, which is lower than the typical USA and UK specifications (i.e., load should be more than 50 kN) (HMSO, 1986). However, TFV in the massive limestones were found within the permissible range specified in the USA and UK standards of 50-110 kN loads (HMSO, 1986).

Toughness index, which is a unique value, can be used as performance indicator for the aggregates (Kamal et al., 2006). According to this classification (see Table 1), aggregates with the TI values less than 90 can be considered as of poor quality and therefore, can be either avoided or to be used with proper caution. In this study, the layered limestones showed the TI values below 90. They would be inferred as of poor quality and should be used with proper preventive measure. However, it was found that these values in the massive limestones were fair in their quality and would be suitable for pavement construction purposes.

Because of the presence of soft mica rich layers, these variations observed in the selected aggregate samples are expected. These mica rich layers are sandwiched between calcite rich layers (see Figure 1).

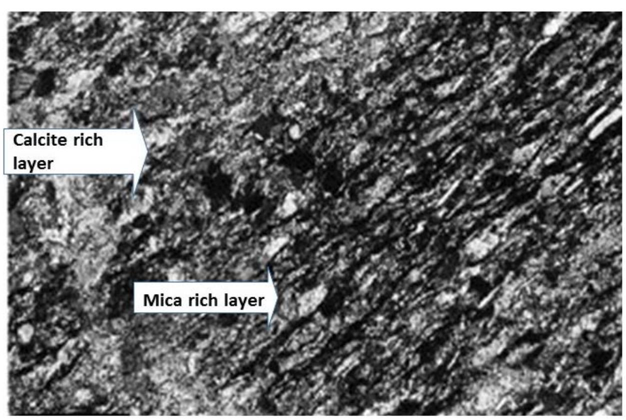

Figure 1. Photomicrograph of Layered Limestone

Presence of these layers indicates impurities in the compactness of the aggregates (Tuğrul and Zarif, 1999; Tandon and Gupta, 2013, Banerjee and Melville, 2015). These impurities are to be correlated with comparatively high porosity values of the layered limestone to its lower relative density. It is important to note that the thickness of the soft layers varies from the scale of meter to micron (see Figures 2 and 3).

5. Conclusion and Recommendations

Determination of mechanical properties, especially toughness and abrasion resistance of aggregates is very vital in the selection aggregates. Though this study is primitive, it can be very important and informative for Trinidad and Tobago, and for the region. The specific conclusions from this study are as follow:

1) The massive limestone was found to have half aggregate crushing and impact values than that found in the layered limestone.
2) The loads required for 10% fines were more than two times lower in the layered limestone than the massive verity.
3) The TI, which can represent a unified mechanical property to classify aggregates for pavement construction, also suggested layered limestone to be of poor quality.
4) The mechanical properties measured (except LA values) in both types of limestones indicated that the massive limestones met the internationally recognised standards required in desirable road and pavement aggregates. However, the layered limestones were unable to meet the respective international standards.

Detailed petrographic and micro-structural (fabric) analysis will be helpful to assess the control of these micro-fabric on these mechanical properties.

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