

Preliminary Investigation of Geotechnical Properties of the Rock Aggregates Commonly Used for Civil Engineering Construction in Trinidad and Tobago

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Abstract: To assess the geotechnical quality of rock aggregates used for construction purposes, two (2) rock types namely Blue Limestone (both massive and layered) and quartzite have been collected from the Northern Range of Trinidad. Blue Limestone is heavily used in the Trinidad and Tobago construction industry as aggregates for ready mix concrete, asphalt design mixes and for the production of steel among other uses. Rocks such as quartzite rather play a smaller role (if any) within the same industry. These rock samples were tested to evaluate the correlations between some important petrographic properties (e.g. rock foliation plane, mineral cleavage plane, rock texture and micro-structure) and the measured geotechnical findings (e.g. uniaxial compressive strength and Schmidt Hammer test values). Then these comparative studies have been examined by rock porosity and density parameters. This study confirms a good control of these geological parameters on the strength of the rock aggregates. This study also suggests quartzite to be more compatible than limestone for these types of construction purposes. Limestone may be disadvantage as it may easily react with acidic water. If limestone is the only choice for these purposes, then layered variety of limestone may be avoided because of its anomalous mechanical properties, which is resulted by alternate layers of different mineral assemblages.

Keywords: Rock aggregates, geotechnical properties, geological significances

1. Introduction

Rocks and rock aggregates are one of the major sources of construction materials in the world. Geotechnical behaviours of these materials, which control the life of any civil engineering construction, are mainly governed by some important geological parameters whenever these materials are being exposed to the environment or external load is applied on them. Therefore, correlation of their geological and expected geotechnical parameters is very important before starting any construction project. Numerous studies have been conducted in this topic by many researchers all over the world (Bieniawski, 1974; Behrestaghi et al., 1996; Tuğrul and Zarif, 1998; Agustawijaya, 2007). These geological properties are said to be influenced mainly by the mineral constituents and also by the textural characteristic (e.g., grain size, grain shape, grain orientation, and arrangement of grains) of the material (Sharma et al., 2011). Other physical and mechanical factors that may be considered include but are not limited to porosity, density and compressive strength, which are consequently influenced by mineral and textural properties of the material (Behrestaghi, et al., 1996; Tuğrul and Zarif, 1998; Dimantis et al., 2009; Tandon and Gupta, 2013). This type of study can

accomplish the high demand of information required in the construction industry before designing the project.

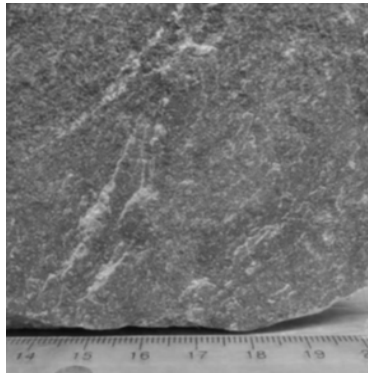
Because of negligible amount of available data in Trinidad and Tobago (T&T), this study was designed for the benefit of Trinidad and Tobago construction industry. With the aim to provide preliminary information by correlating geotechnical properties and petrographic properties of rocks and rock aggregates in T&T, simple, inexpensive and easy-to-use methods were considered in the present study, which could eventually lead to deeper studies using improved methods. For this purpose, two major rock types namely blue limestone and quartzite, which are profusely used in Trinidad and Tobago construction industry, were considered. The research approaches adopted were (a) petrographic study of these selected rocks and (b) their geo-mechanical properties (which include uniaxial compressive strength, point load strength index, porosity, dry density, and Schmidt hammer rebound values). Therefore, the objectives of the present study are (i) to examine these rocks by their petrographic properties and geotechnical properties, (ii) to correlate and describe the relationship between their geological and geotechnical properties and (iii) to provide information that can help the local construction industry to select the best available materials.

2. Methodology

2.1. Sample collection

This study was undertaken in two major rock types namely quartzite and metamorphosed limestone, which were collected from the Northern Range of Trinidad. These limestone samples are of two varieties – massive limestone and layered limestone (see Figure 1). A total of eight (8) massive limestone, nine (9) layered

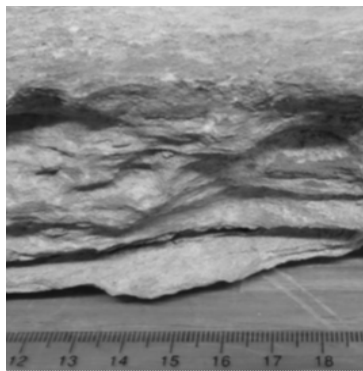
limestone samples were collected from a quarry (currently in operation) in La Pastora district along Cutucupano road (i.e., $10^{\circ}43'15.15''\text{N}$ and $61^{\circ}28'41.40''\text{W}$) and ten (10) quartzite samples were collected from a fresh rock exposure along the Long Coast Road in Arima-Blanchisseuse area (i.e., $10^{\circ}47'47.55''\text{N}$ and $61^{\circ}19'05.60''\text{W}$).



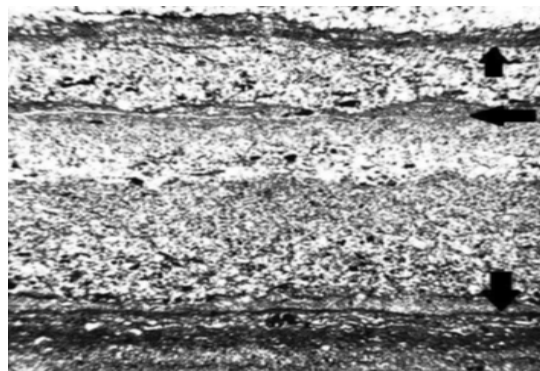
Massive limestone (scale in cm)



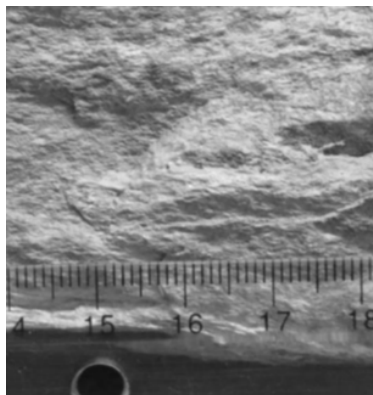
Photomicrograph of massive limestone (50x magnification)



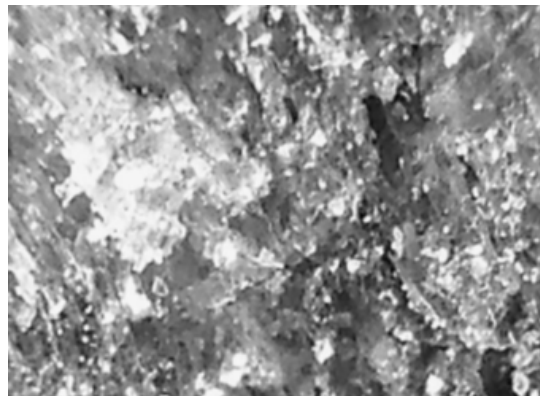
Layered limestone (scale in cm)



Photomicrograph of layered limestone (20x magnification)



Quartzite (scale in cm)



Photomicrograph of quartzite (50x magnification)

Note: Black arrows in layered limestone photomicrograph show foliation plane.

Figure 1. Petrographic Views of Selected Rocks

Fresh rock samples were taken back to the laboratory for further examination and detailed petrographic study after in situ measurements were carried out in the field. All rock samples were physically examined by their grain size, foliation planes, micro-features (such as fractures and mineral cleavage planes) and hardness. A fabricated magnifier was used to closely examine these petrographic properties.

2.2 Measurement of Porosity and Mass Dry Density

In this study, effective porosity (i.e., a measure of inter-connectedness of pores with reference to water permeability (Gibb et al., 1984)) and mass density (kg/m^3) were measured for all the rock samples under investigation. Effective porosity was determined by immersing rock pieces ($\sim 450\text{g}$) into water for 24 hours and drying to a constant mass. This water displacement method was adopted to measure the bulk volume of saturated rock pieces. Porosities for the samples are shown in Table 1. The values were obtained by averaging three vigilant test results from individual sample in order to minimise probable experimental errors particularly in volume measurement (ISRM, 1981).

Effective porosity is taken into consideration as opposed to the total porosity which is simply the ratio of the total void volume to the total bulk volume. In each case of effective porosity measurement, water absorbed by the rock was deducted.

2.3 Measurement of Geotechnical Properties

2.3.1 Schmidt Hammer Rebound Test

The Schmidt hammer is an apparatus to measure the hardness of concrete by measuring the correlation of hammer-rebound principle and strength of the material. All tests performed with the hammer were done on both parallel and perpendicular direction to the foliation plane (Malhotra and Carino, 2004; Sharma et al., 2011). At least 3 readings were taken from each rock specimen, and up to 12 readings, depending on the similarity of numbers recorded. The means of the five values were used for the analysis and a correction factor of 1.4 was also applied.

2.3.2 Point Load Strength Test

Point load test is a well-accepted rock mechanics testing procedure to calculate the rock strength index, which can be used to estimate other rock strength parameters. The

Table 1. Porosities for the Samples

Sample	Rock Type	Average Schmidt Hardness	Uniaxial Compressive Strength(UCS) MN/m ²		Dry Density (Kg/m ³)	Porosity (%)
KL-1	Massive Limestone	31.7 \pm 8.7	97.9 \pm 2.4		2244.2 \pm 120.5	BDL
KL-2			102.6 \pm 2.8		2286.0 \pm 135.6	0.27
KL-3			95.7 \pm 4.5		2304.5 \pm 140.2	0.39
KL-4			102.77 \pm 5.2		2549.3 \pm 142.3	BDL
KL-5			100.8 \pm 6.7		2524.7 \pm 122.5	0.16
KL-6			95.2 \pm 2.8		2364.4 \pm 152.3	0.32
KL-7			93.4 \pm 9.5		2482.1 \pm 146.3	BDL
KL-8			119.8 \pm 8.4		2366.7 \pm 125.8	0.18
Average			101.0 \pm 8.4		2390.2 \pm 115.0	0.16
			Parallel to foliation plane	Perpendicular to foliation plane		
KL-9	Layered Limestone	32.8 \pm 6.5	89.7 \pm 3.2	136.4 \pm 10.6	2413.0 \pm 150.6	1.94
KL-10			96.9 \pm 3.8	155.4 \pm 10.8	2132.0 \pm 148.2	2.11
KL-11			95.0 \pm 4.2	129.3 \pm 9.4	2305.4 \pm 174.2	1.71
KL-12			76.5 \pm 5.8	155.5 \pm 12.3	2536.2 \pm 165.3	3.27
KL-13			92.7 \pm 6.2	122.3 \pm 6.5	1948.1 \pm 156.3	1.59
KL-14			79.3 \pm 4.9	175.5 \pm 18.5	1883.1 \pm 125.3	3.31
KL-15			97.7 \pm 3.8	107.3 \pm 11.2	2736.8 \pm 142.8	2.21
KL-16			96.6 \pm 4.4	109.8 \pm 6.8	2701.1 \pm 155.2	1.83
KL-17			115.3 \pm 5.7	124.8 \pm 9.4	2539.5 \pm 147.2	2.15
Average			93.3 \pm 11.3	135.1 \pm 22.9	2355.0 \pm 311.5	2.23
KL-18	Quartzite	66.1 \pm 11.2	195.0 \pm 35.3		2692.3 \pm 221.3	0.98
KL-19			202.0 \pm 28.9		3080.5 \pm 185.3	3.62
KL-20			237.6 \pm 31.5		3031.0 \pm 153.8	2.75
KL-21			245.5 \pm 41.5		2889.3 \pm 115.9	1.81
KL-22			233.0 \pm 39.6		2314.3 \pm 214.3	3.45
KL-23			213.5 \pm 43.0		2971.4 \pm 152.3	1.76
KL-24			222.5 \pm 56.3		2539.5 \pm 185.4	2.60
KL-25			197.9 \pm 25.3		2413.7 \pm 124.3	1.96
KL-26			233.7 \pm 29.4		2637.8 \pm 214.2	2.66
KL-27			184.4 \pm 35.2		2641.0 \pm 184.7	1.94
Average			216.5 \pm 20.9		2721.1 \pm 263.2	2.35

*BDL – As per normal water displacement procedure.

apparatus for this test consists of a rigid frame, two point load platens, a hydraulically activated ram with pressure gauge and a device for measuring the distance between the loading points (Rusnak and Mark, 1999). This cost-effective test is highly favoured not only for its efficiency to analyse fragile materials but also the result from this test shows less scatter than other uniaxial compressive strength, which makes the measurement of strength anisotropy simple.

The point load test involves compressing of a rock sample between conical steel platens until failure occurs. The procedure used was adopted from the ASTM D5731-08 standard Uniaxial compressive strengths were then determined from the compressive strength of rock specimens measured using point load test.

3. Results and Discussion

3.1 Porosity and Dry Density Test

It is observed from Table 1 that both types of limestone specimens had similar dry densities which fall within the range of densities expected in these types of rocks (edumine.com). Quartzite specimen recorded the highest dry density value, while the mica schist specimen had the lowest dry density value. These values may be influenced by the porosity values that were observed during this study. Massive limestone recorded very low level porosity ($\sim 0.16\%$) while its layered counterpart recorded a 3.66% porosity value. The quartzite recorded a small porosity value of 1.47% .

3.2. Geotechnical Investigation

Table 1 shows the results of Schmidt hammer test on porosities for the samples. It was found that massive limestone had slightly higher rebound values than layered one, while quartzite produced the highest rebound value which coincides with its high hardness rating of more than 6.5 in Mohs Hardness scale.

The uniaxial compressive strength (UCS) of the selected rock samples is also given (see Table 1). Here quartzite again showed the highest strength with an average value of $101.83 \pm 8.36 \text{ NM/m}^2$. Layered limestone exhibited good anisotropy in UCS values, as the results were low (i.e., average value of $93.30 \pm 11.32 \text{ NM/m}^2$) when test was conducted parallel to the foliation plane, but the results were high in perpendicular direction (i.e., average value of $135.14 \pm 22.86 \text{ NM/m}^2$). Massive variety of limestone produced strength values higher than the strength values in layered limestone along foliation parallel direction but these values were less than the foliation perpendicular strength values in layered limestone (i.e., average value in massive limestone $216.50 \pm 20.93 \text{ NM/m}^2$).

3.3. Geological Contribution to Geotechnical Variations

Study of the petrography and physical properties of the material are subsidiary part of any geotechnical

investigation (Irfan, 1996; Tuğrul and Zarif 1998; Sharma et al., 2011)

Rock groups selected in this study indicated significant difference in their geotechnical properties whether these are compared in the same group or in separate groups. Both massive and layered limestone samples produced half of the Schmidt hardness showed by quartzite samples. UCS results were also 1.5 to 2 times higher in quartzite than both types of limestones. These contrasting features can be explained with the help of their pretograpical signatures, which are identified in this study. Quartzite is mainly composed of quartz minerals and it has granoblastic texture (see Figure 1), which makes in one of the most compact rock in the world. In quartzite, early formed quartz grains are generally recrystallised to very fine and equant sizes due to metamorphic process, and during this process partial melting of the mineral also plays an important role by arranging these crystals in an inter-locking framework (Török and Vásárhelyi, 2010; Zhang et al., 2011; Tandon and Gupta, 2013).

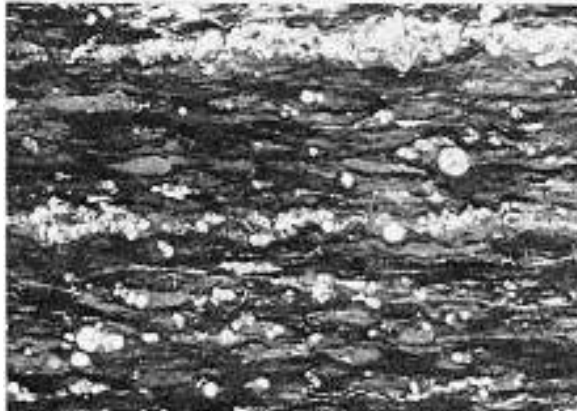
All these rearrangement processes help quartzite to reduce its void spaces and can be reconciled with its compactness to resist high amount of external load. The only possible way that can develop porosity in quartzites is impurities created by small portion of mica and internal fractures.

On the other hand, porosity of limestone was also low especially in massive one and it was nearly similar to quartzite. Low porosity can be attributed to the same granoblastic texture in limestone, which mainly composed of partially recrystallised and equant calcite minerals. Moreover, difference in melting point of calcite (i.e., below 850°C) and quartz (i.e., above 1600°C) also has a good control on the crystal rearrangement processes during metamorphism of the pre-existing rocks (MLPt, Digitalfire Reference Database).

In similar type of deformation and metamorphism, calcite mineral behaves ductile while quartz shows brittle nature (Brodie and Rutter, 2000). This ductility or plasticity of calcite helps to reduce more porosity in limestone. Layered limestone acquires marginally higher porosity due to the presence of foliation plane, which is produced by impurities in the form of mica and in some cases elongated calcite grains. Figure 2 shows the foliation plane resulted by arrangement of mica rich layers of limestone.

Two main parameters that may decrease UCS values in limestone are hardness and internal structure (rather crystal habit) of calcite crystal. In Mohs' Hardness scale calcite shows the hardness of 3 while quartz has the hardness of 7. Limestone is mainly composed of calcite, therefore hardness of calcite crystals help significantly to reduce the UCS values in limestone. Calcite has one more important property due to its crystallographic feature called mineral cleavage plane.

It is defined by the tendency of a mineral to break along flat planar surfaces as determined by the structure of its crystal lattice, which are caused by the alignment of weaker bonds between atoms in the crystal lattice. Calcite has three (3) sets of cleavage planes that again help it to break at comparatively low external pressure.



Note: White layers are the calcite rich layers while the elongated grains (mainly mica) form foliation plane. Some calcite grains (white in colour) found to be elongated in their shape (magnification 50x).

Figure 2. Photomicrograph of Layered Limestone

More interestingly, in layered limestone, UCS values were nearly two-times higher along the foliation perpendicular direction than the UCS values along foliation parallel direction. This variation may be acceptable due to the presence of then mica rich calcite layers, which are sandwiched between calcite rich layers (see Figure 2). These layers produce impurities in the compactness of the limestone by arranging mica-flakes in a same direction developing foliation planes in these rocks. Mica is one of the soft mineral (i.e., hardness is ~2.5 in Mohs' Scale of hardness and has 1 set cleavage plane), hence, these thin layers with different mechanical properties produce anomaly in the overall rock strength.

4. Conclusion and Recommendations

Determination and correlation of important geological and geotechnical properties of rock and rock aggregates are very crucial part of rock mechanics. Though present study was very primitive, but it can be very important and informative in the context of Trinidad and Tobago construction industry.

This study affirms certain important geological parameters (such as rock foliation plane, mineral cleavage plane, rock texture and micro-structure) have good impact on the strength of the rock or rock aggregates. Among the two analysed rocks, quartzite was found to be more efficient for civil construction. Apart from the geotechnical imperfections, limestone may be avoided for its readiness to react with acidic water.

Moreover, this study observed heterogeneity in the geo-mechanical behaviour of layered limestone. It is therefore recommended to avoid layered limestone particularly in the field of compression. Detailed petrographic and micro-structural (fabric) analysis is required to assess more geo-mechanical properties (such as tension and abrasion along with compression) of the rock aggregates used in T&T.

References:

- Agustawijaya, D.S. (2007), "The uniaxial compressive strength of soft rock", *Civil Engineering Dimension*, Vol. 9, pp. 9-14.
- ASTM (2008), *Standard D5731-08: Standard Test Method for Determination of the Point Load Strength Index of Rock and Application to Rock Strength Classifications*, American Society for Testing and Materials, Pennsylvania, USA
- Behrestagi, M.H.N., Rao, K.S., and Ramamurthy, T. (1996), "Engineering geological and geotechnical responses of schistose rock from dam project areas in India", *Engineering Geology*, Vol. 44, pp. 183-201.
- Bieniawski, Z.T. (1974), "Estimating the strength of rock materials", *Journal of the South African Institute of Mining and Metallurgy*, Vol. 15, pp.312- 320.
- Brodie, K. H., and Rutter, E.H. (2000), "Deformation mechanisms and rheology: why marble is weaker than quartzite", *Journal of the Geological Society*, Vol. 157, pp. 1093-1096.
- Dimantis, K., Gartzos, E., and Migiros, G. (2009), "Study on Uniaxial Compressive Strength, Point Load Index, Dynamic and Physical properties of Serpentinities from Central Greece: test Results and Empirical Relations", *Engineering Geology*, Vol. 108, pp.199-207.
- Gibb, J.P., Barcelona, M.J., Ritchey, J.D., and LeFaivre, M.H. (1984), "Effective porosity of geologic materials", *EPA Project No. CR 811030-01-0 First Annual Report*, Illinois State Water Survey.
- Irfan, T.Y. (1996), "Mineralogy, fabric properties and classification of weathered granites in Hong Kong", *Quaternary Journal of Engineering Geology*, Vol. 29, pp.5-35.
- ISRM (1981), *Rock Characterisation, Testing and Monitoring. ISRM Suggested Methods*, International Society for Rock Mechanics/Pergamon Press, Oxford.
- Malhotra, V.M., and Carino N.J. (2004), *Handbook on Nondestructive Testing of Concrete*, Second Edition, CRC Press LLC, Florida.
- Rusnak, J.A., and Mark, C. (1999), "Using the point load test to determine the uniaxial compressive strength of coal measure rock", *Proceedings of the 19th International Conference on Ground Control in Mining*, pp. 362-371.
- Sharma, P.K., Khandelwal, M., and Singh, T.N. (2011), "A correlation between Schmidt Hammer Rebound Numbers with Impact Strength Index, Slake Durability Index and P-wave Velocity", *International Journal of Earth Sciences*, Vol.100, pp. 189-195.
- Tandon, R.S., and Gupta V. (2013), "The control of mineral constituents and textural characteristics on the petrophysical and mechanical (PM) properties of different rocks of the Himalaya", *Engineering Geology*, Vol. 153, pp. 125-143.
- Tuğrul, A., and Zarif, I.H. (1999), "Correlation of mineralogical and textural characteristics with engineering properties of selected granitic rocks from Turkey", *Engineering Geology*, Vol. 51, pp.303-317.
- Török, Á., and Vásárhelyi, B. (2010), "The influence of fabric and water content on selected rock mechanical parameters of travertine, examples from Hungary", *Engineering Geology*, Vol. 115, pp. 237 – 245.
- Zhang, W., Wang, Si-Jing, and Han, Geng-You (2011),

“Engineering properties of quartz mica schist”, *Engineering Geology*, Vol. 121, pp. 135-149.

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