PRELIMINARY GEOMECHANICAL STUDY OF QUARTZITE FROM KAOLIN SMALL MINES AT SÍTIO POLAR, JUNCO DO SERIDÓ, STATE OF PARAÍBA, BRAZIL

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ABSTRACT

Kaolin is one of the main rocks exploited by small mining companies in the region of the city of Junco do Seridó, state of Paraíba. It occurs in form of pegmatite seams filling fractures on Quartzite following Patos lineation. The extraction is done from surface using excavators and manual picks creating sub vertical openings. In order to perform a preliminary geomechanical study on Quartzite, host rock of Kaolin, in the location of Sítio Polar, city of Junco do Seridó, we used rock mass classification systems Rock Mass Rating (RMR) and Rock Tunnelling Quality Index (Q) combined to a correlation of Point Load Strength Test Index to Uniaxial Compressive Strength. Results from rock mass classification and point load strength index agree with rock mass characteristics observed on field, indicating a stable slope for open pit operations and the need of support systems for underground excavations. The simplicity of structures makes easier to predict and analyse stability and behaviour of rock mass, in this case, requiring less local knowledge to achieve reasonable conclusions. Point Load Strength Index correlated to Uniaxial Compressive Strength (UCS) showed accurate results confirming the efficiency and convenience of using Point Load Test against UCS tests. This study aims the improvement of the local economy and social development of miner municipalities in the region of the Borborema Pegmatitic Province, providing a first approach to rock mass characteristics that can utterly contribute to more robust mining design projects.

KEYWORDS
Quartzite, Kaolin, Rock Mechanics, Geomechanics, Mining, Rock Mass Classification, Point Load Index Test, UCS, Paraíba.

INTRODUCTION

Junco do Seridó is known in the state of Paraíba, Brazil, as a miner potential municipality. The main rock and mineral substances extracted in the region are Kaolin, Quartzite, Quartz, Feldspar, Mica, Tantalite and Tourmaline. Many of these extractions are small sized operations in which there is few technical support mainly due to the small output and low selling prices. However, some of the mines are operational for many years and have reached a technical level that satisfies buyer’s requirement for the final product. Still, improvements on safety, mineral prospection, mining planning, mineral processing and rock mass stability studies can make the production safer, add value to the final product and improve the performance of mining operations.

These improvements are considered a challenge for The Federal University of Campina Grande (UFCG) which has been developing studies along with the Centre of Mineral Technology (CETEM) aiming the improvement of the local economy and social development of miner municipalities in the region of the Borborema Pegmatitic Province.

This paper focuses on the characterization and classification of the enclosing Quartzite of Kaolin surface extraction at Sítio Polar, in the municipality Junco do Seridó, by using the rock mass classification methods Rock Tunnelling Quality Index, Rock Mass Rating and correlations of Point Load Index tests to Uniaxial Compressive Strength tests.

The study provides a first approach to rock mass characteristics that can utterly contribute to robust mining design projects, which aim to present alternative Kaolin extraction methods, and database for feasibility studies.
Borborema Pegmatitic Province

Located between the states of Paraíba and Rio Grande do Norte, this province was originally denominated Borborema Pegmatitic Province by Scorza (1944) to designate the main area of occurrence of mineralized pegmatites in the northeast of Brazil. Geological exploration in the region started during World War II because of the necessity to provide industrial minerals and metals for arms industry. This province is worldwide known as one of the most important sources of Tantalum, Niobium, Beryllium, Kaolin and Gems, in which Paraíba Tourmaline represents the main valuable gem explored.

Local Geology

The Borborema Pegmatitic Province (PPB) occurs in the context of the Seridó range of Rio Grande do Norte Domain (Borborema Province), including occurrence of pegmatites of varied mineralogy hosted in quartzite from formation Equador, Seridó Group. The survey area is dominated by Quartzite, Kaolin pegmatites and residual soil, which outcrop in the area along the Serra da Borborema in an elongated topographic elevation in the direction N-NE. The Quartzite in the region are light coloured, fine grained composed by quartz, muscovite, feldspar and opaque accessories.

From satellite imagery analysis and findings in the field, we observed that rocks of the Seridó range and the associated pegmatites have an E-W trend in the southern portion, while in the central portion presents a NNE-SSW trend, which systematically bend to N-S in the northern portion. Brittle structures occur secondarily affecting mainly the pegmatite. This tectonic is represented by faults and fractures striking towards E-W, NW-SE and N-S. Veins mineralized in Feldspar or Kaolin may be associated with such fractures. In the area of study, the Sítio Polar, for example, veins of Kaolin Pegmatite fill E-W fractures.

The structural behaviour of pegmatite strongly reflects the influence of Patos Lineation and local shear zones striking NNE-SSW. Regional folds with various styles, occur with E-W direction fold line associated with regional transcurrent E-W, especially Patos Lineation. The Map 1 summarizes structural geology and topography of the region.
Rock Mass Classification

In early stages of a mining project, when there is little or no database available, using rock mass classification methods contribute on the first approach for determining general rock characteristics. The information gathered by classification methods are relevant to give an overview of the rock mass strength, deformation, possible failure mechanisms and support requirements. As projects progresses and more information is acquired, classification can be updated and used in conjunction with new available data, making it more accurate.

The study area presents kaolin mines operating for decades. However, rock mass classification has not been performed, being mines stability assessed by local experienced miners. According to Hartman (2002), a rock mass classification needs ‘local knowledge’ from the engineer or geologist, which means a familiarity developed over many years working on a particular rock mass and therefore being able to interpret and collect data reliably. The simpler the structures presented in a rock mass, the less complex the classifications are, thus ‘local knowledge’ become easier to acquire. For example, a homogeneous rock mass which has well defined structures takes less field work and experience to classify and understand the responses to excavations than a massive jointed, heterogeneous rock mass. In this way, it is possible combine the local knowledge of the miners with the information retrieved from classification methods and then improve mining stability.

The rock mass study presented in this paper consists of a single lithology, the quartzite. It occurs in sub-horizontal layers with east-west fractures, following Patos lineation, intruded by Kaolin Pegmatite. The exploitation of the intruded pegmatite, a very common practice in the region, exposes faces of quartzite and the simplicity of the main structures. When used in conjunction with more elaborated design procedures, rock mass classification can be an important tool to ensure a safe operation and to avoid production losses. Therefore, the study here provided has one of its objectives to serve as a contribution for future robust stability and feasibility studies.
METHODOLOGY

In this study, we defined three different openings for taking measurements and samples. The data acquired is composed by: Rock Quality Designation (RQD), traverse orientation, rock type, joint dip and dip direction, structure type, joint spacing, roughness, JRC roughness, planarity, joint filling, aperture, persistence, visible ends and water condition. Map 2 represents the openings of study, topography and mining concessions.

Map 2 – Area of study

The data acquired in the field is then translated to technical language for evaluating rock mass strength. The application of this method brings Quartzite rock mass particularities to a technical language worldwide spread for rock mass classification which will facilitate further studies in the near future.
Barton et al. (1974) proposed an index for determining the necessity of tunnelling support according to rock mass characteristics, the Rock Tunnelling Quality Index, also known as Q-Barton. The numeric value of the index varies in logarithm scale from 0.001 to 1000 and is defined by equation 1:

\[
Q = \frac{RQD}{J_a} * \frac{J}{J_a} * \frac{J_w}{SRF}
\]  

(1)
Where RQD is Rock Quality Designation, \( J_n \), the joint set number, \( J_r \), the roughness number, \( J_a \), the alteration number, \( J_w \), the water reduction factor and SRF the stress reduction factor. In summary, \( Q \) is a measure of block size (RQD/\( J_n \)), inter-block shear strength (\( J_r/J_a \)) and active stress (\( J_w/\text{SRF} \)). According to Hartman (2002), this method is of easy application, simple in measuring critical factors to stability such as block size, inter-block shear strength and active stress, and gives a simple relation to decide whether support systems are needed or not.

**Rock Mass Rating**

Developed by Bieniawsky (1976), the Geomechanics Classification or the Rock Mass Rating (RMR) considers six parameters to classify a rock mass: Uniaxial compressive strength of rock material, RQD, spacing of discontinuities, condition of discontinuities, ground water conditions, and orientation of discontinuities. Each parameters score is sum and result in a RMR value that varies from 0 to 100. The system is applied by dividing rock mass in structural domains, which are defined by changes in rock type, faults and other major structural features. Significant changes in spacing and characteristics of discontinuities may also divide rock mass in smaller domains.

**Point Load Strength test (PLT)**

According to Hoek (1977), the Unconfined Compressive strength is undoubtedly the geotechnical property that is most often quoted in rock engineering practice. It is widely understood as a rough index which gives a first approximation of the range of issues that are likely to be encountered in a variety of engineering problems including roof support, pillar design, and excavation technique. However, performing a Uniaxial Compressive Strength test is often expensive and difficult because of sample preparation requirements such perfectly parallel endings and specific proportions.

In this context the Point load strength test (PLT) has been widely accepted as an efficient empirical tool for indirect estimation of the UCS through the calculation of a rock strength index (\( I_{50} \)). It is a simple, easy handed experiment which can be carried out quickly in the field and with relatively very low cost and easy sample preparation requirements.

In order to standardize the results obtained by point load strength tests, the International Society of rock mechanics (ISRM) established in the ASTM D 5731 – 05, a basic procedure to acquire the data and calculate the Point Load Strength Index (\( I_{50} \)). According to it, the test can be performed in core samples (with the load platens parallel or perpendicular to the diameter – Axial or diametral tests respectively) or using block or irregular lump samples. In this study, we used block samples in the calculation of \( I_{50} \). The standard calculation for block and irregular lump samples is provided as:

\[
I_s = \frac{P}{D_s^2} \tag{2}
\]

Where \( I_s \) is the uncorrected point load strength index in MPa, \( P \) the Failure load in Newtons. \( D_s^2 \) is defined by equation 3:

\[
D_s^2 = \left( \frac{4 \times W \times D}{\pi} \right) \tag{3}
\]

Where \( W = \text{Width and D = Height in mm.} \)

As the standard sample for this test is defined as diametral cylinders with approximately \( D \) equal to 50 mm and width equivalent to 0.3 \( D \) to 1.0 \( D \) for axial tests and greater than 1 \( D \) for diametral, the uncorrected point load strength index is calculated when samples have diameters different than 50 mm or in case of block and irregular lump tests. In order to provide an approximation to the standard core diameter a correction factor is applied according to the equation 4.
\[ I_{50} = F \times I_e \]  

(4)

Where \( I_{50} \) is the standard Point load strength index and \( F \) can be obtained as shown by the equation 5:

\[ F = \left( \frac{D^2 e}{50} \right)^{0.5} \]  

(5)

The experimental study was performed using the ROCTEST TELEMAC Point Load Tester PIL -7, shown in figure 3.

Figure 3 – ROCTEST TELEMAC and cut samples

RESULTS AND DISCUSSION

The structures observed on the field are predominantly horizontal, therefore RQD in this direction retrieves 100% score, while a vertical measurement depends on joint spacing which is mostly constant and varies abruptly in altered packages. RQD mean score is 85.

In general, the traverses are composed by quartzite sub-horizontal layers of variable width (0.5m to 1m). The face of the traverses represents a sub-vertical fracture striking towards E-W filled by Kaolin Pegmatite. The joints have aperture, length, filling conditions, spacing and rock strength well defined and constant, with some small altered portions. Such portions, and its structures, are not considered as different sets of joints considering that they have the same orientation, despite the discrepancy observed on joint spacing and rock strength. In this occasion, altered packages are not representative for the general classification of the rock mass, being the result of alteration processes that seldom occur in the surface of small portions of the rock mass.
We considered then four set of joints for the rock mass: Quartzite layers, sub-horizontal with dip direction varying due to surface undulation (green); two sub-vertical joints with azimuths of 230 and 330 (yellow and blue); and a 10 azimuth joint dipping 48 degrees to east (red). Figure 5 shows the set of joints represented on a stereogram.

As many structures are sub-horizontal, a frequency diagram of strike or dip direction would not be meaningful since they would vary abruptly according to quartzite layers undulation. Therefore, a dip rosette diagram is presented in figure 6.
It is important to notice that the combination of yellow and blue joint sets on figure 5 indicates the possibility of a wedge failure occur, which is confirmed by wedges already failed towards north observed in the field. In joint contacts we observed thick layers of kaolin. The spacing of discontinuities varies from 0.5 m to 1.0 m with undulated, slightly rough and dry surfaces.

Rock Tunneling Quality Index Results

Given all the considerations above about rock mass characteristics, the Rock Tunnelling Index Q scored 1.7 class D, poor rock. Considering underground excavations height of 4 meters and an Excavation Support Ratio (ESR) of 1.6 for permanent mining openings, the red square in the figure 7 represents the Q index and support requirements for the rock mass studied.
This rock support diagram suggests fibre reinforced shotcrete and bolts with five to nine centimeters of diameter spaced 1.3 meters.

**Point Load Strength Test results**

The interpretation of Point Load Index Strength and its most precise correlation with the unconfined compressive strength (UCS) has been issue of extensive debate amongst many authors. Bieniawski (1975) tested a range of different lithology and came up with the relationship presented in the equation 6.

\[
UCS = 23 \times I_{50}
\]  

(6)

However, as there is a wide range of rock type occurring naturally, from extremely weathered and loose to stiffer and compact, there is also a huge variety in the relationship expressed by equation 6 which can change from one lithology to another. In order to address such variability and sharpen Bieniawski approximation, many studies have been conducted for samples from the same rock type. Singh and Singh (1993) conducted a study to identify the correlation between UCS and PLT of Quartzite rocks, achieving similar results to those expressed by Bieniawski (1975). Equation 7 shows Singh and Singh (1993) expression.

\[
UCS = 23.27 \times I_{50}
\]  

(7)

There are some samples which are highly weathered retrieving very low \(I_{50}\) values. But they appear to happen only in the contact zone between Kaolin and Quartzite, therefore represent only a small portion of the rock mass.

The following table presents results of PLT test after correction using Sing and Sing equation. Samples tested are from middle and top of openings, thus called as being from intermediate zone and top zone.

<table>
<thead>
<tr>
<th>Table 1 – Intermediate zone UCS</th>
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</thead>
<tbody>
<tr>
<td>Intermediate Zone</td>
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<tr>
<td>Average</td>
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</tbody>
</table>
Table 2 – Top zone UCS

<table>
<thead>
<tr>
<th>Top Zone</th>
<th>$I_1$ (MN/m²)</th>
<th>$I_{50}$</th>
<th>UCS (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>0.04</td>
<td>0.30</td>
<td>6.95</td>
</tr>
</tbody>
</table>

**Rock Mass Rating Results**

Given an average UCS of 8 MPa, RQD 85%, 0.6 m average joint spacing, a slightly rough and weathered surface with an average aperture of $< 1$ mm, considering that rock mass is dry and joints orientation unfavourable for tunnels, result in 57 RMR score which represents a moderate rock quality class III.

**CONCLUSIONS**

Patos Lineation and local shear zones striking NNE-SSW strongly influences structural behaviour of the pegmatite. Regional folds with various styles, occur with E-W direction hinge line associated with regional transcurrent E-W. This tectonic is represented by faults and fractures striking towards E-W, NW-SE and N-S. The veins mineralized in Feldspar or Kaolin are associated with such fractures in the area of study, the Sítio Polar, where the veins of Kaolin Pegmatite fill E-W fractures.

The rock mass studied in this paper consists of a single lithology, Quartzite. The exploitation of intruded pegmatite, regionally a very common practice, exposes faces of quartzite and the simplicity of main structures. A combination of joint sets indicates the occurrence of wedge failure, which is confirmed by two wedges already failed towards north observed in the field.

All results from rock mass classification and point load strength index converge to rock mass characteristics. We expected results indicating a stable slope for open pit operations and the need of support systems for underground excavations, expectations all confirmed by test results. Again, considering simpler structures makes easier to predict and analyse stability and behaviour of rock mass, requiring less local knowledge to achieve reasonable conclusions.

This study aims the improvement of the local economy and social development of miner municipalities in the region of the Borborema Pegmatitic Province providing a first approach to rock mass characteristics that can utterly contribute to more robust mining design projects, which aim to present alternative Kaolin extraction methods, and database for feasibility studies.

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