Weakening of Some Physical Properties of Fresh Gneissic Rocks Subjected to Artificial Weathering

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Abstract: There is an abundance of gneissic rock formations found in Sri Lanka. Gneiss is a banded rock with fairly continuous segregation of different minerals. Foundations of most of the large-scale civil engineering structures like dams, bridges and high-rise buildings are extended up to or into the fresh gneissic rocks. As Sri Lanka has a tropical climate, investigation of behaviour of gneissic rocks under tropical conditions would facilitate predictions on the durability of rock masses. This study analyses the weakening of strength and durability characteristics of fresh gneissic rocks subjected to artificial weathering. Gneissic rock samples from a 100m deep exploratory rock core of diameter 54mm were used for this research. One hundred and thirty rock samples selected from biotite gneiss and quartzo-feldspathic gneiss strata are subjected to Ultrasonic Pulse Velocity test, Unconfined Compressive Strength test and Slake Durability test. Pairs of samples were tested so that one sample was tested under the room temperature whereas the other sample was artificially weathered and tested for the selected physical properties. Plots of each normalised physical property vs. normalised temperature are established. The rate of weathering of quartzo-feldspathic gneiss is seen to be more than that of biotite gneiss, and therefore more attention should be paid in the designing of foundations of important civil engineering structures in quartzo-feldspathic gneiss strata, as far as the durability is concerned.

1. Introduction

Sri Lanka has a crustal rock formation of metamorphic origin. A large proportion of it is of gneissic type, which is extensively utilized in civil engineering constructions. Gneiss is a banded rock with fairly continuous segregation of different minerals (Goodman, 1993). Foundations of most of the important civil engineering structures like dams, bridges and some high-rise buildings are extended up to or into the fresh gneissic rock strata. In addition tunnels are excavated through such rock formations.

Biotite gneiss and quartzo-feldspathic gneiss are the two major rock types encountered in many parts of the country, in connection with design of foundations of many important civil engineering structures.

The degree of resistance of the rock material to weathering under conditions of either alternating cycles of wetting and drying or variations in the environmental humidity level is termed as the durability (Oliver, 1976). Sri Lanka has a tropical climate, and therefore the study on durability of gneissic rocks under tropical conditions is immensely beneficial to the civil engineering industry of the country.

As the simulation of exact natural weathering conditions is quite complicated, this study mainly concentrates on how heating followed by sudden cooling affects deterioration of selected physical properties of gneissic rocks.

Most of the bridge abutments and dam abutments are associated with rock masses. In such locations rock mass is subjected to an alternate wetting and drying process. This results in "slaking" of rocks, which is also investigated in this work.
2. Weathering of Rocks

In the weathering process of rocks, an adjustment of the minerals takes place (Bell, 1994). This can happen as a result of physical disintegration, chemical decomposition, and biological activities or as a combination of these.

2.1 Mechanical weathering (Physical weathering)

Mechanical or physical weathering is particularly effective in climatic regions which experience significant diurnal changes of temperature (Bell, 1994). A large range of temperature occurs where freeze-thaw action takes place. This action causes cracks, fissures, joints, and also widens pore spaces. Thermal effects on rocks cause alternate expansion and contraction, and create stresses which eventually rupture the rock.

Sri Lanka belongs to the tropical climate, and hence does not experience a large range of temperature as experienced in the temperate climates. However, due to the difficulty in simulating the natural weathering processes in the laboratory, heating to high temperatures followed by sudden cooling was used to artificially weather the rock samples in this research. Therefore this investigation can be seen as focusing on effects of thermal variations on the durability of Sri Lankan gneissic rocks.

2.2 Chemical and biological weathering

In humid regions (e.g. the tropical areas) chemical and chemico-biological processes are generally much more significant than mechanical disintegration. High temperatures accelerate the weathering process; an increase of 10°C more than doubles the rate of chemical reaction (Goldrich, 1938).

Chemical weathering leads to alteration of minerals in rocks, which is mainly affected by oxidation, hydration, hydrolysis and carbonation. In addition, acidified and alkalized waters bring about solution of rocks. When decomposition takes place within a rock mass, the altered material occupies a greater volume and exerts internal stresses, which causes the rock to rupture.

Chemical and biological weathering of gneissic rocks are not considered for this work.

3. Hypotheses

This work is carried out based on the following hypotheses:

(a). Physical properties of gneissic rocks deteriorate when subjected to weathering.

(b). Thermal fluctuations weaken the structure of the rock mass due to development of micro fractures.

4. Objectives

Objectives of the present research are as follows:

(a). Investigate the deterioration of selected physical properties of gneissic rocks subjected to artificial weathering.

(b). Investigate the structural changes of gneissic rocks subjected to artificial weathering.

5. Methodology

Fresh gneissic rock samples of NX size (diameter = 54mm) collected from a 100m deep borehole were used for this work. These samples belonged to Class-I according to the geomechanics classification of rock masses of Bieniawski (1989). These were subjected to artificial weathering to investigate the deterioration of physical properties.

Accelerated artificial weathering was achieved in this research by heating the rock samples to different temperatures (50°C to 900°C) and cooling them suddenly by immersing in water at normal temperature (32°C).

Testing was carried out in two stages. In the initial stage, deterioration of the physical properties was investigated with the increment of temperature, in order to find the trend of behaviour of rocks under these conditions. Depth-wise variation of these properties had been investigated earlier (Samaradivakara, 2004).

In the second stage, deterioration of physical properties with the increment of temperature was investigated in detail, utilizing the normalized parameters of physical properties and temperature.
The above testing programmes were carried out on fresh biotite gneiss (BG) and fresh quartzofeldspathic gneiss (QFG) samples separately and the results were compared. A total of 130 rock core barrel samples were used in this work.

Drop of magnitude of physical property with temperature was initially studied. The residual sum of squares (R²) of each graph was acceptable. It was further identified that the percentage drop of magnitude of a physical property vs. temperature curves are more appropriate according to the residual sum of squares. Therefore, the percentage drop of magnitude of each physical property was calculated using the following formula and the plots were established. They are illustrated in Fig. 1 and Fig. 3.

\[
\% \text{ drop of magnitude of a physical property} = \frac{V_1 - V_2}{V_1} \times 100\%
\]

where,
\( V_1 = \) magnitude of physical property under room temperature
\( V_2 = \) magnitude of physical property after heat treatments

The following Physical Properties were investigated in this work at both the first and second stages:
(i). UCS (Unconfined Compressive Strength), determined by the “CONTROLS” UCS test apparatus.
(ii). Slake durability index, determined by the “WYKEHAM FARRANCE” slake durability test apparatus.

The following Physical Property was investigated at the second stage only:
(i). Ultrasonic Pulse Velocity, determined by “PUNDIT plus” test apparatus.

In addition, a thin section study was carried out to observe any structural changes taking place due to the development of micro fractures as a result of temperature variations. This was done for one pair of biotite gneiss samples subjected to heat treatment. Four numbers of thin sections prepared from the cross sections as well as from the longitudinal sections of the above samples were observed by means of a polarizing microscope.

The samples of 2B/36 and 2B/37 are a pair of adjacent samples of biotite gneiss. Sample 2B/36 was kept at room temperature and sample 2B/37 was heat-treated.

Thin sections prepared from the cross sectional samples are 2B/36H and 2B/37H, whereas the thin sections prepared from the longitudinal samples are 2B/36V and 2B/37V. Thin sections made from the cross sections and longitudinal sections are compared to study the propagation of micro-fractures due to heat treatments. The microscopic views (magnification= 100X) of thin sections prepared are illustrated in Fig. 8 to Fig. 11.

6. Results of the first stage

In this stage, analyses of deterioration of physical properties of gneissic rocks were carried out based on the variation of unconfined compressive strength and slake durability index tests.

According to Fig. 1, rate of percentage drop of UCS value of quartzo-feldspathic gneiss is higher than that of fresh biotite gneiss. Therefore, the rate of deterioration of fresh quartzo-feldspathic gneiss is higher than that of fresh biotite gneiss, when subjected to heat treatments. The two curves intersect at 573°C.

But, it has been found that quartzo-feldspathic gneiss is stronger than biotite gneiss at room temperature (Samaradivakara, 2004), based on analysis of samples from a 100m deep exploratory bore hole, as shown in Fig. 2.

According to Fig.3, the percentage drop of slake durability index values of quartzo-feldspathic gneiss is more than that of biotite gneiss. This result further confirms that the rate of deterioration of fresh quartzo-feldspathic gneiss is higher than that of fresh biotite gneiss, when subjected to heat treatments. The two curves intersect at 573°C.

The above two curves also intersect at the temperature of 573°C, which confirms that this temperature is significant in this investigation.

7. Results of the second stage

In this stage, a larger number of samples were heat treated so that more accurate plots could be established.
The behavior of ultrasonic pulse velocity (UPV) with artificial weathering caused by temperature increments and cooling is presented in Fig. 5, using normalized parameters.

The behavior of unconfined compressive strength (UCS) with artificial weathering caused by temperature increments and cooling is presented in Fig. 6, using normalized parameters.

The behavior of slake durability index with artificial weathering caused by temperature increments and cooling is presented in Fig. 7, using normalized parameters.

All the temperature values were normalized using the formula, \((T-573^\circ C)/573^\circ C\), where \(T\) is any temperature in Celsius degrees.

Each physical property was normalized by dividing by the mean value of the corresponding physical property given in Table 1.

All these tests illustrate that quartzo-feldspathic gneiss deteriorates faster than biotite gneiss.

**Table - 1 – Mean values of physical properties of fresh**

<table>
<thead>
<tr>
<th>Physical Property</th>
<th>Mean value</th>
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<tbody>
<tr>
<td></td>
<td>BG</td>
</tr>
<tr>
<td>Ultrasonic pulse velocity, (km/s)</td>
<td>5.071</td>
</tr>
<tr>
<td>Unconfined compressive strength, (MPa)</td>
<td>66.243</td>
</tr>
<tr>
<td>Slake durability index, (%)</td>
<td>99.271</td>
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</tbody>
</table>
Figure 3 – Comparison of the behaviour of Slake Durability Index with Temperature for the two rock types.

Figure 4 - Depth vs. Slake Durability Index (Comparison of Biotite Gneiss and Quartzo-Feldspathic Gneiss)

Figure 5 - Comparison of UPV of fresh quartzo-feldspathic gneiss and biotite gneiss

Figure 6- Comparison of UCS of fresh quartzo-feldspathic gneiss and biotite gneiss
The quartzo-feldspathic gneiss sample 2Q/41 which was heat-treated by raising the temperature up to 910°C showed major fractures on surface. This sample when tested for unconfined compressive strength (UCS) the value obtained was as low as 8MPa.

This fracturing process was common for biotite gneiss as well. The biotite sample 2B/41 which was heat-treated by rising the temperature up to 790°C showed a fractured surface and its UCS was 28MPa.

Propagation of micro-fractures and macro-fractures reduces the load bearing capacity of the rock mass and hence would deteriorate faster in the field.

9. Conclusions

- Strength of gneissic rocks drops significantly with increasing heat effect as applied in this study.
- Observational studies of thin sections further indicate that micro-fracturing is the dominant deformation mechanism in the deterioration of gneissic rocks due to physical weathering.
- Even though quartzo-feldspathic gneiss has greater strength and higher durable properties than biotite gneiss, it deteriorates faster than the biotite gneiss under similar processes of accelerated weathering. Therefore, this information may be taken into consideration when designing civil engineering structures founded on such geological formations.

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