Weathering influence and weatherability evaluation of some metamorphic rocks from Brazil

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Abstract: This paper describes an attempt to characterize the influence of weathering on the physical and mechanical properties, and to evaluate the weatherability, of some metamorphic rocks that are commonly found in surface and underground mines located in the Iron Quadrangle region of southeast Brazil. Laboratory tests were carried out to determine some of the physical, mechanical and weatherability properties of these rocks. The results clearly demonstrate the influence of weathering processes on these properties. The study has also shown that medium- to long-term weathering must be considered in the design of surface and underground mining openings.

Résumé: Cet article décrit une tentative de caractériser l'influence de la décomposition sur les propriétés mécaniques et physiques de quelques roches métamorphiques fréquemment trouvées dans l'ouverture de mines superficielles et souterraines localisées dans la région du quadrilatère de fer de l'État de Minas Gerais, au Brésil. L'article aussi essaye d'évaluer le potentiel de décomposition de ces mêmes roches. Des essais de laboratoire ont été exécutés pour déterminer quelques propriétés physiques, mécaniques et le potentiel de décomposition de ces roches. Les résultats prouvent l'influence du processus de décomposition sur ces propriétés. Cette étude met, aussi, en évidence que la décomposition au long et au moyen délai doit être considérée dans le projet des mines, superficielles et souterraines, où ces roches sont présentes.

Keywords: Weathering; Physical properties; Metamorphic rocks; Laboratory studies; Excavations; Underground mining; Surface mining.

INTRODUCTION

Mining operations in Brazil have been expanding in recent years. As a result, surface and underground mines have reached greater depths, and higher cut-slopes have been formed. As a result, problems related to slope and underground stability (stress induced by excavations, weathering effects, etc.) have increased, so that better knowledge of the engineering characteristics of the rocks masses present in the mines is now required. Among the main properties that need to be considered, the most important (Azevedo & Marques, 2002) are uniaxial compressive strength, weatherability, mineral composition, absorption capacity, dry and saturated specific weight, and apparent porosity.

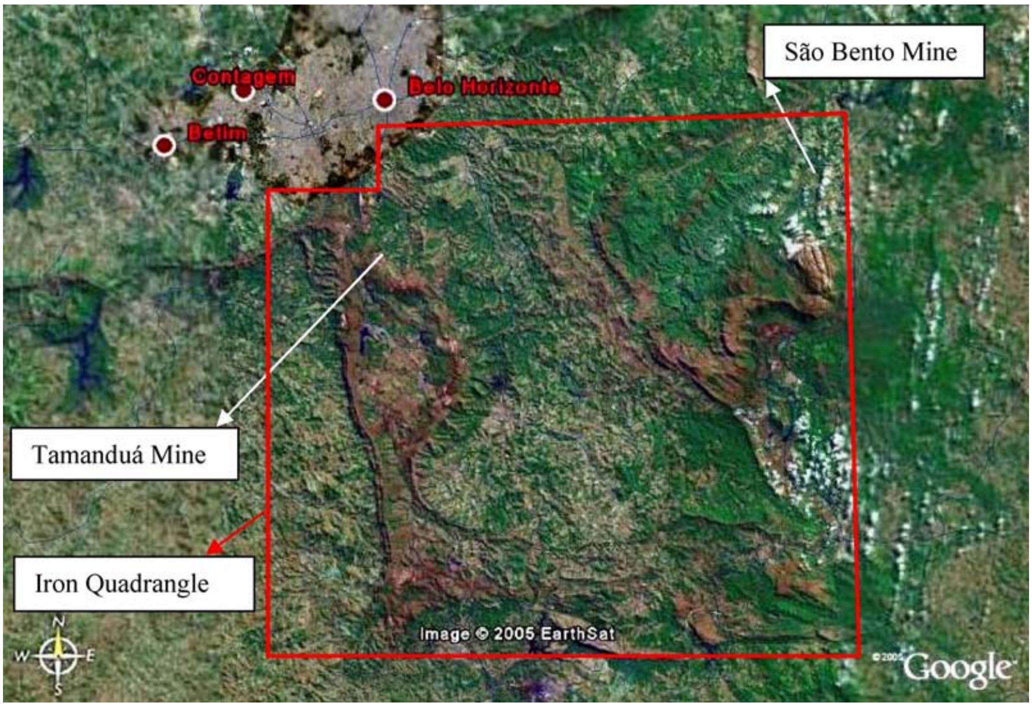


Figure 1. The Iron Quadrangle in south-east Brazil and locations of mines where rock samples were collected. (satellite image from GoogleEarth, 2005).

The São Bento Mine is a very old gold mine, dating from the 19th Century, which had reached a depth of 1200m at the time of this study. High confining pressures occur, and therefore the stabilization costs for the underground excavations are high also (Goodman, 1993). By contrast, the Tamanduá Mine is a surface iron ore mine that was opened in 1999, and which has slopes up to 150m high. The stability of surface and underground mines depend basically upon the presence of water under pressure, structural geology, weathering and weatherability of rock masses, and stress induced by excavation (ABGE, 1998). It is the weathering and weatherability of rocks from the two mines that is the particular focus of this paper.

PROBLEM CHARACTERIZATION

The main purpose of this paper is to characterize the influence of weathering on the mechanical and physical properties of the most problematic rocks present at the São Bento and Tamanduá mines in the IQ. The rock types selected were a phyllite and a metamorphosed intrusive basic rock from Tamanduá mine and an itabirite (laminated, metamorphosed oxide-facies iron formation) from São Bento mine. These rocks were selected because previous mineralogical tests carried out had shown that they contain readily weatherable minerals such as pyrite (in the itabirite) and clay-minerals (in the phyllite and intrusive rocks).

In the case of itabirites, pyrites can easily oxidize, generating secondary minerals in a very expansive process, well described by Taylor (1988). This process can produce very high pressures that can, in association with in situ pressures, produce rock bursts in deep excavations at the São Bento mine. Phyllites and basic rocks, on the other hand, have shown a very high rate of weathering when exposed in cut-slopes at Tamanduá mine, quickly changing to very weathered materials (ISRM´s V to VI rock mass classes) which no longer have the properties assumed in the original slope designs.

Therefore, it is important to characterize the weathering influences on the physical and mechanical properties of such rocks to predict their behaviour during a mine's lifetime, and so reduce accidents and stabilization costs.

METHODOLOGY

Samples of sound rocks (rock blocks and borehole samples) were collected for laboratory testing at the two sites: the underground São Bento Mine, and the surface Tamanduá Mine (Figure 1). Data from the São Bento mine is based on the work of Lopes (2000), while data from the Tamanduá Mine is based on the work of Santiago, Marques & Costa (2005).

Point load and cycling (Cyclic Wetting & Oven Drying) tests, and tests for physical properties (dry and saturated specific weight, apparent porosity and absorption capacity) were carried out at the Rock Mechanics Laboratory of the Civil Engineering Department of the Federal University of Viçosa, Brazil. The physical properties were calculated according to Brazilian standards (ABNT, 1992a), the cycling test was carried out according to Brazilian standards (ABNT, 1992b) and the point load tests were carried out according to ISRM (1981) suggested methods. Both qualitative and quantitative analyses were carried out for all samples.

10 samples were prepared, each of approximately 90 kg. The point load and physical properties tests were carried out on the samples of sound rock before the cycling tests. The dimensions of each rock sample also allowed its use in point load tests after cycling and artificially weathered samples (obtained from the cycling tests) were tested after each interval of 7 or 10 complete cycles (depending on the rock type). This procedure had the aim of studying the influence of weathering on the physical and mechanical properties. For each durability cycle, at least 8 samples were tested. Samples of intrusive basic rock (Tamanduá mine) were tested after 50, 75 and 100 durability cycles. For phyllite, samples were tested after 15, 30, 31, 37 and 45 cycles. Finally, for itabirite, samples were tested after 30, 50, 80 and 100 cycles. Additionally, for samples from Tamanduá mine, loading was done both parallel and perpendicular to foliation, in order to evaluate anisotropy of these rocks.

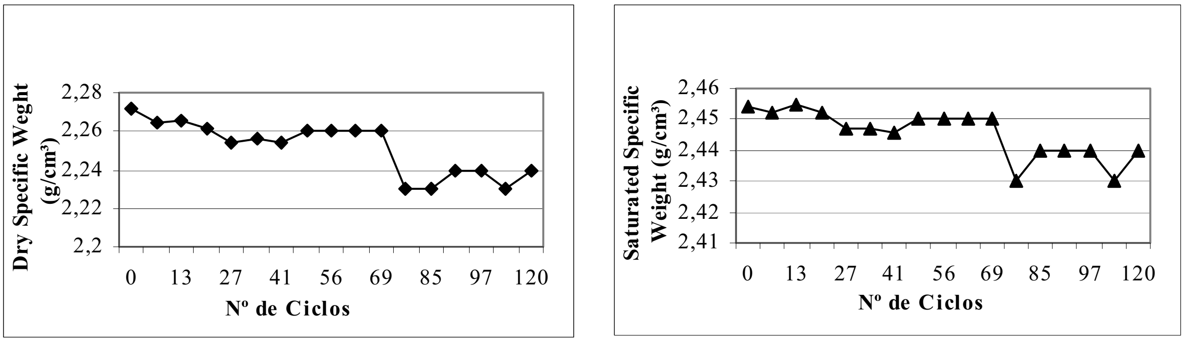
RESULTS

All results from the physical properties, cycling and point load tests are briefly presented below.

Physical Characterization, and its variation during Cycling

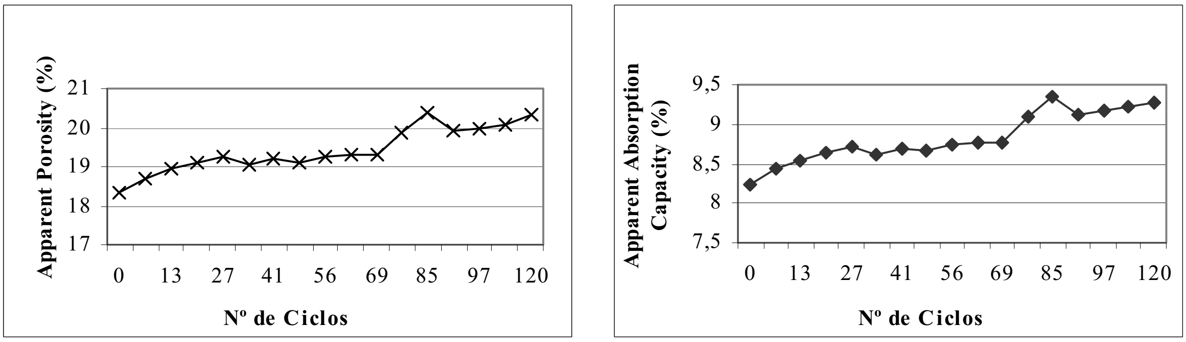
The characterization of physical properties (dry and saturated specific weight, apparent porosity and absorption capacity) was done for each of 10 cycles for itabirites, and for each of 7 cycles for phyllites and intrusive basic rock. The difference in the number of cycles was related to the response for each rock type to a battery of previous cycling tests.

Figures 2, 3 and 4 shows the results obtained for each rock type.



(a) Variation in dry specific weight during cycling.

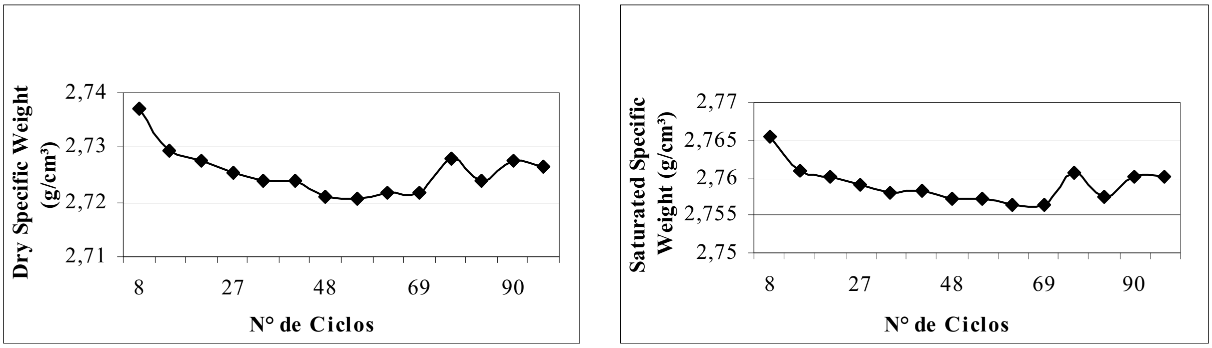
(b) Variation in saturated specific weight during cycling.



(c) Variation in apparent porosity during cycling.

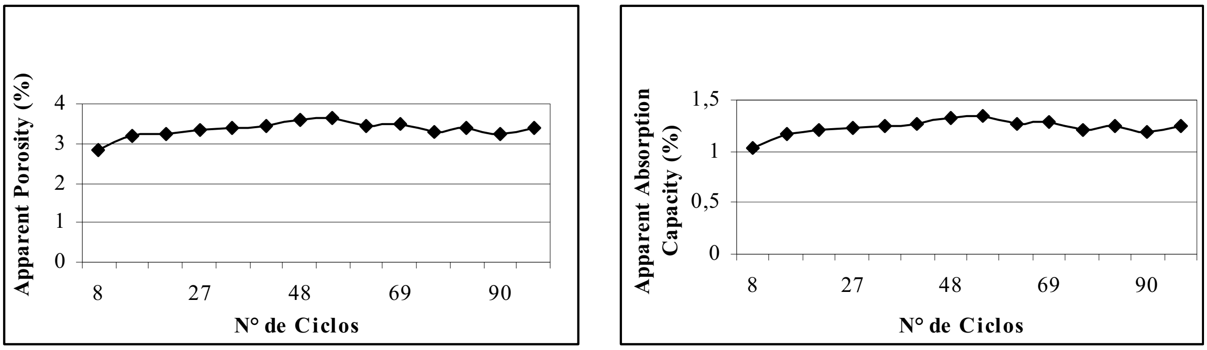
(d) Variation in absorption capacity during cycling.

Figure 2. Physical characterization of phyllite from Tamanduá mine, and its variation during cycling.



(a) Variation in dry specific weight during cycling.

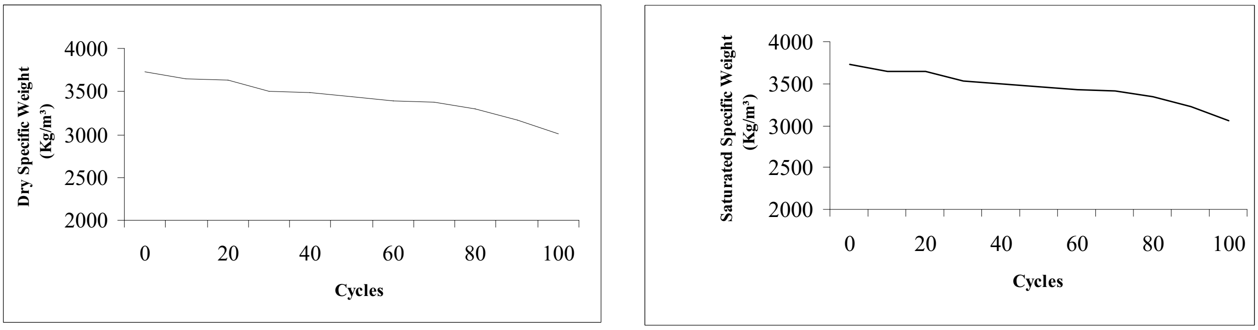
(b) Variation in saturated specific weight during cycling.



(c) Variation in apparent porosity during cycling.

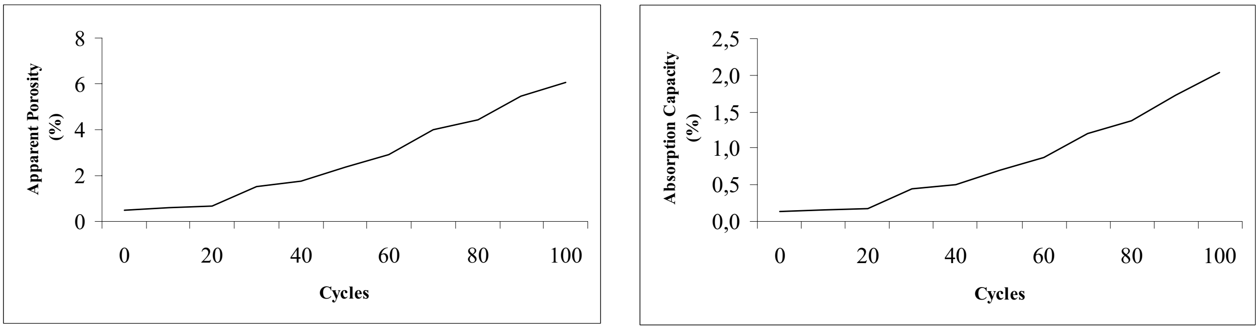
d) Variation in absorption capacity during cycling.

Figure 3. Physical characterization of intrusive basic rock from Tamanduá mine, and its variation during cycling.



(a) Variation in dry specific weight during cycling.

(b) Variation in saturated specific weight during cycling.



(c) Variation in apparent porosity during cycling.

d) Variation in absorption capacity during cycling.

Figure 4. Physical characterization of itabarite from São Bento mine, and its variation throughout cycling.

Point Load testing and its variation during cycling

Tables 1, 2, 3 and 4, and Figures 5, 6 and 7 shows the results obtained from point load tests for sound and weathered samples during the cycling tests.

Table 1. Point load test results and anisotropy index for phyllite, and its variation during cycling.

Number of cycles	Direction of Test (with foliation)		Anisotropy Index (AI)
	Perpendicular (MPa)	Parallel (MPa)	
0	0.31	0.19	1.63
15	0.20	0.14	1.43
30	0.09	0.09	1.00
45	0.04	0.06	0.66

Table 2. Strength loss of phyllite during cycling.

Weathering Grade	Parallel to foliation (MPa)	Strength Loss (%)	Perpendicular to foliation (MPa)	Strength Loss (%)
Sound Rock	0.19	0.0	0.31	0.0
After 15 cycles	0.14	26.3	0.20	35.5
After 30 cycles	0.09	52.6	0.09	71.0
After 45 cycles	0.06	68.4	0.04	87.1

Table 3. Point load test results and anisotropy index for intrusive basic rock during cycling.

Number of cycles	Direction of Point Load Test (with foliation)		Anisotropy Index (AI)
	Perpendicular (MPa)	Parallel (MPa)	
0	2.05	1.05	1.95
50	1.16	0.35	3.31
75	0.76	0.62	1.23
100	0.58	0.64	0.91

Table 4. Strength loss of intrusive basic rock during cycling.

Weathering Grade	Point Load Parallel to foliation (MPa)	Strength Loss (%)	Point Load Perpendicular to foliation (MPa)	Strength Loss (%)
Sound Rock	1.05	0.0	2.05	0.0
After 15 cycles	0.35	67.0	1.16	43.3
After 30 cycles	0.62	41.2	0.76	62.9
After 45 cycles	0.64	39.1	0.58	71.8

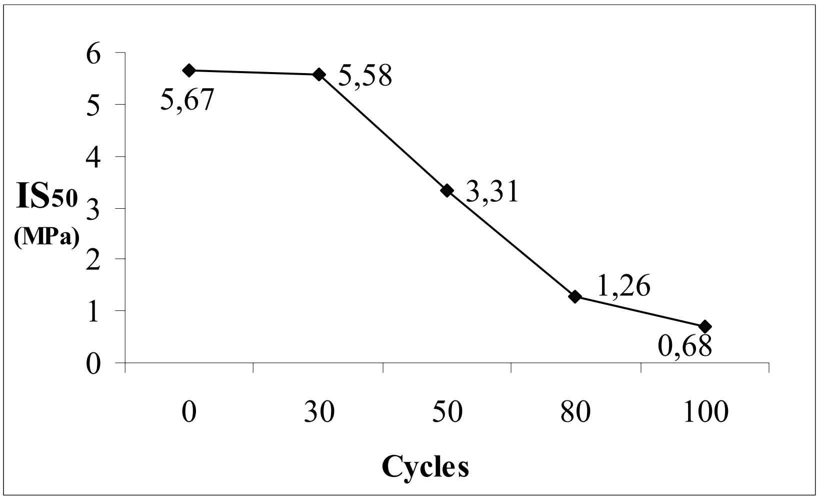


Figure 5. Strength variation of itabirite during cycling.

DISCUSSION

Physical Characterization

As expected, the results show that (prior to cycling) only phyllite has significant porosity and absorption capacity (around 185% and 8% respectively), while the intrusive basic rock and itabirite present very low porosities (around 3% for intrusive basic rock and lower than 1% for itabirite) and absorption capacities (around 1% for intrusive basic rock and 0% for itabirite).

It can also be seen that the accelerated weathering caused by cycling induces a considerable increase in the porosity of the rocks, except for the intrusive basic rock, which has an initial increase at the onset of cycling and then stabilises. Itabirite was the most affected rock type of the three studied. It appears, therefore, that the oxidation of pyrite crystals (commonest in the itabirite) induces a higher disaggregation of the rock than the expansion of clay-minerals (the most important process in the phyllites and intrusive basic rock).

Qualitative analysis of the cycling tests shows that the disaggregation process begins with the propagation of microfracturing, which increases the pathways for water circulation. Subsequently, the processes start to disintegrate the rock samples and it is no longer possible to continue the tests. This behaviour is clearer in the phyllites.

Cycling Tests

During the cyclic wetting & oven drying tests, a qualitative evaluation of rock behaviour was carried out. This evaluation was based according to Brazilian standards (ABNT, 1992a and 1992b).

Physical weathering, observed during cycling, initially occurs by propagation of cracks and splits, which enlarge the free surface area. This process allows water to perform chemical attack in parts of each sample that were not previously exposed. So, crack propagation is of critical significance in the progression of weathering as it increases the opportunity for chemical weathering. This mechanism was observed for all three of the rock types under study.

After the initial fragmentation process, rock fissures started to join together and samples began to disintegrate. Itabirite and the intrusive basic rock started to disintegrate after 20 wetting & oven drying cycles, while phyllite only started to disintegrate after 35 wetting & oven drying cycles. All of the rock types showed a rapid increase in disintegration up to the end of the cycling tests. Figures 6, 7 and 8 shows the results obtained from the wetting & oven drying cycling tests.

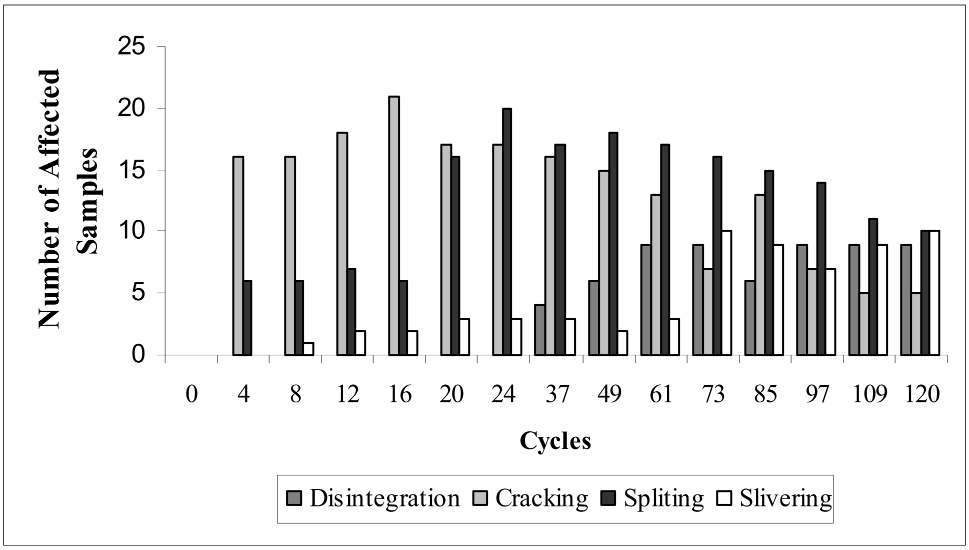


Figure 6. Percentage of affected samples and type of attack suffered by phyllite during cyclic wetting & oven drying test.

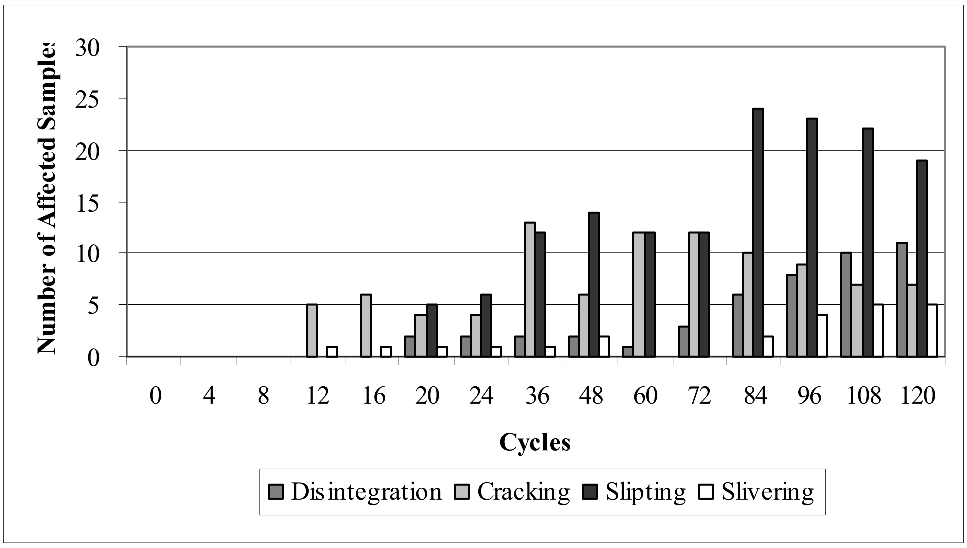


Figure 7. Percentage of affected samples and type of attack suffered by intrusive basic rock during cyclic wetting & oven drying test.

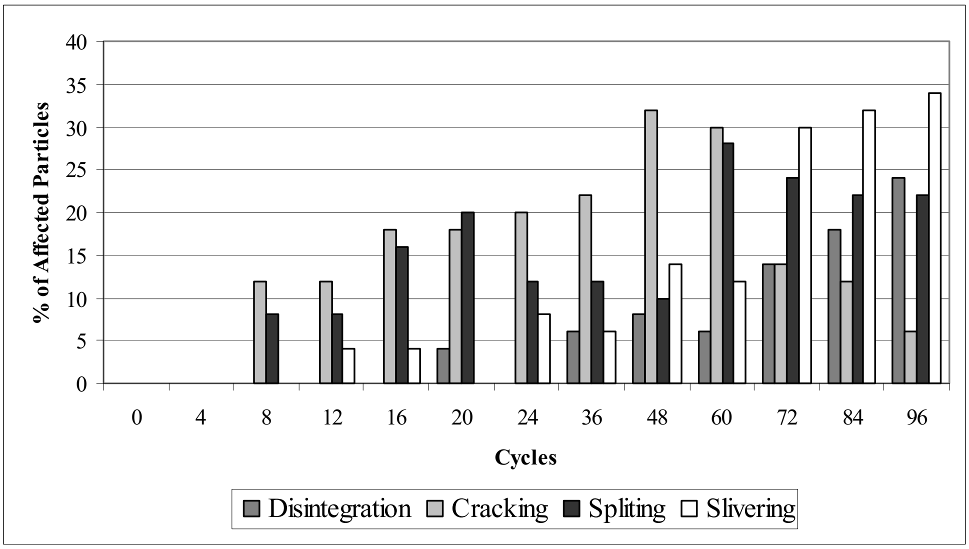


Figure 8. Percentage of affected samples and type of attack suffered by itabirite during cyclic wetting & oven drying test.

Mechanical characterization

As expected, the accelerated weathering induced by cycling caused a significant reduction in strength of all three rocks under study. The amount of reduction in strength was also very high. Itabirite showed a reduction in point load strength of 88% after 100 cycles. Rocks from Tamanduá mine also showed very substantial reductions in strength, varying from 54% (basic intrusive) to 87% (phyllite).

The anisotropy was also affected by weathering. Both the phyllite and basic intrusive rocks showed a reduction in the anisotropy index (AI) during cycling. Phyllite showed an increase of AI after 45 cycles, when the value of the point load index parallel to foliation became higher than that measured perpendicular to the foliation. This behaviour was only noted for this rock and its causes needs further mechanical and mineralogical testing to be understood.

CONCLUSIONS

This study has clearly demonstrated the importance of physical weathering as a major control of chemical weathering, by increasing the surface area available for attack by the weathering agents, and especially water. Weathering was also shown to influence the physical and mechanical properties of all three of the rock types under study. All of the rocks showed a considerable decrease in strength during the cycling tests. This strength loss behaviour must, therefore, be taken into account in the design of underground and surface mining projects to avoid medium- to long-term failure of slopes and underground excavations.

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