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ORIGINAL PAPER

# Physical and mechanical characterization of phyllites and metagreywackes in central Portugal

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**Abstract** This work defines the physical and mechanical characteristics of phyllites and metagreywackes belonging to a schist–greywacke complex in central Portugal. The index properties, point load strength, uniaxial compressive strength, slake durability and Schmidt rebound hardness were determined. In general, the metagreywackes gave a higher strength than phyllites with the same weathering degree. Possible correlations and estimation models were established and compared with the equations obtained by different researchers.

**Keywords** Mechanical characterization · Index properties · Rock classification · Anisotropy · Phyllites · Metagreywackes

**Résumé** Cet article présente les caractéristiques physiques et mécaniques des phyllites et métagrauwackes appartenant au "Complexe Schiste–Grauwacke" situé dans le centre du Portugal. Les indices géotechniques, l'indice de résistance entre pointes, la résistance à la compression simple, la durabilité et la dureté de rebond Schmidt ont été déterminés. En général, les métagrauwackes présentent une plus grande résistance que les phyllites ayant le même degré d'altération. Des corrélations possibles et des modèles d'estimation ont été développés et comparés aux équations obtenues par des différents chercheurs.

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**Mots clés** Caractérisation mécanique · indices géotechniques · classification des roches · anisotropie · phyllites · métagrauwackes

## Introduction and geology

In order to establish a geotechnical characterisation of phyllites and metagreywackes, a series of laboratory and in situ tests were carried out. The physical and mechanical characteristics of the rock material were identified and compared with the results of a geological survey of the area with regard to the different lithological types and their weathering degree.

The rock materials studied are part of the Beiras Group of the "Xisto–Grauváquico" complex (Fig. 1) which occupies a substantial part of northern and central Portugal and extends into Spain. The formations have characteristics that are, in general, typical of flysch.

The Beiras Group, found mainly in central Portugal, essentially consists of alternating phyllites and metagreywackes and sometimes includes quartzitic phyllites, quartzites and quartz veins. The Beiras Group rocks are Vendian-Cambrian in age; the regional metamorphic grade rarely exceeds beyond the greenschist chlorite zone facies.

The phyllites and metagreywackes can vary significantly in their mineralogical and textural composition, sometimes within a matter of centimetres, such that it can be difficult to clearly delineate the two rock materials.

The phyllites, in lighter or darker shades of grey or sometimes slightly greenish in colour, are fine grained and their behaviour is influenced by their anisotropy. The most weathered phyllites were generally found near the surface and/or surrounding faults. The minerals most commonly found in the phyllites were white mica, quartz and chlorite;

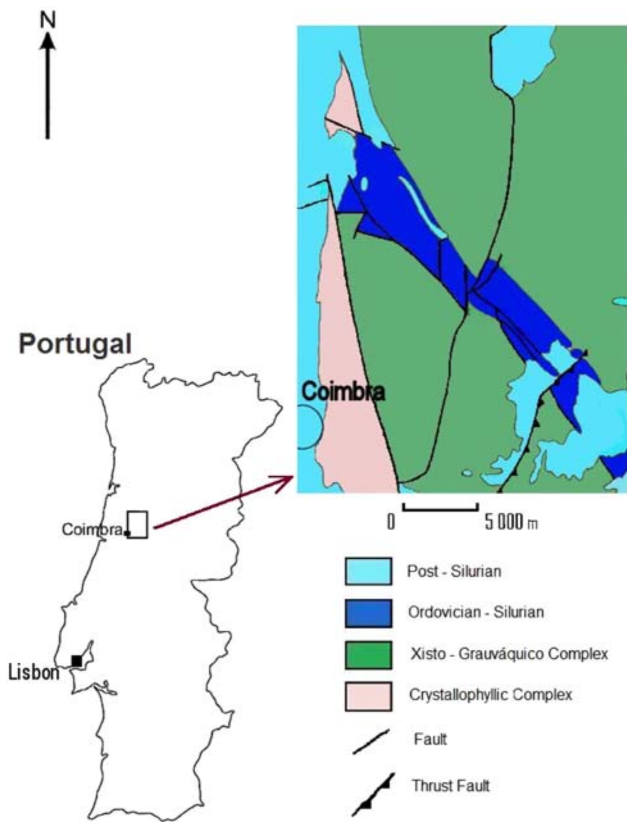


**Fig. 1** Location and geological map adapted from SGP (1992)

feldspars and biotite could also be observed. In addition, the accessory minerals tourmaline, zircon, pyrite and iron oxides were identified. In the most weathered phyllites there was a significant presence of iron oxides and hydroxides and clay minerals.

The metagreywackes studied were medium to fine grained and were associated with impure sandstone and "wackes" that have experienced low grade metamorphism. There was less evidence of foliation in the metagreywackes than in the phyllites. The main minerals identified were quartz and feldspar, together with some fragments of quartz and pelitic rock material. White mica and chlorite were found to be important minerals, often present in amounts exceeding 15%.

## Methodology

The index properties defined included apparent density ($\gamma$), porosity ($p$), quick absorption (qa), water absorption (abs) and $P$-wave velocities ($V_p$). In addition, slake durability tests, point load strength ($I_s$), uniaxial compressive strength (UCS) and Schmidt hammer rebound hardness ($R$) were obtained.

The phyllites and metagreywackes rock samples were collected from different slopes roads located in the "Xisto–Grauváquico" complex. The rock block samples were generally obtained from excavated rock slopes and were extracted using hammers and picks. The block samples varied from 0.2 × 0.3 × 0.3 to 0.6 × 0.6 × 0.9 m in size. From the block samples, rock specimens were obtained in the form of core, cut blocks and irregular lumps. Core specimens with NX size were used for the Vp and UCS tests. Cut blocks of approximately 8 × 10 × 10 cm were used for the $\gamma$, $p$, qa and abs tests. Irregular lumps were used for the slake durability and the $I_s$ tests according to the ISRM (1981) and the ISRM (1985) suggested methods respectively.

The number of phyllites samples used was as follows:

(a) 39 for the $\gamma$, $p$, qa, abs, $I_s$ and slake durability tests.
(b) 26 for the $R$ tests executed in the field.
(c) 12 for the $V_p$ and UCS tests.

Regarding the number of metagreywackes samples, the following were used:

(a) 32 for the $\gamma$, $p$, qa, abs and slake durability tests.
(b) 27 for the $I_s$ tests.
(c) 20 for the $R$ tests executed in the field.
(d) 8 for the $V_p$ and UCS tests.

Whenever possible, variations in mechanical properties were analysed in terms of anisotropy, in particular the relationship to the schistosity. The discontinuity roughness of the studied rock materials is given in Andrade and Saraiva (2008).

The rock materials were grouped for characterisation purposes as follows: W1-2 slightly weathered, W3 moderately weathered, W4 highly weathered.

### Index properties tests

Laboratory tests to determine $\gamma$ were performed using CEN (1997) standards based on specimen vacuum saturation and hydrostatic weighing.

The porosity tests followed ISRM (1981). Water absorption was obtained following ASTM (1992) and quick absorption following Hamrol (1961). Some difficulty was experienced in carrying out the tests on the most weathered rocks, due to disintegration caused by immersion in water.

The sound velocity tests were conducted in accordance with ISRM (1981) using cylindrical core specimens. $V_p$ depends on the elastic properties of the rock material (Goodman 1989) as well as on its mineralogical composition and orientation (Guyader and Denis 1986). According to Kossev (1970) the specific weight, porosity, fissuring, strength and weathering degree of the rock material also influence the $V_p$ results. Ultrasonic measurements of longitudinal waves were obtained normal to the schistosity ($V_p^a$) and parallel to the schistosity cleavage ($V_p^b$).

The slake durability and UCS tests followed ISRM (1981). The second-cycle slake durability index [$I_d$ (second cycle)] was defined. For the foliated rocks it was decided to carry out tests with the loading applied both normal ($UCS^a$) and parallel ($UCS^b$) to the schistosity. The point load strength, corrected to a specimen diameter of 50 mm ($I_{s50}$), was based on ISRM (1985) using dried irregular lumps with the loading perpendicular ($I^a_{s50}$) and parallel ($I^b_{s50}$) to the schistosity. For the Schmidt hardness test, an L-type hammer was used (model RM-710) with 0.735 N m of impact energy, following ISRM (1981).

**Table 1** Apparent density ($\gamma$), porosity ($p$), quick absorption (qa), water absorption (abs) and $P$-wave velocities ($V_p$) of studied rocks

| Rock type | $\gamma$ | $p$ (%) | qa (%) | abs (%) | $V_p$ (m/s) |
|---|---|---|---|---|---|
| Phyllites W1-2 | 23.2–26.0 | 4.2–11.5 | 0.9–5.7 | 1.5–6.1 | 1,810–3,288[a]<br>3,533–5,323[b] |
| Phyllites W3 | 18.4–24.8 | 5.4–23.6 | 1.2–8.9 | 1.9–11.7 | 1,530–2,250[a]<br>2,760–3,208[b] |
| Phyllites W4 | 17.2–24.3 | 11.6–39.5 | 3.3–16.0 | 3.9–17.0 | 1,178–1,800[a]<br>1,918–2,330[b] |
| Metagreywackes W1-2 | 23.9–26.3 | 2.2–10.4 | 0.7–2.9 | 1.0–3.7 | 3,550–4,360 |
| Metagreywackes W3 | 20.2–25.8 | 4.8–23.7 | 1.5–8.7 | 2.2–11.1 | 2,697–3,937 |
| Metagreywackes W4 | 17.9–24.3 | 9.3–32.4 | 2.7–14.1 | 3.3–17.6 | |

[a] Carried out on cylindrical specimens cored across schistosity

[b] Carried out on cylindrical specimens cored along schistosity

**Table 2** Second-cycle slake durability index [$I_d$ (second cycle)], point load strength corrected to a specimen diameter of 50 mm ($I_{s50}$), uniaxial compressive strength (UCS) and Schmidt hammer rebound hardness ($R$) values of studied rocks

| Rock type | $I_d$ (second cycle) (%) | $I_{s50}$ (MPa) | UCS (MPa) | $R$ |
|---|---|---|---|---|
| Phyllites W1-2 | 90.7–98.9 | 1.4–3.8[a]<br>1.2–2.3[b] | 45.2–52.2[a]<br>40.3–45.6[b] | 25.2–38.9[a]<br>22.6–36.0[b] |
| Phyllites W3 | 59.6–98.2 | 0.6–3.9[a]<br>0.4–1.4[b] | 25.8–35.2[a]<br>24.0–33.1[b] | 18.2–35.0[a]<br>17.1–32.0[b] |
| Phyllites W4 | 33.7–96.6 | 0.4–3.0[a]<br>0.3–1.0[b] | 16.6–23.9[a]<br>17.0–21.0[b] | 14.9–30.0[a]<br>14.2–28.0[b] |
| Metagreywackes W1-2 | 92.1–99.1 | 2.8–7.1 | 51.4–73.9 | 27.8–40.0 |
| Metagreywackes W3 | 58.5–98.6 | 1.0–3.2 | 32.4–50.8 | 18.0–34.4 |
| Metagreywackes W4 | 44.8–97.6 | 0.9–2.8 | | 16.9–30.2 |

[a] Direction of loading normal to the schistosity

[b] Direction of loading parallel to the schistosity

**Table 3** Classification of index properties

| Rock type | $\gamma$ | $p$ | $V_p$ |
|---|---|---|---|
| Phyllites W1-2 | Moderate to high | Low to medium | Very low to low[a]<br>Moderate to very high[b] |
| Phyllites W3 | Low to moderate | Medium to high | Very low[a]<br>Low[b] |
| Phyllites W4 | Very low to moderate | Medium to very high | Very low[a]<br>Very low[b] |
| Metagreywackes W1-2 | Moderate to high | Low to medium | Moderate to high |
| Metagreywackes W3 | Low to moderate | Low to high | Low to moderate |
| Metagreywackes W4 | Very low to moderate | Medium to very high | – |

[a] Carried out on cylindrical specimens cored across schistosity

[b] Carried out on cylindrical specimens cored along schistosity

**Table 4** Two-cycle slake durability classification, strength classification of intact rock material and results of the anisotropy index ($I_a$)

| Rock type | $I_d$ (second cycle) | $I_{s50}$ | UCS | $I_a$ |
|---|---|---|---|---|
| Phyllites W1-2 | Medium high to very high | Low to medium[a] | Low to medium[a] | 1.47–2.00 |
| | | Low to medium[b] | Low[b] | |
| Phyllites W3 | Low to very high | Very low to medium[a] | Low[a] | 1.07–1.76 |
| | | Very low to low[b] | Very low to low[b] | |
| Phyllites W4 | Low to high | Very low to medium[a] | Very low[a] | 1.00–1.58 |
| | | Very low to low[b] | Very low[b] | |
| Metagreywackes W1-2 | Medium high to very high | Medium to high | Medium | – |
| Metagreywackes W3 | Low to very high | Low to medium | Low to medium | – |
| Metagreywackes W4 | Low to high | Very low to medium | – | – |

[a] Direction of loading normal to schistosity

[b] Direction of loading parallel to schistosity

**Table 5** Matrix of Spearman's rank correlation coefficient of phyllites results

| Tests | $\gamma$ | abs | qa | $p$ | $I_d$ (second cycle) | $I^a_{s50}$ |
|---|---|---|---|---|---|---|
| $\gamma$ | 1 | | | | | |
| abs | −0.930 | 1 | | | | |
| qa | −0.907 | 0.974 | 1 | | | |
| $p$ | −0.909 | 0.933 | 0.920 | 1 | | |
| $I_d$ (second cycle) | 0.848 | −0.879 | −0.852 | −0.873 | 1 | |
| $I^a_{s50}$ | 0.794 | −0.782 | −0.778 | −0.762 | 0.810 | 1 |

Number of samples 39

**Table 6** Matrix of Spearman's rank correlation coefficient of metagreywackes results

| Tests | $\gamma$ | abs | qa | $p$ | $I_d$ (second cycle) |
|---|---|---|---|---|---|
| $\gamma$ | 1 | | | | |
| abs | −0.876 | 1 | | | |
| qa | −0.907 | 0.980 | 1 | | |
| $p$ | −0.948 | 0.926 | 0.957 | 1 | |
| $I_d$ (second cycle) | 0.628 | −0.738 | −0.718 | −0.630 | 1 |

Number of samples 32

## Results

The results of the index property tests are shown in Table 1 and the durability and strength results in Table 2.

### Index properties results

The values for $\gamma$ were classified in accordance with an adaptation of dry density classification (IAEG 1979); see Table 3. In general the $\gamma$ of the metagreywackes was higher

**Table 7** Regression and correlations results for the phyllites

| $X$ | $Y$ | Number of samples | Equation | Regression coefficient |
|---|---|---|---|---|
| $\gamma$ | $I^a_{s50}$ | 39 | $Y = 0.01e^{0.22x}$ | 0.790 |
| $R^a$ | $p$ | 26 | $Y = -0.50x + 26.44$ | −0.554 |
| qa | $I^b_{s50}$ | 23 | $Y = -0.12x + 1.85$ | −0.765 |
| $R^b$ | $R^a$ | 15 | $Y = 1.01x + 2.38$ | 0.991 |
| $R^a$ | $I^a_{s50}$ | 26 | $Y = 0.61e^{0.04x}$ | 0.513 |
| $I^b_{s50}$ | $I^a_{s50}$ | 23 | $Y = 1.81x - 0.32$ | 0.953 |
| $I^a_{s50}$ | UCS[a] | 12 | $Y = 32.07\ln(x) + 16.83$ | 0.940 |
| $I^a_{s50}$ | UCS[a] | 12 | $Y = 16.61x + 3.47$ | 0.918 |
| $\gamma$ | UCS[a] | 12 | $Y = 0.08e^{0.28x}$ | 0.985 |
| abs | UCS[a] | 12 | $Y = 80.63e^{-0.13x}$ | −0.854 |
| $p$ | UCS[a] | 12 | $Y = 106.09e^{-0.09x}$ | −0.931 |
| $I_d$ (second cycle) | UCS[a] | 12 | $Y = 0.001e^{0.11x}$ | 0.848 |
| $R^a$ | UCS[a] | 12 | $Y = 3.17e^{0.07x}$ | 0.875 |
| $V^a_p$ | UCS[a] | 12 | $Y = 0.019x - 1.76$ | 0.700 |
| qa | UCS[a] | 12 | $Y = 70.72e^{-0.13x}$ | −0.756 |
| qa | $R^b$ | 15 | $Y = 38.96e^{-0.06x}$ | −0.725 |

**Table 8** Regression and correlation results for the metagreywackes

| $X$ | $Y$ | Number of samples | Equation form | Regression coefficient |
|---|---|---|---|---|
| $\gamma$ | $I_{s50}$ | 27 | $Y = 0.01e^{0.25x}$ | 0.748 |
| $I_{s50}$ | UCS | 8 | $Y = 42.86\ln(x) + 1.15$ | 0.958 |
| $I_{s50}$ | UCS | 8 | $Y = 11.91x + 11.29$ | 0.948 |
| $\gamma$ | UCS | 8 | $Y = 15.34x + 321.33$ | 0.893 |
| abs | UCS | 8 | $Y = 75.72e^{-0.13x}$ | −0.848 |
| qa | UCS | 8 | $Y = -19.67\ln(x) + 67.38$ | −0.867 |
| $I_d$ (second cycle) | UCS | 8 | $Y = 0.03e^{0.08x}$ | 0.816 |

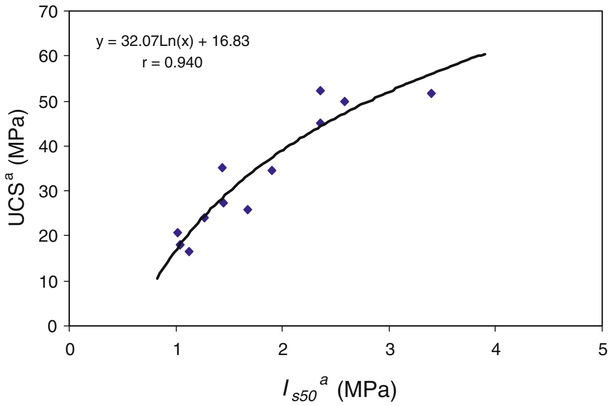


**Fig. 2** Correlation of point load strength corrected to a specimen diameter of 50 mm with the loading perpendicular to schistosity ($I^a_{s50}$) and uniaxial compressive strength with the loading normal to schistosity (UCS$^a$) of phyllites (logarithmic relationship)

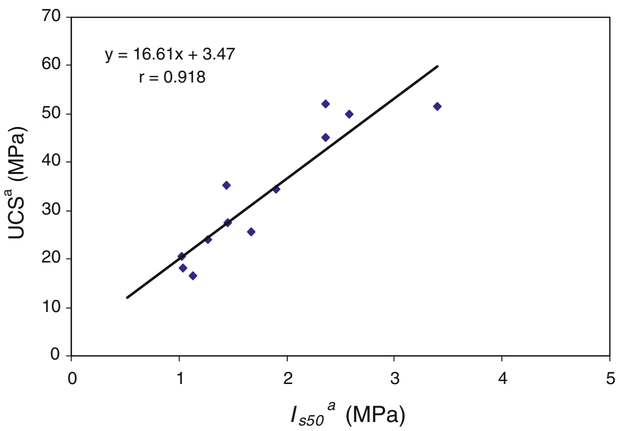


**Fig. 3** Correlation of $I^a_{s50}$ and UCS$^a$ values of phyllites (linear relationship)

than for phyllites with the same weathering degree. The porosity values are generally low for the relatively unweathered metamorphic rocks, with the $p$ for the metagreywackes generally lower than that for the phyllites with the same weathering degree. The classification used was based on IAEG (1979).

In general, the quick absorption results for the phyllites showed a higher rate of rapid absorption than for the metagreywackes with the same weathering degree. As with the variation found in the results for qa, a clear increase in abs values was also recorded for rocks with the highest weathering degrees (Table 1). The abs values were higher than those defined in the qa tests and lower than the $p$ results. In the latter tests, the specimens were subjected to vacuum conditions to remove the air present in the pores.

The results for the $V_p$ tests were very varied; the classification system used to analyse these results was based on IAEG (1979). Not surprisingly, a significant reduction in the velocity of the longitudinal waves was noted when the testing involved an orientation normal to the schistosity planes. This reduction was much more marked than that reported by Song et al. (2004).

The slake durability tests also gave very varied results (Table 2) although the phyllites generally produced lower $I_d$ (second cycle) values than metagreywackes with the same weathering degree. The classification system developed by Gamble (1971) was used to analyse the results.

As seen in Table 2, the metagreywackes (W1-2) showed the highest $I_{s50}$ values (2.8–7.1 MPa) and the phyllites (W4) the lowest. The Bieniawski (1974) rock mass strength classification was used (Table 4). In order to assess the results obtained for the different orientations used in the $I_{s50}$ tests, an adapted anisotropy index ($I_a$) was used. In the case of the phyllites, the $I_a$ tended to decrease as the weathering degree increased (Table 4) and the planar anisotropy seemed less important for their mechanical behaviour.

The UCS of the metagreywackes was generally higher than that of the phyllites with the same weathering degree. With the metagreywackes, diagonal failures and failures parallel to the axis plane of the load occurred whereas for the phyllites these failures occurred when the load was applied parallel to the schistosity. The UCS was classified in accordance with Bieniawski (1974, 1989) and Deere (1964).

In general, the metagreywackes gave higher Schmidt hammer $R$ values than the phyllites (Table 2).

**Table 9** Equations correlating the $I_{s50}$ with the uniaxial compressive strength of phyllites, metagreywackes and other rock types

| Equations | References | Rock type |
|---|---|---|
| $UCS = 16.61\ I^a_{s50} + 3.47$ | This study | Phyllites |
| $UCS = 16.0 I_{s50}$ | Ghosh and Srivastava (1991) | Granites |
| $UCS = 18.6 I_{s50}$ | Wiesner and Gillate (1997) | Sandstones and weathered basalts |
| $UCS = 15.25 I_{s50}$ | Tugrul and Zarif (1999) | Granites |
| $UCS = 11.91 I_{s50} + 11.29$ | This study | Metagreywackes |
| $UCS = 12.0 I_{s50}$ | Jenni and Balissat (1979) | Limestones and dolomites |
| $UCS = 12 \ldots 14 I_{s50}$ | Forster (1983) | Dolerites |
| $UCS = 10.91 I_{s50} + 27.41$ | Kahraman et al. (2005) | Igneous, sedimentary and metamorphic |

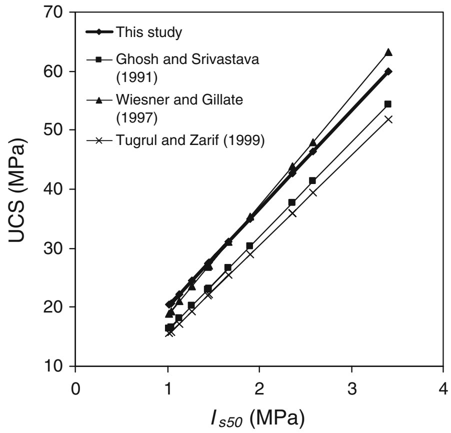


**Fig. 4** Comparison of the relationships between the $I_{s50}^{a}$ and uniaxial compressive strength (UCS) of phyllites (this study) and between the point load strength corrected to a specimen diameter of 50 mm ($I_{s50}$) and UCS obtained by others researchers

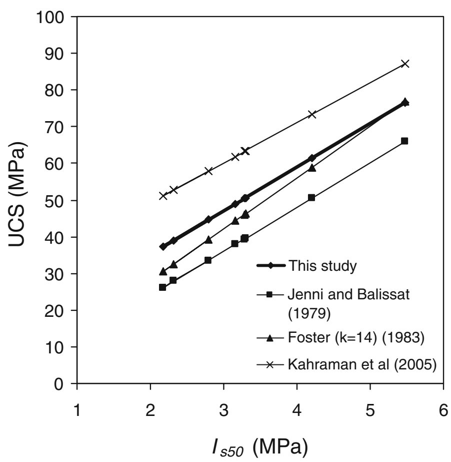


**Fig. 5** Comparison of the relationships between the $I_{s50}$ and uniaxial compressive strength of metagreywackes (this study) and those obtained by others researchers

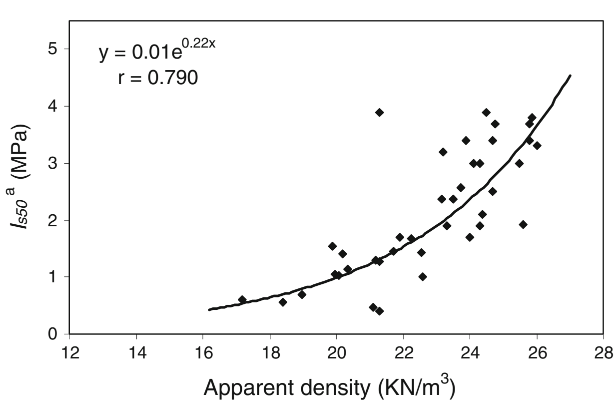


**Fig. 6** Correlation between apparent density and $I_{s50}^{a}$ values of phyllites

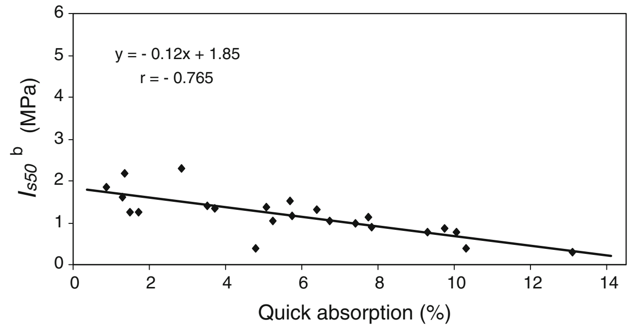


**Fig. 7** Correlation between quick absorption and point load strength corrected to a specimen diameter of 50 mm with the loading parallel to schistosity ($I_{s50}^{b}$) values of phyllites

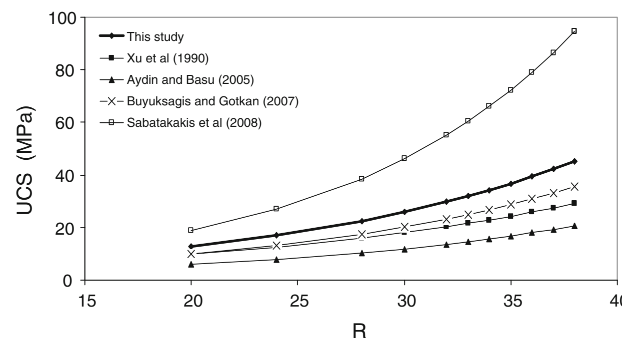


**Fig. 8** Comparison of the relationships between the rebound hardness ($R$) and uniaxial compressive strength of phyllites (this study) and those obtained by others researchers

## Analysis of test results

As the majority of the test results did not produce a normal distribution pattern, Spearman's rank correlation coefficient matrixes (Tables 5, 6) were drawn up for the 39 phyllite and the 32 metagreywacke samples. It can be seen that the highest correlation coefficients for the phyllites, in absolute terms, were found between the abs and qa and $p$ and the lowest, in absolute terms, between $I_{s50}^{a}$ and qa and between $I_{s50}^{a}$ and $p$. In general, the correlation coefficients (in absolute terms) were lower for the metagreywackes than for the phyllites (Tables 5, 6).

In addition to defining Spearman's rank correlation coefficients, an attempt was made to establish empirical relationships between the different properties of the rock materials, using only those test results which fitted a normal distribution. Linear, logarithmic, exponential and potency models were tested. The results of the regression analyses are given in Tables 7 and 8.

In many of the empirical relationships studied, the independent variable corresponded to strength or hardness parameters such as UCS, $I_{s50}$ or $R$. An increase in strength was recorded following an increase in $\gamma$, durability and $V_p$.

**Table 10** Equations correlating $R$ with UCS

| Proposed equations | References | Rock type |
|---|---|---|
| $UCS = 3.17e^{0.07R}$ | This study | Phyllites |
| $UCS = 2.98e^{0.06R}$ | Xu et al. (1990) | Micaschists |
| $UCS = 1.45e^{0.07R}$ | Aydin and Basu (2005) | Granites (Grade W1 to W4) |
| $UCS = 2.48e^{0.07R}$ | Buyuksagis and Goktan (2007) | Igneous, sedimentary and metamorphic |
| $UCS = 3.1e^{0.09R}$ | Sabatakakis et al. (2008) | Limestones, sandstones, marlstones |

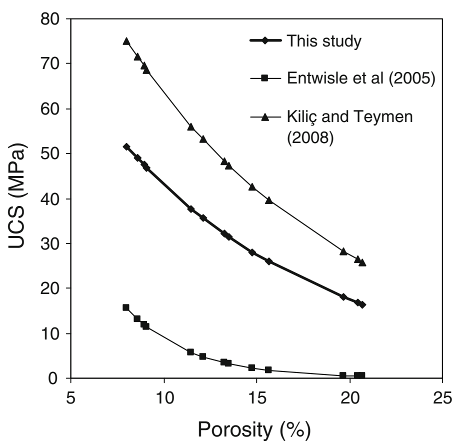


**Fig. 9** Comparison of the relationships between the porosity and uniaxial compressive strength of phyllites (this study) and those obtained by others researchers

It is usual to convert the $I_{s50}$ values to an equivalent UCS using a conversion factor ($k$). Widely varying $k$ values (7–68) are reported in literature, particularly for anisotropic rocks (Broch and Franklin 1972; Bieniawski 1975; Beavis et al. 1982; Forster 1983; ISRM 1985; Smith 1997; Hawkins 1998; Kahraman 2001), although values of 16 to 24 predominate. ISRM (1981) recommend $I_{s50}$ should be multiplied by $k$ values of 20–25 while Hawkins (1998) suggested that for dry core samples of sedimentary and igneous rocks, the value for $k$ would be 15 for $I_{s50}$ values below 2 MPa and 20 for $I_{s50}$ values between 2 and 5 MPa. Weaker rocks such as clay phyllites, in general, require lower $k$ values than would be applicable for stronger rocks.

With regard to the UCS[a] and $I^{a}_{s50}$ results for the phyllites studied, two empirical relationships were defined using regression analysis: a logarithmic equation (Fig. 2) and a linear equation (Fig. 3). Table 9 and Figs. 4 and 5 compare these equations with those found by various authors who have correlated UCS values with $I_{s50}$ values. It can be seen that the values are generally of the same order as those obtained in this study.

Empirical relationships proposed in literature for the other parameters studied were also considered, e.g. between $\gamma$ and $I^{a}_{s50}$ (Fig. 6), qa and $I^{b}_{s50}$ (Fig. 7), $R$ and UCS (Fig. 8; Table 10), $p$ and UCS (Fig. 9; Table 11), $V_p$ and UCS and between $p$ and $R$ (Table 11). Frequently, the differences found could be related to the mineralogical composition and texture of the rock materials and/or the different techniques used for sampling and performing the tests. Those closest to the results from the present study were for $R$ and UCS, $p$ and UCS and $R$ and $p$ which are comparable to those defined by Buyuksagis and Goktan (2007), Kiliç and Teymen (2008) and Aydin and Basu (2005), respectively.

## Conclusions

Geotechnical tests were undertaken to determine the index properties, strength and durability of phyllites and metagreywackes with different weathering degrees.

**Table 11** Equations correlating the $V_p$, $p$ with the UCS and $R$

| Proposed equations of this study | Rock type | References | Proposed equations of the references | Rock type |
|---|---|---|---|---|
| $UCS = 0.019V_p - 1.76$ | Phyllites | Tugrul and Zarif (1999) | $UCS = 0.0355V_p - 55$ | Granites |
| $UCS = 0.019V_p - 1.76$ | Phyllites | Sharma and Singh (2008) | $UCS = 0.064V_p - 117.99$ | Igneous, sedimentary and metamorphic |
| $UCS = 106.09e^{-0.09p}$ | Phyllites | Entwisle et al. (2005) | $UCS = 159.52e^{-0.29p}$ | Volcanic rocks |
| $UCS = 106.09e^{-0.09p}$ | Phyllites | Kiliç and Teymen (2008) | $UCS = 147.16e^{-0.084p}$ | Igneous, sedimentary and metamorphic |
| $p = -0.50R + 26.44$ | Phyllites | Aydin and Basu (2005) | $p = -0.32R + 21.15$ | Granites (grades W1 to W4) |
| $p = -0.50R + 26.44$ | Phyllites | Yaşar and Erdoğan (2004) | $p = -0.20R + 11.21$ | Igneous, sedimentary and metamorphic |

The metagreywackes revealed higher strength and durability values than phyllites with the same weathering degree. These differences may be explained by the fact that metagreywackes exhibit a stronger isotropic texture than the phyllites, which have a different mineralogical composition and are more susceptible to weathering.

The data obtained from the study allowed empirical equations to be defined from various parameters, which were compared with those in the existing literature. Some of the empirical relationships established for phyllites which presented high to extremely high correlation coefficients were between $I_{s50}^{a}$ and $\gamma$, UCS$^{a}$ and R, UCS$^{a}$ and $p$, UCS$^{a}$ and $\gamma$, UCS$^{a}$ and $I_{s50}^{a}$.

Some of the most reliable empirical relationships for metagreywackes were between $I_{s50}$ and $\gamma$, UCS and $I_{s50}$.

It must be pointed out that the proposed models should not be extended to other types of rock material, although it would be useful to compare them with correlations established for the mechanical and physical characterisation of similar rocks.

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