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Correlation between physical and mechanical properties of mudrock

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ABSTRACT

The paper describes the statistical relationship between physical and mechanical properties of mudrock. It focuses particularly on the correlation between index parameters that are relatively easy to measure and mechanical properties that are difficult to determine. Data for regression analysis were extracted from available published information. Moreover, many tests were carried out on different types of mudrock from various sites. Reasonably good correlation is found between some index parameters and mechanical properties, and various regression equations are proposed for predicting mechanical properties for available data. There is a good correlation between the point load, water content, porosity, and modulus of elasticity with the uniaxial compressive strength, whereas the correlation between the density, elastic wave velocity, and Poisson's ratio with the compressive strength is poor.

Theses correlations may aid engineers to make preliminary estimation of the mechanical properties of mudrock when samples of adequate size for testing are generally not available. Furthermore, the selective use of proposed relationships may even reduce the testing requirements of specific projects.

INTRODUCTION

Mudrock is the most common type of sedimentary rock. It accounts for nearly 70% of the total sedimentary rock of the crust exposed at the surface of the earth. Consequently, it is frequently encountered in all types of engineering project as construction material for rock fills and embankments, and in natural and undisturbed state in foundations, cut slopes, tunnels, and underground spaces. Despite its importance, however, little information is available on the mechanical properties of this rock in comparison with other sedimentary rocks, such as carbonates and sandstones. Probably, one of the main reasons for this lack of data is difficulty in working with mudrock, largely because this rock is difficult to sample, store, characterise, and test on a practical basis. This material can easily be disturbed by the usual drilling, sampling, and specimen preparation. Furthermore, the measurement of mineralogical and mechanical properties is complicated by the extremely fine grain size and the large clay content. It is also characterised by a wide variation in its engineering properties, particularly due to short-term weathering by wetting and drying.

The paper describes the statistical relationship between physical and mechanical properties of mudrock. It focuses particularly on the correlation between index parameters that are relatively easy to measure and mechanical properties that are difficult to determine. Data for statistical analyses were extracted from different types of available published information such as technical reports, papers from journals and conference proceedings, books, as well as from the experimental results.

RELATIONSHIP BETWEEN PHYSICAL AND MECHANICAL PROPERTIES

Regression analyses were applied to evaluate the physical and mechanical properties of mudrock. A short description of them is given below.

Relationship between water content and compressive strength

Changing the water content of a rock can significantly alter its strength. It has been well established that the water content in fine-grained sedimentary rocks can significantly affect their mechanical properties, since the uniaxial compressive strength decreases with increasing water content.

To study the effect of water content on the strength of mudrock, a large number of the Ashfield Mudrock samples were collected from various locations. In these samples, the water content ranged widely (i.e., from 1.12% to 8.76%). Fig. 1 indicates that the uniaxial compressive strength decreases with increasing water content, which confirms with the previous findings for other mudrocks (Steiger and Leung 1990; Hsu and Nelson 1993; Lashkaripour 1998). Steiger and Leung (1990) reported that, in mudrocks, the uniaxial compressive strengths measured with dry samples could be 2 to 10 times higher than for wet samples. Hsu and Nelson (1993) determined a strong correlation between compressive strength and water content for the Cretaceous mudrocks of North America. Also, the mudrock is more affected by the addition of water, especially the rock containing a lot of montmorillonite.

The relationship between uniaxial compressive strength and water content appears to be exponential. A small increase in water content causes a large reduction in uniaxial compressive strength and it is described by the following equation:

$$\sigma_c = 600\ p_a . e^{-0.42w} \quad (1)$$

where σ_c= uniaxial compressive strength (MPa); p_a= atmospheric pressure (= 0.1 MPa); and w = water content (%).

Relationship between wave velocity and compressive strength

There seems to be a weak correlation between the uniaxial compressive strength and wave velocity of the mudrock, which is consistent with previous finding for other fine-grained sedimentary rocks (Inon and Ohami 1981; Lashkaripour and Passaris 1995). Therefore, the wave velocity is not reliable predictor for the strength of mudrock.

Relationship between density and compressive strength

The relationship between the uniaxial compressive strength and density for available data is fairly poor (Fig. 2). In general, the uniaxial compressive strength increases with density, but the form of the relation cannot be accurately defined, as the data points are scattered. The correlation is improved when plotted data are from the same geological formation (i.e., the samples are similar in age, depositional environment, and stress history). Therefore, it seems that there is no good correlation between the density and uniaxial

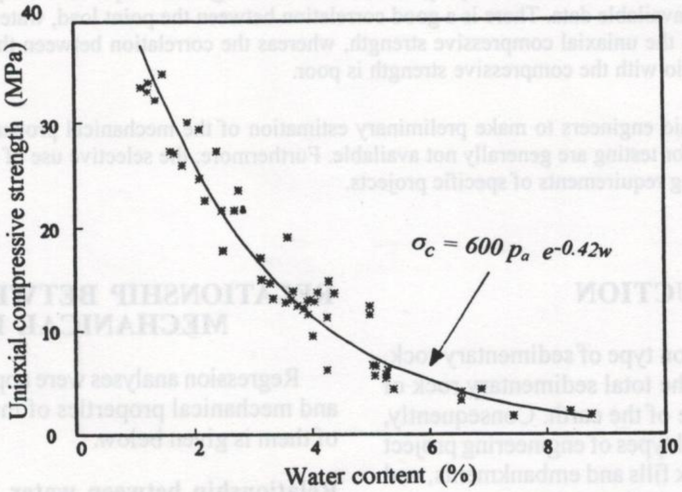


Fig. 1: Correlation between uniaxial compressive strength and water content for Ashfield Mudrock

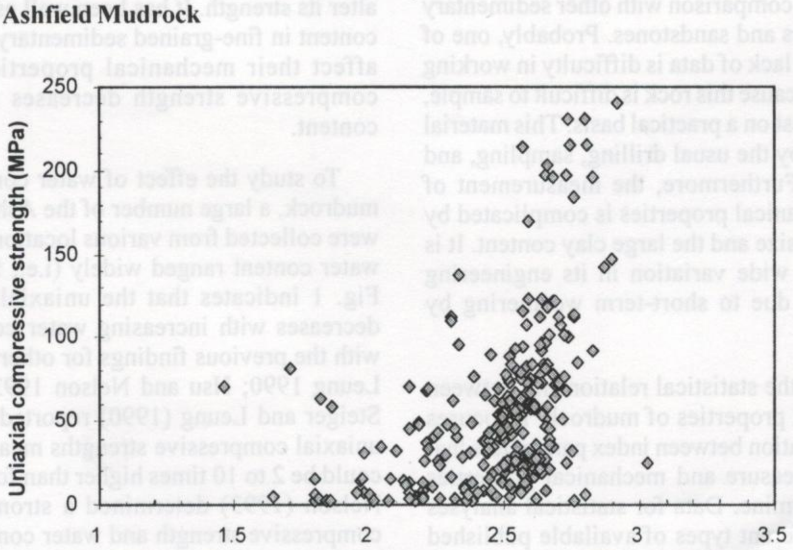


Fig. 2: Correlation between compressive strength and density

compressive strength of mudrock from different geological formations. Inoue and Ohami (1981) reported a generally poor correlation between uniaxial compressive strength and density for weak rocks (including mudrock), and the available results confirm their conclusion.

Relationship between point load index and compressive strength

The point load index is a simple, relatively quick, and inexpensive method for determination of rock strength indirectly. Whereas, the determination of the compressive strength of mudrock by employing compression testing is costly, time consuming, and is not always possible since these rocks are weak and disintegrate when immersed in water.

Uniaxial compressive strength data versus point load strength are plotted in Fig. 3. A strong correlation exists between the uniaxial compressive strength values and the point load index for both collected and tested data. The proposed relationship differs slightly from the observations of Broch and Franklin (1972), and Cargill and Shakoor (1990). This difference could be attributed to the fact that published data correspond to tests carried out on relatively isotropic rocks of high strength. However, the coefficient of correlation of 22 (i.e., y = 22 x) between the point load strength index (x) and the uniaxial compressive strength (y), as suggested by ISRM (1985), Brook (1985) and Schrier (1988), is near to the findings in this research. It seems that the coefficient of correlation varies for different lithologies, and as noted by Hawkins (1998), the values given in the literature range from less than 10 to more than 50.

The following equation was derived to allow the estimation of the uniaxial compressive strength (σ_c) of mudrock as a function of the point load strength (I_s):

$$\sigma_c = 21.43\, I_s(50) \tag{2}$$

where, $I_s(50)$ = point load index of 50 mm diameter core, and both I_s and σ_c are in MPa.

Because of the closeness of this correlation, and because the point load index of a mudrock sample is a relatively simple parameter to determine in practice, Equation (2) provides an indirect but very convenient means of estimating σ_c for the mudrock.

Relationship between porosity and compressive strength

It appears that there is a non-linear relationship of a hyperbolic nature between strength and porosity, for both tensile and compressive strengths. Fig. 4 exhibits a sharp decrease in both compressive strength and tensile strength with an increase in the porosity. A number of investigators also reported the non-linear relationship between the compressive strength and porosity (Vernik et al. 1993; Hoshino 1993; Lashkaripour and Passaris 1994).

The following expressions were derived to relate the uniaxial compressive strength and tensile strength with the porosity:

$$\sigma_c = 210.12\, n^{-0.82} \tag{3}$$

$$\sigma_t = 13.52\, n^{-0.57} \tag{4}$$

where σ_c = uniaxial compressive strength (MPa), and σ_t = tensile strength (MPa); and n = porosity (%).

Equations (3) and (4) may be used for evaluate the uniaxial compressive strength and tensile strength of mudrock when the porosity is known. Several researchers (e.g. Vernik et al. 1993; Lashkaripour 1994) reported that porosity seems to be the best single-variety predictor of strength in sedimentary rocks.

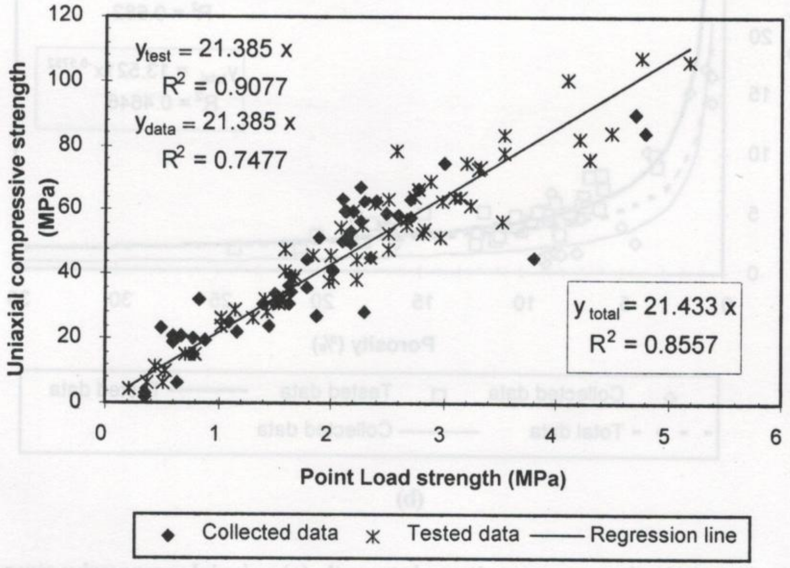
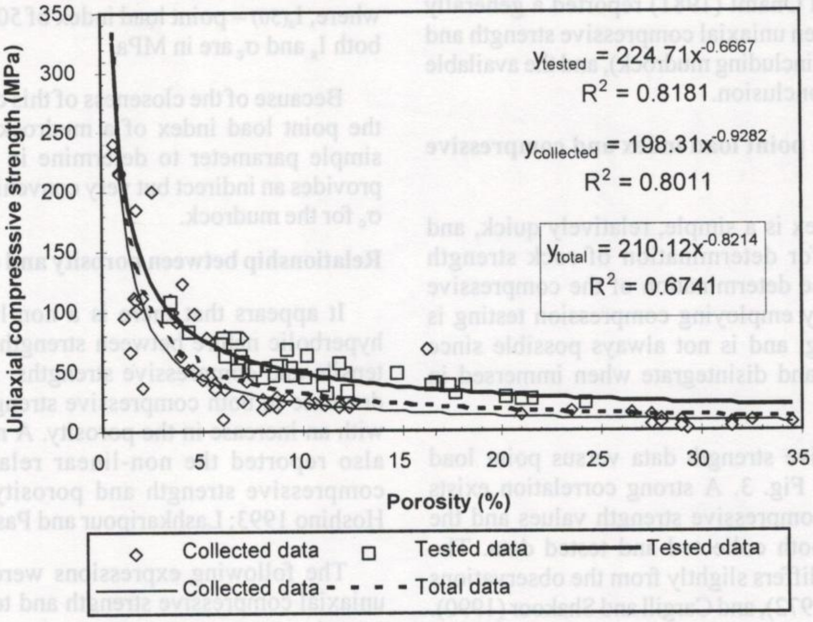
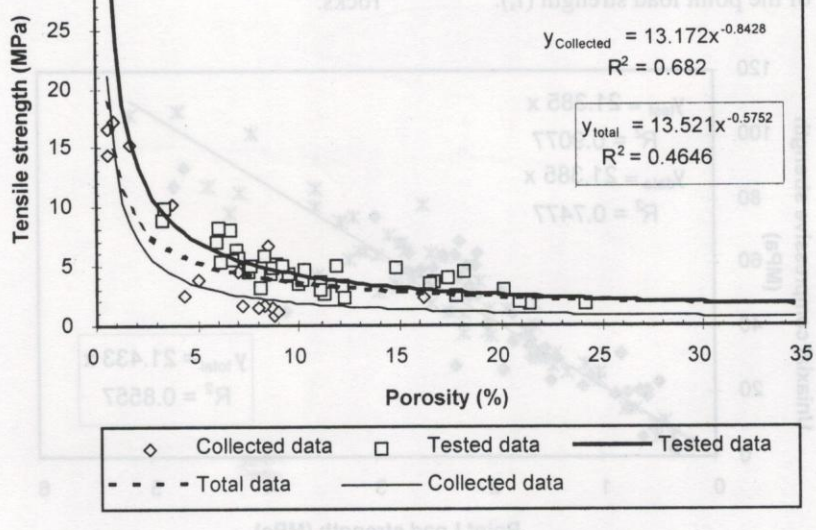


Fig. 3: Correlation between uniaxial compressive strength and point load strength



(a)



(b)

Fig. 4: Correlation between porosity and strength, (a) uniaxial compressive strength and porosity, (b) tensile strength and porosity

Relationship between modulus of elasticity and compressive strength

There is a non-linear relationship between uniaxial compressive strength and static modulus of elasticity (Fig. 5). Imazu (1986) found a linear correlation between uniaxial compressive strength and modulus of elasticity for different rock types (including mudrock). The following formula relates the uniaxial compressive strength to static modulus of elasticity:

$$E_s = 0.103\ \sigma_c^{1.086} \quad (5)$$

where, E_s = static modulus of elasticity in GPa and σ_c in MPa.

In equation (5), the independent variable σ_c is treated as a known quantity, since it is used for predicting E_s.

A log-log plot of the modulus of elasticity and compressive strength is shown in Fig. 6. It indicates ratios ranging from 19 to 903. The majority of the data (i.e., 56.9%) have modulus ratios <200 (low modulus ratio), 35.8% are in the range of 200 to 500 (medium modulus ratio), and 7.3% of data have the ratios > 500 (high modulus ratio). As shown in Fig. 6, the data have a wide range of ratios and the majority of the data cluster between the value of 100 and 500.

Several writers have reported low modulus ratios for mudrocks. For example, Franklin (1981) reported a ratio of

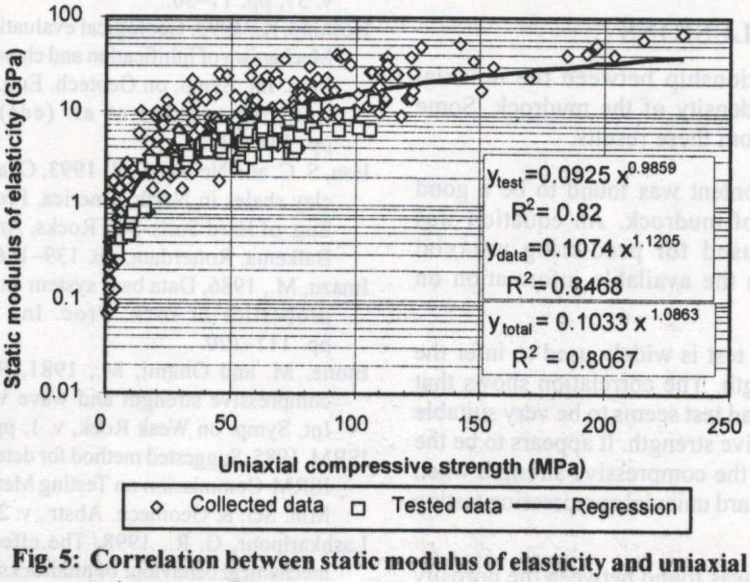


Fig. 5: Correlation between static modulus of elasticity and uniaxial compressive strength

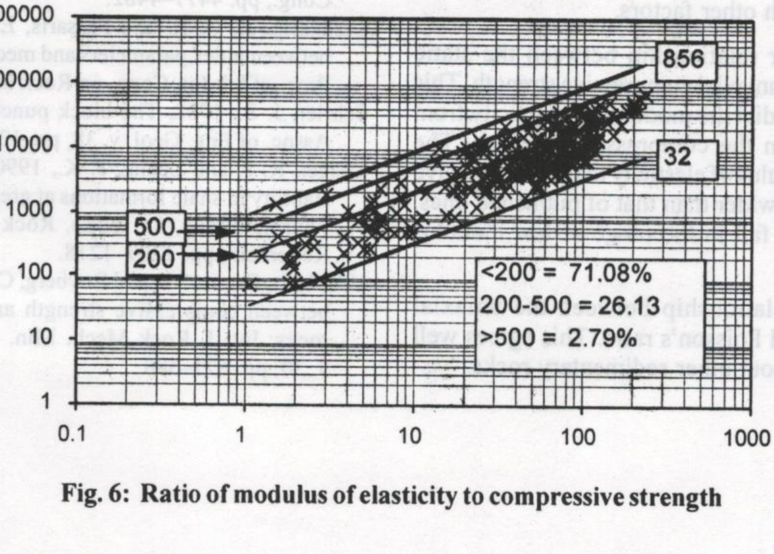


Fig. 6: Ratio of modulus of elasticity to compressive strength

modulus of elasticity to compressive strength in the range of 50–200. However, the results of this research indicate that the ratio of modulus of elasticity to uniaxial compressive strength is wider than the reported values.

Relationship between Poisson's ratio and compressive strength

A plot of uniaxial compressive strength versus Poisson's ratio indicates that there is no essential relationship between the uniaxial compressive strength and Poisson's ratio for the available data. This result was also confirmed by Imazu (1986), who reported that there was no relationship between the uniaxial compressive strength and Poisson's ratio for different rock types (including mudrocks).

CONCLUSIONS

There is no clear relationship between the uniaxial compressive strength and density of the mudrock. Some published results deviate from these results.

The natural moisture content was found to be a good predictor of the strength of mudrock. An equation was developed that may be used for predicting uniaxial compressive strength from the available information on moisture content.

The point load strength test is widely used to infer the uniaxial compressive strength. The correlation shows that the axial method of point load test seems to be very suitable for predicting the compressive strength. It appears to be the best method for estimating the compressive strength when sample preparation for standard uniaxial compression testing is problematic.

Non-linear relationship was found between the porosity and strength, for both tensile and compressive strengths. Therefore, the porosity may be considered as a good indicator of the strength of mudrock and is worthy of more detailed study in combination with other factors.

There is a non-linear relationship between the static modulus of elasticity and uniaxial compressive strength. This model may be used to predict the modulus of elasticity from the given information on the compressive strength. The range of ratios of the modulus of elasticity to the compressive strength for mudrocks is wider than that of published ones, and the majority of data fall in the range of low modulus ratios.

There is no clear relationship between the uniaxial compressive strength and Poisson's ratio. This agrees well with published results about other sedimentary rocks.

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