CHARPY IMPACT TEST TO SEDIMENTARY ROCKS

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1. ABSTRACT

In this work a relative simple experimental and theoretical procedure is presented in case of site work to determine the uniaxial strength and/or the tensile strength of a specific type of rock. Adapting the Charpy impact test for metals and/or polymers, a simplified method is presented to calculate the uniaxial strength and/or the tensile strength functions of the Permian red sandstone in function of the specific impact value, as example. For sake of simplicity a linear fitting and a polynomial approximation is suggested. The relative errors of the approximations were calculated.

KEYWORDS

Charpy hammer; impact test; rock; mechanical properties

2. Introduction

Hungary is very rich in sedimentary rocks, so this type of rock was also used as a building material in most of the buildings. Qualifying building materials, especially when it comes to natural materials is not easy, time consuming and labour intensive. A good solution for this would be the Charpy impact test, as it can be done easily and quickly. For many materials, such as metals and polymers, the standardized Charpy impact test has already been developed (e.g. for metals [1]). A further advantage of the test is that it can be performed with the test material in any condition in which it can be incorporated as a building material. From room temperature samples to frozen samples, samples with different water contents can be used to easily model the most diverse cases of everyday use. The only drawback is that the specimens must be of similar size, otherwise the results will not be comparable. This test method is addressed, inter alia, by Furuzumi et al [2,3], Borg [4], Komurlu [6], although in these articles somewhat differently and non-sedimentary rocks have been studied. In the improved version of the examination, it is already possible to monitor the formation and spread of cracks ([7,8,9,10])

3. Theoretical background

The study was originally developed by Georges Augustin Albert Charpy (1865-1945), a French scientist and university professor, for the study of metals at different temperatures [11]. Specific impact work is a measure used to characterize the toughness of structural materials, primarily metals. The harder a material is, the more energy it takes to tear or break it. The resulting measure is an empirical value, theoretically cannot be deduced from other strength properties of materials, it is suitable for ranking between individual materials.

In addition to material quality and technology, the specific impact work is also highly dependent on the test temperature and is suitable for testing the resistance of materials to brittle fracture.

High-impact materials are tough, small-impact materials are brittle. The behaviour of the material can also be judged visually from the environment of the fracture: the brittle fracture is not preceded by a large plastic deformation and contraction, the surface of the fracture is fine-grained. When the tough material breaks, the material stretches and contracts significantly (in cross-section, its cross-section decreases), the surface of the fracture is rough, possibly the last torn part shows the fine grains of the brittle fracture. Most materials exhibit brittle and then tough behaviour as the temperature increases. If impact tests are performed on a material under the same conditions only by changing the temperature, the results of the measurements may be plotted in a diagram similar to the figure. The temperature at the inflection point of the "S" -shaped curve is called the transition temperature.

Since this is not a familiar test in geology, it is important to know its theoretical background as well. When the specimen is struck (fractured), part of the kinetic energy of the pendulum is digested and the remaining part swings the pendulum further. Impact work is the impact energy used to impact (break) the test piece, which can be read on the scale of the equipment.

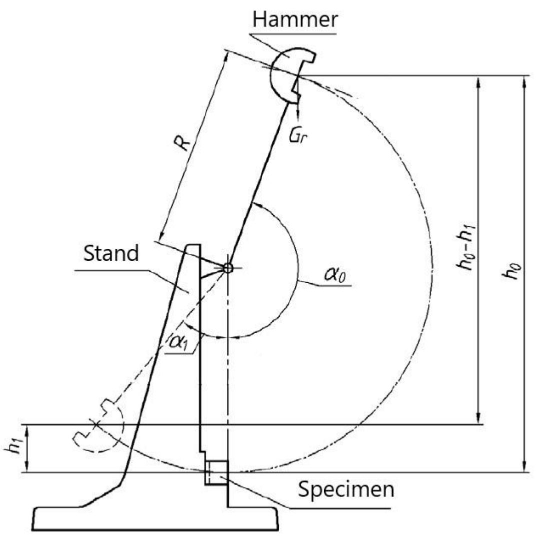

Figure 1. Theoretical arrangement of the Charpy hammer test and in the laboratory

As shown in Figure 1 above, a hammer of mass m fixed to the end of a rod of length R (Gr = m·g) starts from a position of height h_0. In this case, the gravitational (positional) potential energy:

$$E_0 = m \cdot g \cdot h_0 \tag{1}$$

After the impact, the hammer swings to a position of height h_1, where it's gravitational (positional) potential energy:

$$E_1 = m \cdot g \cdot h_1 \tag{2}$$

The difference in gravitational (positional) potential energies gives the value of the energy expended to break the specimen, i.e. the value of the impact work (W).

$$W = E_0 - E_1 = m \cdot g \cdot (h_0 - h_1) \tag{3}$$

Height measurement is problematic during measurement; therefore the value of heights is determined using the starting (α_0). and overshoot angles (α_1).

$$W = m \cdot g \cdot R \cdot (\cos\alpha_0 - \cos\alpha_1) \tag{4}$$

Impact bending machines are already designed so that the value of the impact work can be read directly by means of a drag pointer, so that the value of the impact work can be easily calculated by substituting it into the formula.

During the experiments we used Permian red sandstone in the Balaton Uplands in Hungary. The results for each sample group are shown in Table 1. Each sample group contain at least 5 specimens. The aim of the experiment is to find a correlation between the specific impact work and the compressive strength results taken from the same sample groups. In this research two types of approximations are used to determine the mathematical connection between the specific impact work and the compressive (tensile) strength. The first approximation is based on a linear curve fitting, while the second one is a polynomial approximation (Lagrange interpolation). Briefly, the strength function approximation is presented here by of the use of this C(0) continuous functions. Given a set of n+1 points in the X-Y plane (where x is the specific impact work, and y is the compressive or the tensile strength). Find the polynomial of degree n which passes through these points. The solution of the problem above can be obtained by the use of Langrange interpolation polynomials,

$$P_n(x_i) = \sum_{i=1}^{n+1} y_i \, L_i(x); \tag{5}$$

where the ith Lagrange polynomial is

$$L_i(x) = \frac{(x - x_1)(x - x_2) \dots (x - x_{i-1})(x - x_{i+1}) \dots (x - x_{n+1})}{(x_i - x_1) \dots (x_i - x_{i-1})(x_i - x_{i+1}) \dots . (x_i - x_{n+1})} \tag{6. a}$$

Introducing $\omega(x) = (x - x_1)(x - x_2) \dots (x - x_{n+1})$ the base polynomial can be calculated by

$$L_i(x) = \frac{\omega(x)}{(x - x_i)\omega'(x_i)}. \tag{6.b}$$

Here

$$L_i(x) = \begin{cases} 0; & if\ x = x_j;\ j = 1,2,\dots,i-1,i+1,\dots,n+1 \\ 1; & if\ x = x_i \end{cases} \quad (7)$$

In addition, a comparison is performed to find the relative error in these approximations (linear and polynomial) of the compressive (tensile) strength. This would greatly facilitate the development of an on-site inspection that is easy and quick to perform to get the unknown strength value if the specific impact work values (min. 3) are known.

4. New Red Sandstone

Two periods in the history of the earth have been characterized by globally extensive red sandstone formation. One is Devon (Old Red Sandstone) and the other is Perm (New Red Sandstone). In both cases, these formations formed in a semi-desert climate, in a riverine environment, and their material was the debris of a newly formed mountain system. In Devon it is the Caledonian mountain system, while in Perm it is the Variscian.

The red colour is usually due to iron oxide coatings common in desert climates, but can also occasionally be associated with fermentation. Typically, most of the composition is quartz, but feldspar, mica, jasper, volcanic pieces may also appear. In Hungary, Devonian sandstones are not usually found, especially Permian sandstones.

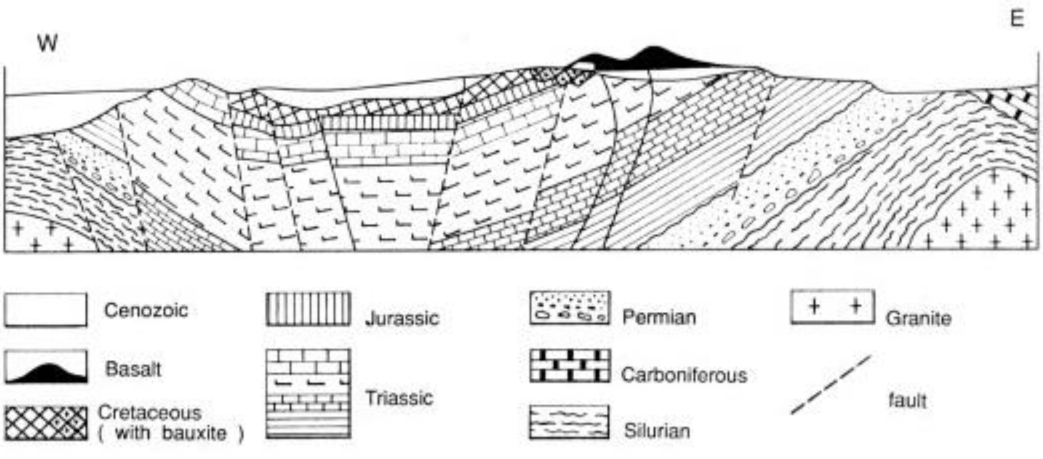

Figure 2. A conceptual geological section through the Bakony [12]

In the case of the ALCAPA microplate, the red sandstone (Balaton Uplands Sandstone formation) appears in the western part of its farthest sea from the contemporary sea, i.e. in the Balaton Uplands (figure 2).

5. Results

During the experimental program, Permian red stone was investigated. The individual samples were formed from the original block by drilling and cutting with the size and shape required for each test. The dimensions of the specimen were chosen so that they were large enough that the particles of different sizes did not affect the measurement results, but were small enough to be considered homogeneous. For sake of simplicity only three different groups of samples were formed (that is the minimum number of suggested samples). In each group the results of the impact energy test with the results of compressive strength (σ_c) and tensile strength (σ_t) were paired, respectively. By the use of these point pairs two functions (a linear and a polynomial) were calculated to determine the compressive (tensile) strength of the investigated stone in function of the specific impact work. It is noted that more samples can lead more precise strength functions.

The experimental setup is shown in Figure 1 and a sample is shown in Figures 3 and 4 before and after the test. The results obtained (Figures 5-6) are shown in diagrams.

Figure 3. The „Nr.02” sample before the test

Figure 4. The „Nr.02” sample after the test

Table 1.Properties of the samples groups

Specimen group Nr	Density	Ultrasound velocity	UCS	Tensile strength (TS)	Specific impact work
	g/cm^3	km/s	MPa	MPa	J/mm^2
1	2.58	3.83	23.10	2.14	0.013
2	2.20	3.83	28.68	2.45	0.015
3	2.60	3.90	38.61	2.86	0.018

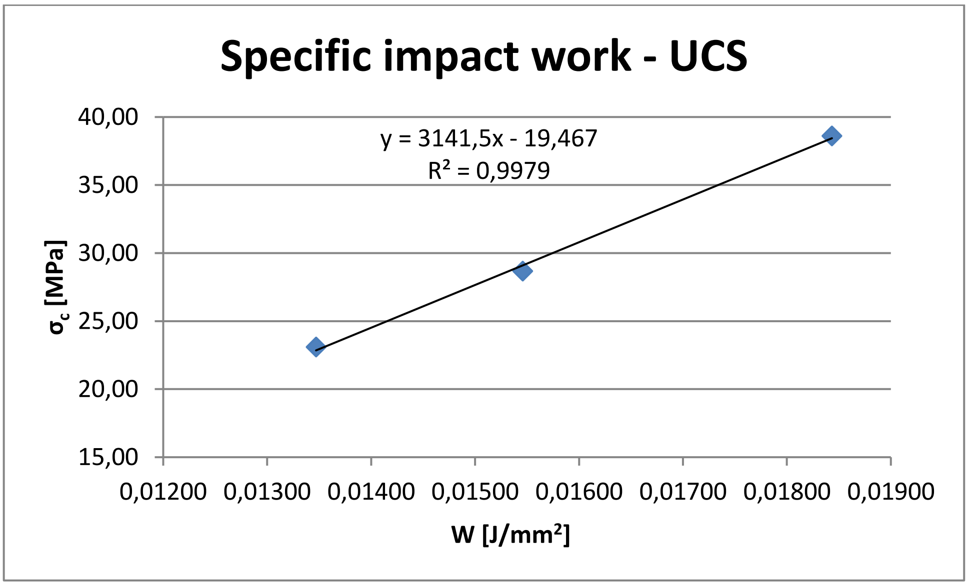

Figure 5. The connection between impact work and UCS (σ_c)

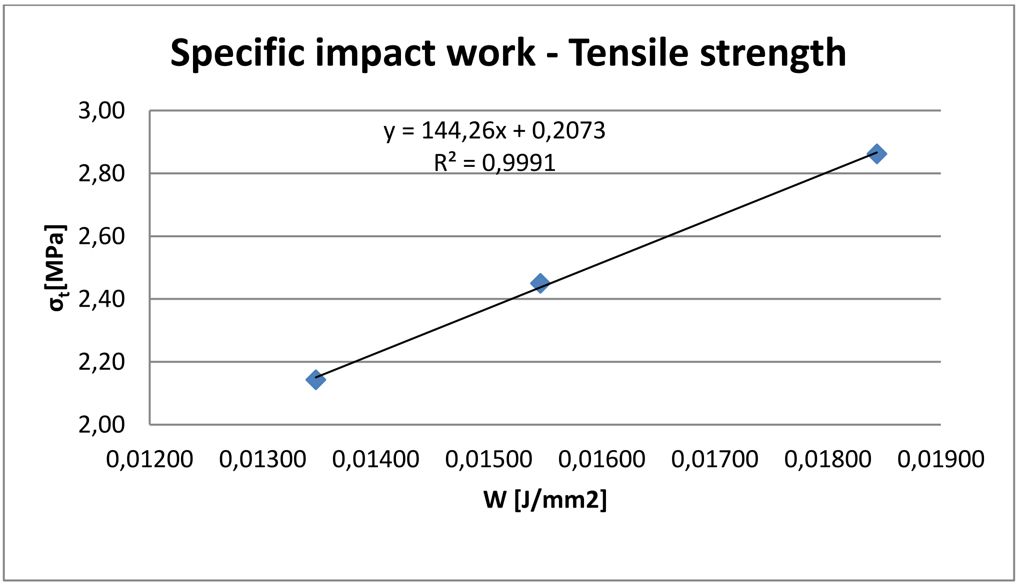

Figure 6. The connection between impact work and tensile strength (σ_t)

The linear approximation is performed by the use of Microsoft EXCEL program. The sample point pair lead for

$$\sigma_c(W) = 3141.5 \cdot W - 19.467 \cdot [MPa] \tag{8}$$

$$\sigma_t(W) = 144.26 \cdot W + 0.2073 \cdot [MPa] \tag{9}$$

Neglecting the details the base polynomials are in case of polynomial approximation -$C^{(0)}$ continuous-
:

$$L_1 = \frac{W^2 - 0.0339 \cdot W + 0.000285}{9.87 \cdot 10^{-6}} \tag{10.a}$$

$$L_2 = \frac{W^2 - 0.0319 \cdot W + 0.000248}{-5.92 \cdot 10^{-6}} \tag{10.b}$$

$$L_3 = \frac{W^2 - 0.0289 \cdot W + 0.000208}{1.48 \cdot 10^{-5}} \tag{10.c}$$

$$\begin{aligned} \sigma_c(W) &= 23.1 \cdot L_1(W) + 28.68 \cdot L_2(W) + 38.61 \cdot L_3(W) = \\ &= 106986.52 * W^2 - 288.07 \cdot W + 7.589 \end{aligned} \tag{11}$$

$$\begin{aligned} \sigma_t(W) &= 2.14 \cdot L_1(W) + 2.45 \cdot L_2(W) + 2.86 \cdot L_3(W) = \\ &= -3651.12 * W^2 + 261.56 \cdot W - 0.7189 \end{aligned} \tag{12}$$

By the use of these functions one can determine the strength (compressive or tensile) values by the use of the specific impact values.

As an example let check the relative error if W=0.017 J/mm^2 is given. By the use of linear fitting the compressive (eq.8) strength is σ_c(0.017)=33.94 MPa, while the tensile (eq.9) strength is σ_t(0.017)=2.66MPa.

By the use of Lagrange approximation these values are:

σ_cL(0.017)=33.59MPa and σ_tL(0.017)=2.67MPa.

The relative errors are:

uniaxial compressive strength Δ%=(33.94-33.59)/(2*33.59)*100%=0.52%

the tensile strength Δ%=(2,67-2.66)/(2*2.66)*100%=0.19%

As a conclusion one can state that the relative error is small in these particular examples.

6. Conclusion

As shown in the diagrams, the Charpy hammer impact energy test can be used not only for steels but also for rocks. By the use of linear fitting or Lagrange type polynomials, the strength functions for uniaxial compressive strength and tensile strength can be determined. These functions provide a possibility to determine the unknown strength values for specific stones if the impact values are known. Comparing the results of each group of samples, the relationship between the impact energy analysis of samples with the same temperature and saturation state and their compressive and tensile strength can be seen. To determine the relationship more precisely, it is necessary to continue the research, both quantitatively with more samples and with samples with different temperatures and saturation states. In addition the model uncertainties and other probabilistic quantities (e.g. distributions of the measured values) can be considered during determination of the strength function functions.

7. Acknowledgements

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