IMPACT STRENGTH OF BRITTLE MATERIALS (ROCKS)

COMPARISON OF THE "PROTODYAKONOV" AND "AIV" (AGGREGATE IMPACT VALUE) METHODS

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Introduction

- The concrete consists of 70-80 vol. % by aggregates. This contributes to the low cost of the concrete, since the aggregates as raw materials are cheap and they are produced by simple and relative low-cost methods (mining, crushing, classification and wet scrubbing).

- The concrete quality is significantly influenced by the aggregates quality. The properties of the aggregates influence the durability and the static behavior of the concrete constructions.

AGGREGATES-PROPERTIES

They depend on the properties of the parent rock, which are:

- chemical and mineralogical composition
- petrographic origin
- specific gravity
- hardness
- strength and elasticity
- physical and chemical stability (behavior)
- particle shape and surface texture
- porosity, absorption and permeability and
- color.

TESTING MECHANICAL PROPERTIES OF AGGREGATES

- Aggregates are subjected to various dynamic stresses (impact, compression, abrasion).
- It must be thoroughly tested for their mechanical properties and their performance.
- Standard methods have been adopted (A.S.T.M., BS, D.I.N., etc.).

- In brittle fracture, the cracks run close to perpendicular to the applied stress. This leaves a relatively flat surface at the break. Besides having a nearly flat fracture surface, brittle materials usually contain a pattern on their fracture surfaces. Some brittle materials have lines and ridges beginning at the origin of the crack and spreading out across the crack surface.

Aggregates impact testing

- **Impact testing** measures the energy required to break a specimen by dynamically applying a load.
- Impact strength is one of the most commonly tested and reported properties of brittle materials in which the aggregates also belong.
- As the cement and concrete industry grows, so do the number of different methods for measuring impact strength of the aggregates - with each method having its own inherent advantages and disadvantages.

Fracture

- Fracture: separation of a body into pieces due to stress, at temperatures below the melting point.

  Steps in fracture:
  - crack formation
  - crack propagation

- Depending on the ability of material to undergo plastic deformation before fracture,

  two fracture modes can be defined –

  ductile or brittle

Ductile & Brittle Fracture

- **Ductile fracture** - most metals (not too cold):
  - Extensive plastic deformation ahead of crack
  - Crack is “stable”: resists further extension unless applied stress is increased

- **Brittle fracture** - ceramics, ice, cold metals, brittle rocks:
  - Relatively little plastic deformation
  - Crack is “unstable”: propagates rapidly without increase in applied stress.

Fundamental Interpretations of Fracture

- **Strain energy approach to fracture**

  The work (*W*) done by a force (e.g. falling hammer) acting on a surface (e.g. mass of rock particles) is converted into:

  - recoverable elastic energy (*U*) and
  - energy which is used for the creation of new surfaces through crack propagation, i.e.

$$\text{Work done} = \text{Elastic energy} + \text{Surface energy}$$

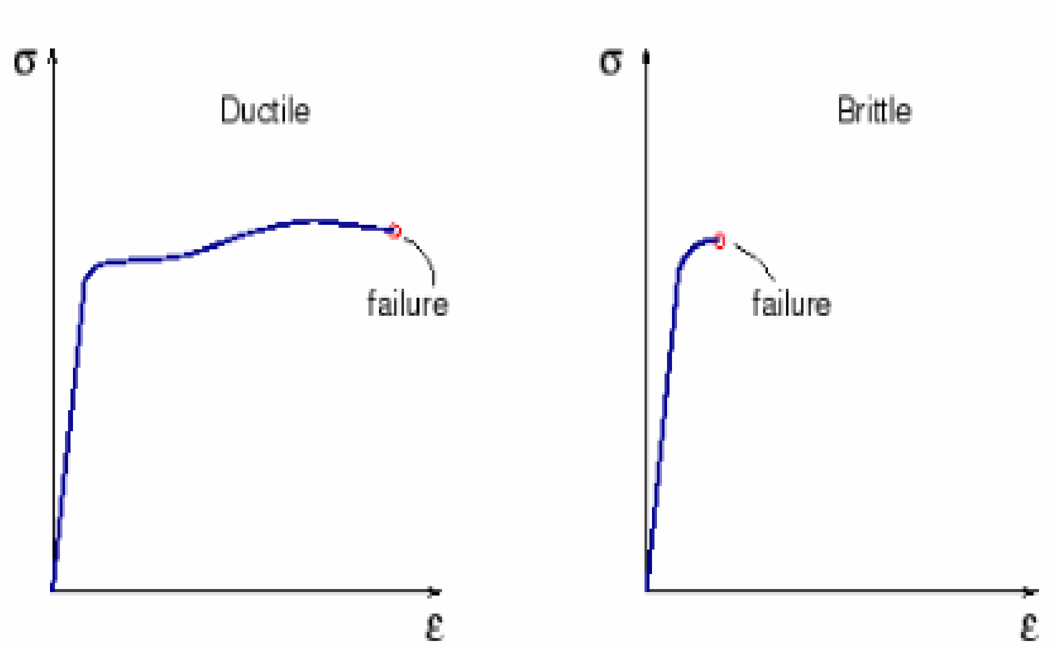
However, unstable crack growth responsible for brittle fracture results when the incremental change in the difference between the work done and the elastic energy exceeds the energy requirements for the creation of a new surface (crack):

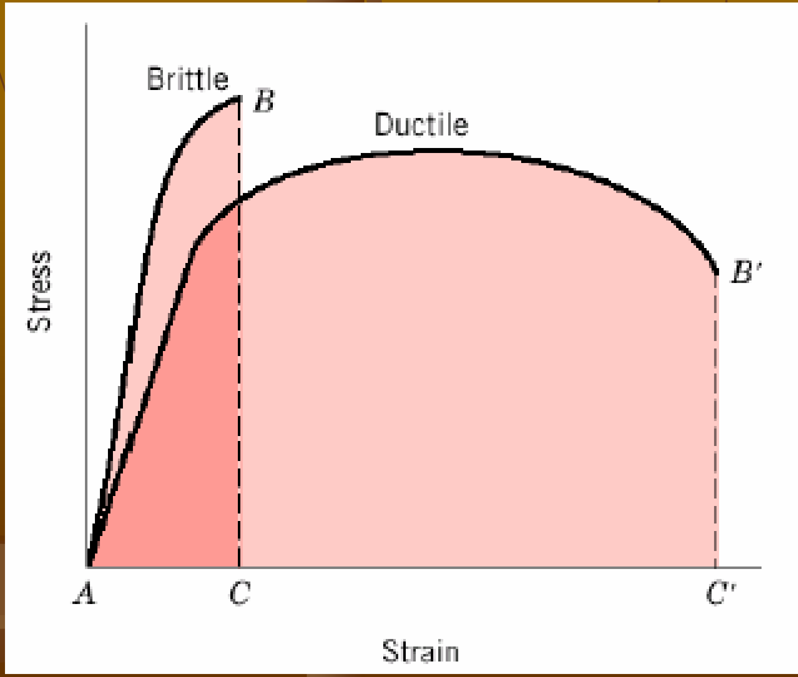
$$\frac{\partial}{\partial a}(W - U) > \gamma \frac{\partial A}{\partial a}$$

- where γ is the surface energy per unit area (A) and a is half the length of a crack.

Brittle vs. Ductile Fracture

- **Ductile materials -** extensive plastic deformation and energy absorption ("toughness") before fracture
- **Brittle materials** - little plastic deformation and low energy absorption before fracture.





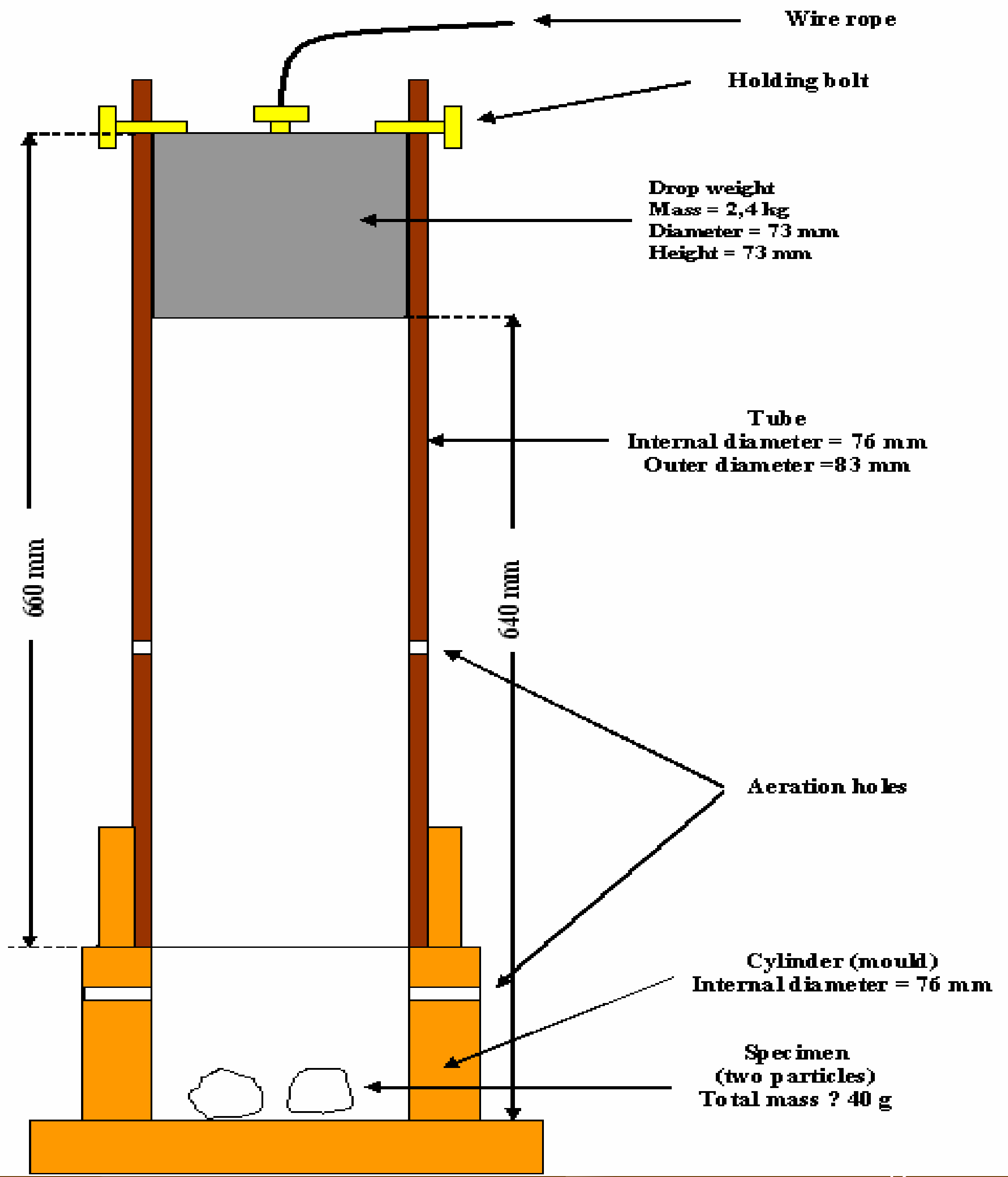
METHODS USED FOR AGGREGATES IMPACT TESTING

- Three basic factors contribute to a brittle-cleavage type of fracture. (*a*) *triaxial state of stress*, (*b*) *a low temperature*, and (*c*) *a high strain rate or rapid rate of loading* (*e*.g. impact stress).
- All three of these factors do not have to be present at the same time to produce brittle fracture. A triaxial state of stress, such as exists at a notch, and low temperature are responsible for most service failures of the brittle type. However, since these effects are accentuated at a high rate of loading, many types of impact tests have been used to determine the susceptibility of materials to brittle behavior.
- Standard tests evaluated here are the Protodyakonov's test and the AIV test (Aggregate Impact Value) used for the determination of the strength of brittle materials (rocks) in impact and compression stresses. The materials, whose impact strength is tested, are limestone, emery and quartzite.

Operating conditions of the various impact test procedures

METHOD	Falling mass, kg	Height of fall, m	Mass of the specimen, g (e.g. 2.7 g/cm^3)	Number of blows, N
Schlagversuch	50	0.37	1350	10
Aggregate impact value (AIV)	13.5-14.0	0.38	640	15
TRETON	15	0.412	135	10
Protodyakonov	2.4	0.64	≈ 40 (2 particles)	Varying

PROTODYAKONOV'S rock strength drop tester



Protodyakonov's test

- For the prediction of the Protodyakonov rock strength coefficient F_N, by the modified from the U.S. Bureau of Mines method, a sample of total weight (g) equal to **75** times of the specific gravity of the rock (g/cm^3) is suitably prepared.
- Every sample consists of ten (10) irregularly shaped particles weighing about **20 g** each, depending on the specific gravity of the material tested.
- For every test, two particles (≈40 g) are put on the bottom of the **Rock strength drop tester** and are crushed by a specific number N of hammer drops. The particles suffer strains and fatigue like those of brittle materials.

Protodyakonov's test (cont'd)

- The strength of each specimen (2 particles) is tested by using, progressively, an increasing number of drops (e.g. 5, 10, 15, 20, 25). Each crushed sample is sieved through a U.S. series No. 35 mesh (0.5 mm) sieve and the mass of the -0.5 mm material produced is determined.
- The solid volume (V_N) of the undersize material is determined from the ratio of the mass (W_N) and the specific gravity (ρ) of the material. ($V_N = W_N / \rho$).

Protodyakonov's test (cont'd)

- The number of drops (N), used to produce the certain volume (V_N) of -0.5 mm material, divided by the volume V_N gives the value of the impact rock strength coefficient (F_N) for this particular number of drops.
- Thus, the Protodyakonov's impact strength coefficient $\boldsymbol{F_N}$, for a specific number N of the hammer falls, is given by:

$$F_N = N / V_N$$

Where:

- N is the number of the free falls
- and V_N is the mean solid volume of the –0,5 mm material produced after N hammer drops.

Protodyakonov's test (cont'd)

- After completing the test procedure for all specimens, a graph ($\boldsymbol{F_N}$, N) is constructed.
- The rock strength coefficient $\boldsymbol{F}_{\mathrm{N}}$ is graphically determined from the curve ($\boldsymbol{F_N}$, N) and corresponds to the minimum value of the curve.
- This minimum value of F_{N} is, by definition, the impact rock strength coefficient (F_{N}), as representing the optimum specific crushing energy (minimum impact energy per unit volume of -0.5 mm material). F_{N} has dimensions cm^{-3}.

It has been previously proved that it correlates with relative accuracy with the mechanical properties of the rock, such as:

- Toughness
- Modulus of resilience
- Uniaxial compressive strength
- Shore hardness and
- Drillability of the rock

Protodyakonov's test (modification)

Here, a ***modified procedure*** is proposed for the determination of the Protodyakonov's rock strength coefficient F_N.

- The modification, applied to the procedure adopted by the U.S. Bureau of Mines, is shown in the ***flow diagram*** of the next slide.
- From the F_N values corresponding to each product (undersize material), graphs (F_N , N), similar to those shown in the following slides, are constructed.
- Then, the minimum F_N values are graphically determined.

Protodyakonov's Test (New modification)

SPECIMEN (2 Particles)
Mass ≈ 40 g

1[st] Test
(5 Hammer drops)

Classification in size fractions

Recombination of the size fractions

2nd Test
(10 Hammer drops)

Classification in size fractions

Recombination of the size fractions

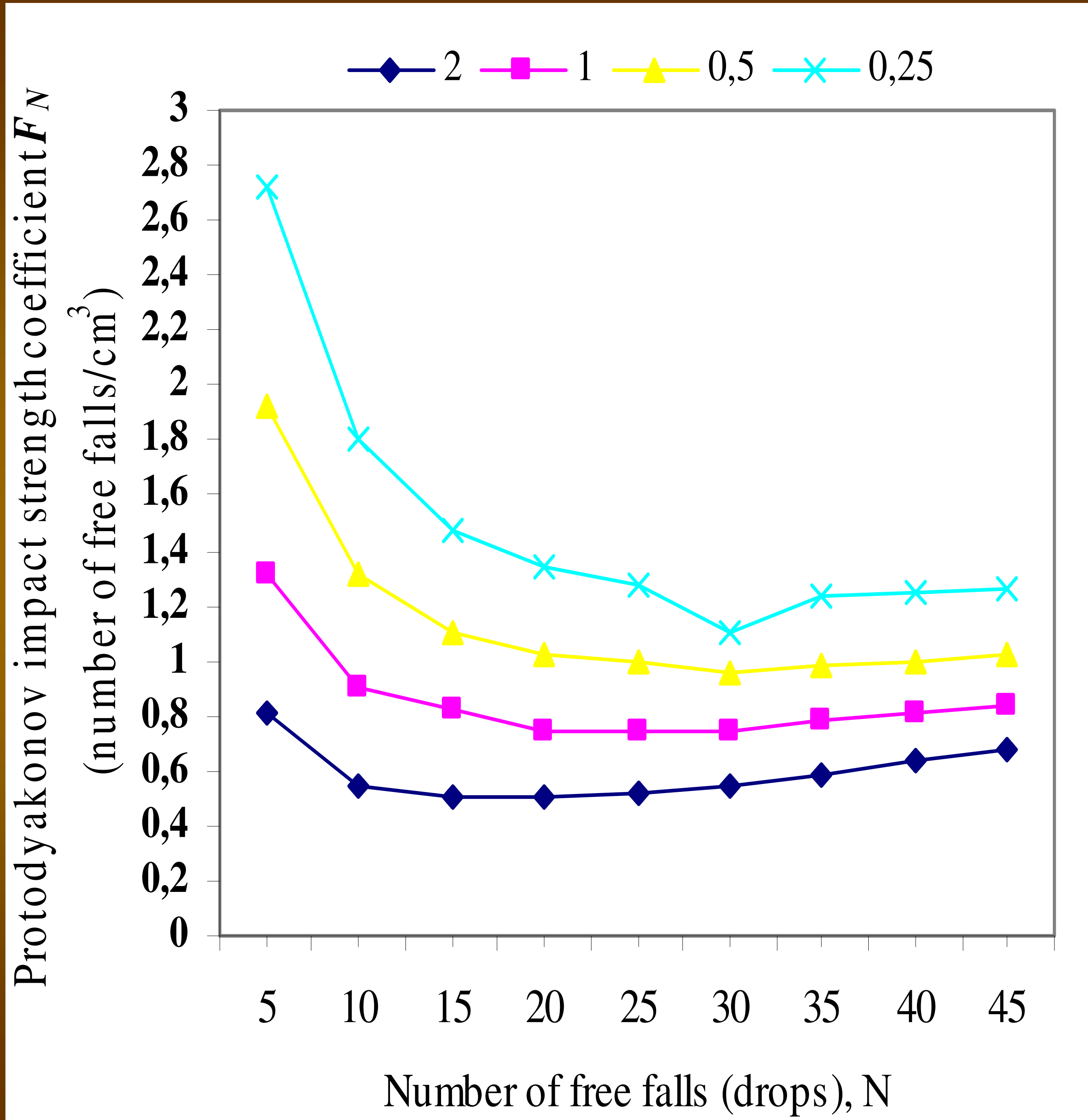
3[rd] Test etc.

Final Test (e.g. 45 Hammer drops)

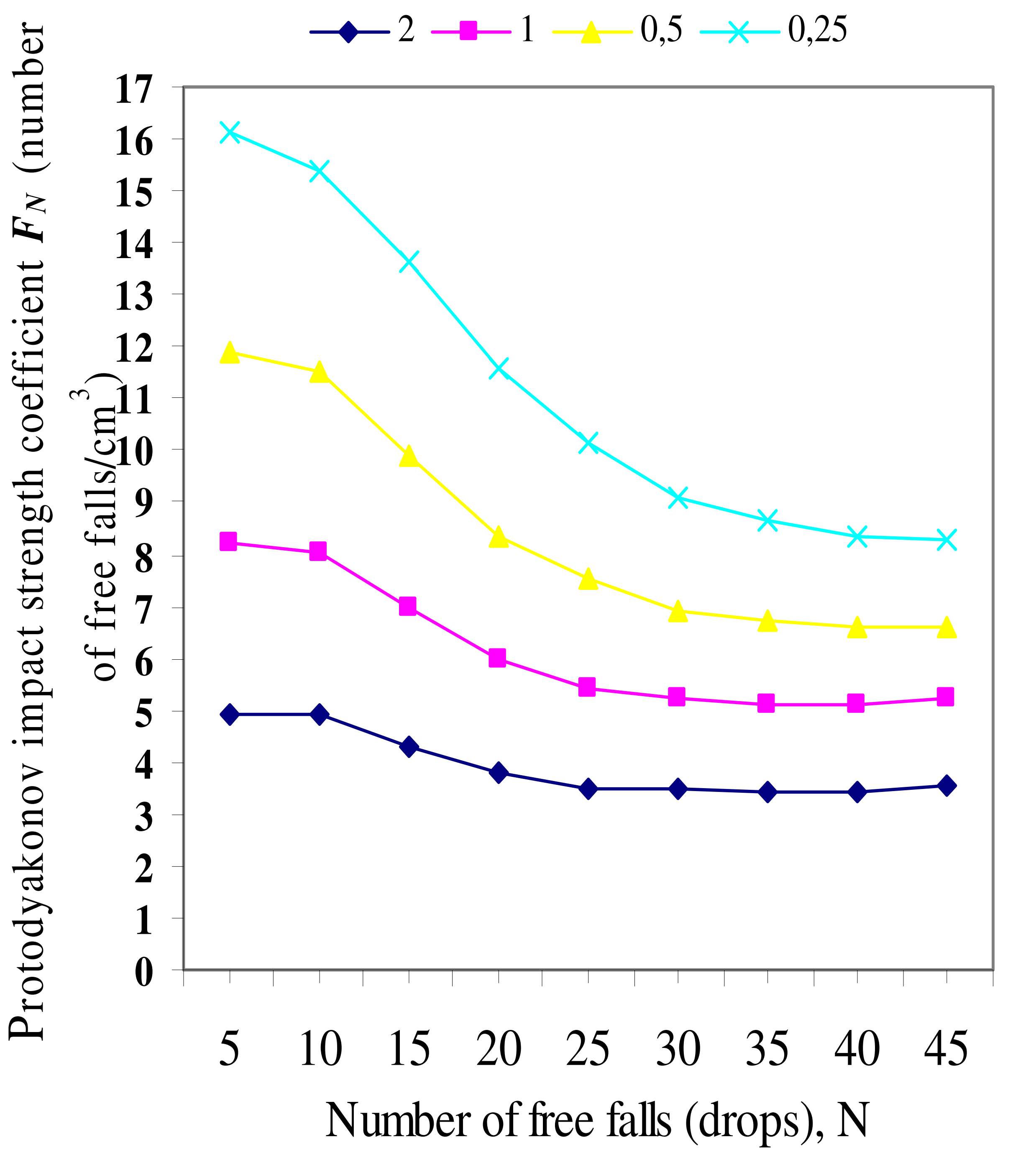
Classification in size fractions

Weighing & F_N prediction

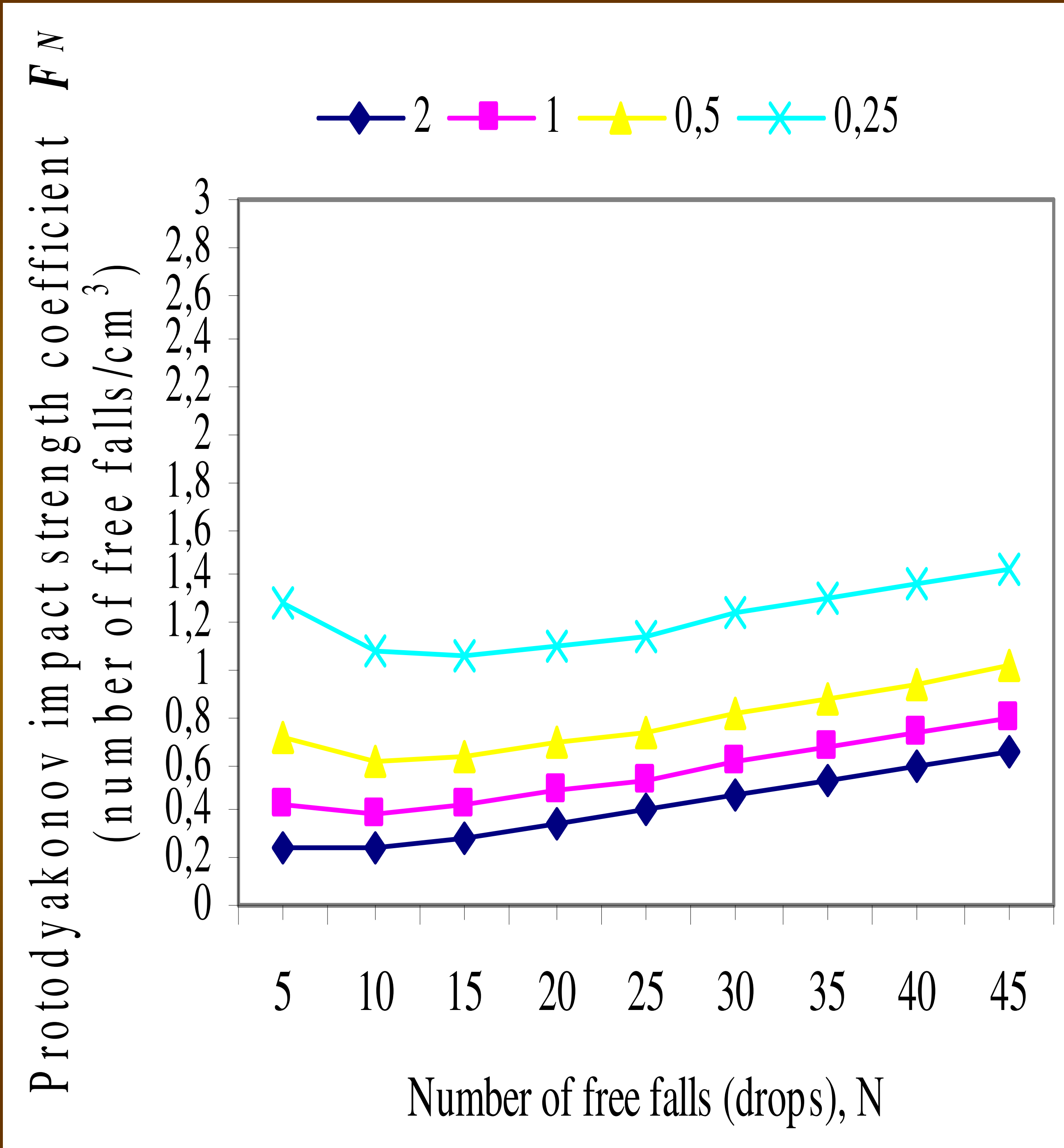
Protodyakonov's IMPACT STRENGTH COEFFICIENT of Limestone



Protodyakonov's IMPACT STRENGTH COEFFICIENT of Emery



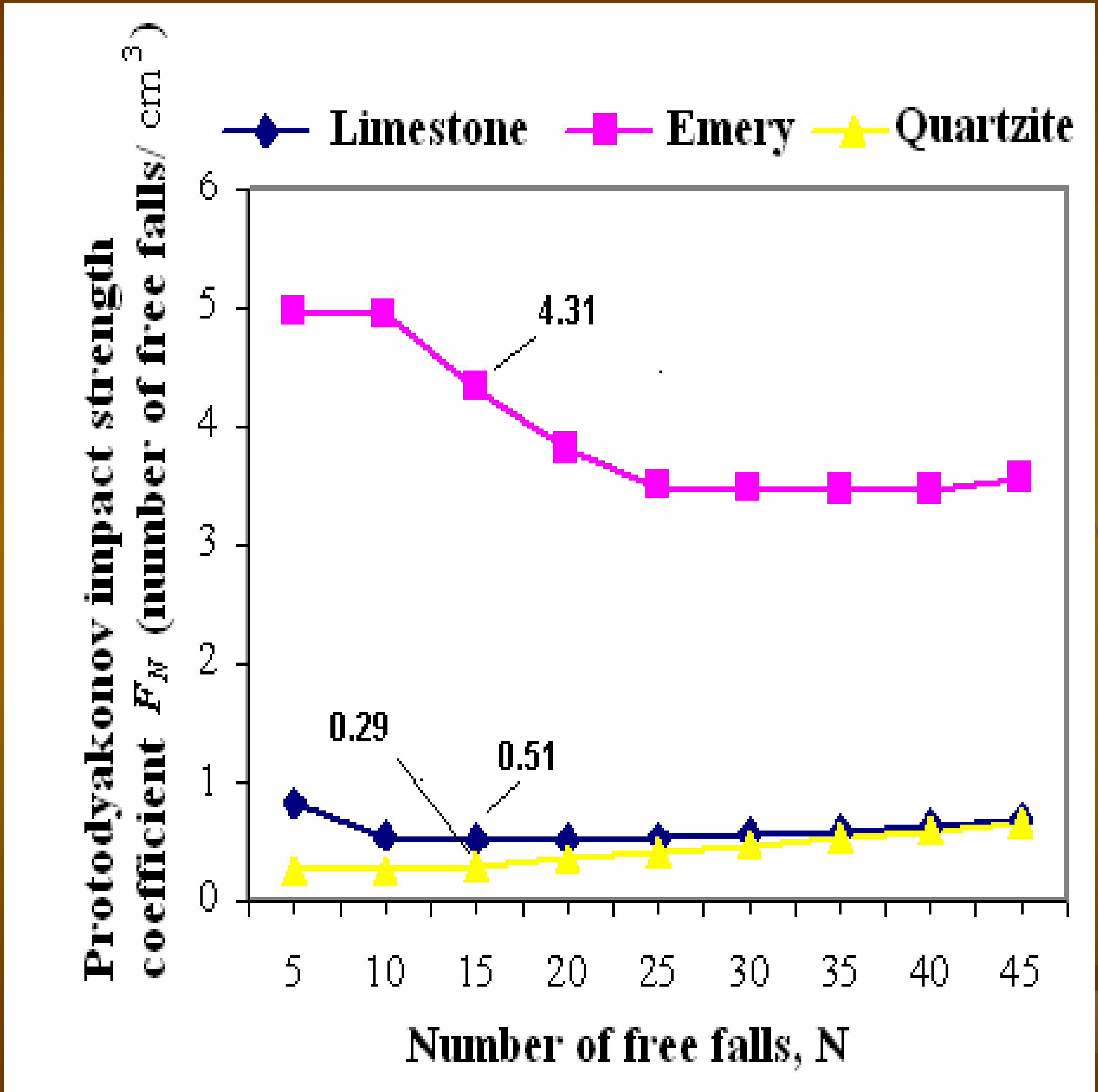
Protodyakonov's IMPACT STRENGTH COEFFICIENT of Quartzite



PROTODYAKONOV'S
Impact strength
(size fraction -2 mm)

Comparison of

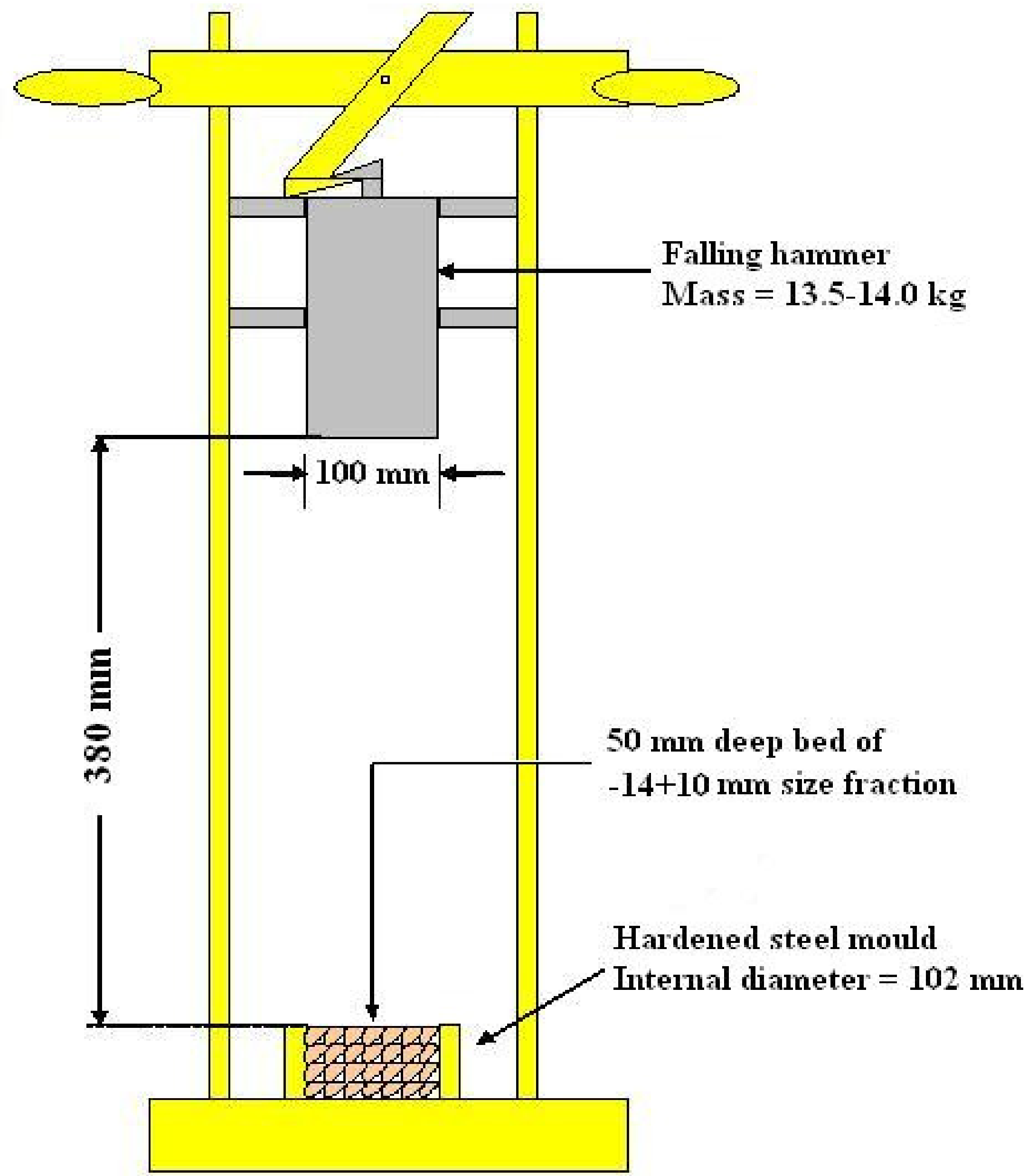
Limestone
Emery
Quartzite



Test AIV (Aggregate Impact Value, *SS 1974*)

- The AIV (Aggregate Impact Value) is a standard test procedure by which the impact strength of aggregates is tested. Just like in Protodyakonov's test, the material used consists of irregularly shaped particles of the -14 + 10 mm size fraction. The weight of the specimen is *A*.

AIV Apparatus



Aggregate impact value (AIV) test procedure

- The two (2) specimens tested are subjected to 15 blows of the hammer dropping 380 mm, at an interval not less than one second.
- The crushed material is removed from the mould and then it is sieved over a 2.36 mm sieve. The mass of the material passing (*B*) and the retained fraction on the sieve (*C*) are weighed to the nearest 0.1 g.
- If $A-(B+C)>1$ g, the result is discarded and the test is repeated with fresh material. The AIV value is calculated from the average of the two tests:

$$AIV = (B / A) \times 100(\%)$$

Conclusions

Applying the Protodyakonov's test procedure for the determination of the impact strength of the three rocks results in:

- The impact rock strength (F_N) of quartzite is lower than that of limestone, for all size fractions tested. This obviously happens, because the quartzite presents greater brittleness than the limestone.
- Emery, as it was expected, presents greater impact strength than the other rocks examined.

Conclusions (cont´d)

- The rock impact strength, according to the AIV method, shows the same tendency of that presented by the Protodyakonov's results.
- The percentage % mass loss (-2.36 mm) calculated from the AIV method is: only 3.68% for the emery and 9.56, 13.6% for the limestone and the quartzite, respectively.

COMPARISON OF THE TWO METHODS

Material	Specific gravity, g/cm^3	**Impact strength for 15 hammer falls (drops)**		Bond work index W_i, kWh/short ton
		Protodyakonov, 2 mm	**AIV, 2.36 mm**	
Emery	3.48	4.31	3.68	56.7
Limestone	2.65	0.51	9.56	12.54
Quartzite	2.68	0.29	13.62	9.58

Conclusions (cont´d)

- The two methods use irregularly shaped specimens (particles).
- Thus, they present certain advantages over the alternative standard tests (compression και tensile tests) in which regularly shaped specimens (cylinders, cubes) are required. The alternative methods present increased cost and are time-consuming for performing the tests.
- The Protodyakonov's method can also be utilized for the determination of the impact strength of other brittle materials (ceramics, cold metals, etc.).

Conclusions (cont´d)

- The AIV method **is preferable** than that of Protodyakonov for a «rough» prediction of the impact strength of the rocks, because:

  - The AIV method is simpler in its application than the Protodyakonov’s (except sizing, no need for particle size preparation of the test sample is required)

  - The AIV method can be ranked as **more reliable due to the greater** mass of the sample tested (at least 15 times that used in Protodyakonov’s test).

Thank you very much

Vielen Dank auf ihre Aufmerksamkeit