Measure of Rock Mechanical Properties from Scratching Test

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ABSTRACT

THE PRESENT PAPER PRESENTS A PORTABLE APPARATUS, THE ROCK STRENGTH DEVICE (RSD), AND METHODOLOGY TO ASSESS STRENGTH OF COHESIVE GRANULAR MATERIALS "PARTIALLY-DESTRUCTIVE" SCRATCHING TESTS.

EXPERIMENTS ON SEVERAL SEDIMENTARY ROCKS SHOW THAT THE COEFFICIENT OF PROPORTIONALITY, REFERRED TO AS THE INTRINSIC SPECIFIC ENERGY ε, IS WELL CORRELATED TO MATERIAL UNIAXIAL COMPRESSIVE STRENGTH, UCS.

FURTHERMORE, THE FRICTION COEFFICIENT μ MOBILIZED ALONG THE WEAR FLAT OF BLUNT CUTTER IS FOUND TO BE WELL CORRELATED TO THE INTERNAL FRICTION ANGLE OF THE ROCK.

THE HIGH SPATIAL RESOLUTION AND PRECISION OF THE FORCE MEASUREMENT PROVIDES FINE LOGGING OF THE TWO ROCK PROPERTIES (ε, μ) AND THUS PERMIT TO ISOLATE WEAK OR DAMAGED INTERVALS, AND CAPTURE HETEROGENEITIES OR ANISOTROPIES.

THE PAPER PRESENTS A PARTICULAR PETROLEUM APPLICATION ON CORE ANALYSIS WHERE UNDERSTANDING THE VERTICAL VARIABILITY OF ROCK PROPERTIES ALONG A RESERVOIR TICKNESS IS OF PRIMORDIAL IMPORTANCE FOR SANDING PREDICTION ANALYSIS, AND SOME OTHER FIELD APPLICATIONS FOR WHICH THE SCRATCHING TEST HAS BEEN USED.

I - Test principle & Experimental apparatus

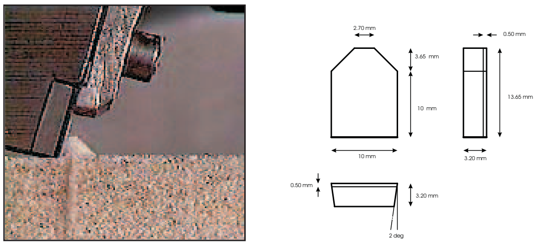


Figure 1 : Picture of the cutter while scratching a sample of Berea sandstone, d = 0.4 mm and drawing of the cutter.

Test principle :

The "scratching" test consists in tracing a groove at constant shallow depth on the surface of a sample with a rectangular cutter of width w. The cutter is inclined by an angle θ = 15° and is displaced at constant horizontal velocity v.

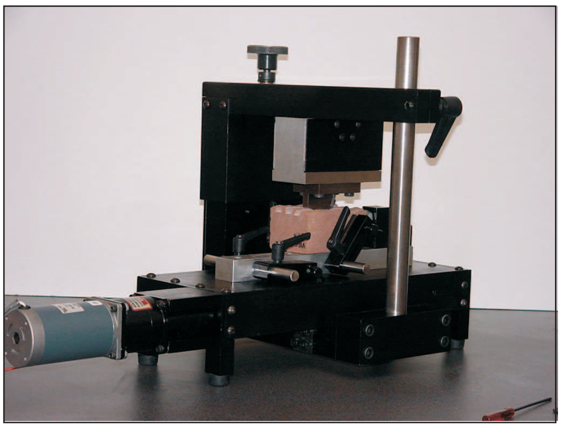


Figure 2 : The Rock Strength Device (RSD)

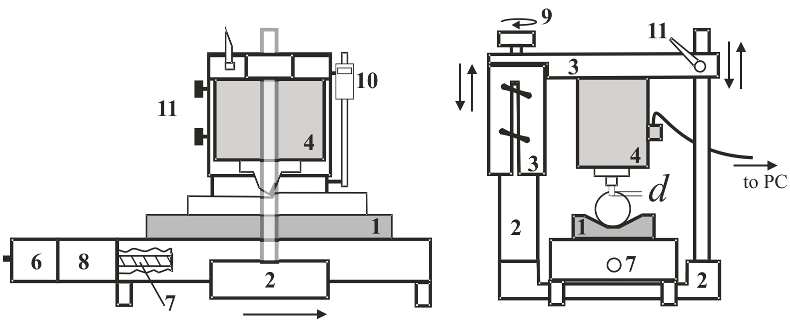


Figure 3 : Conceptual sketch of the Rock Strength Device

The Rock Strength Device (figure 2) consists mainly of a frame, a load sensor, a driving motor and a data acquisition system. The main components of the device are shown in figure 3 : a traverse with a sample holder of length L (indexed 1), a moving cart (2) housing the vertical positionning system (3), the load cell (4), and the cutting element holder (5). The horizontal movement of the cart is operated by a computer controlled stepper-motor (6) driving a horizontal motion Archimedes screw (7) via a gear box (8). A micrometer (10) indicates the depth of cut, adjusted manually with the positionning system (9). The vertical traveling mechanism is locked (11) against the frame, in order to maintain a constant depth of cut while cutting. The load sensor measures the horizontal F_s and vertical F_n components of the force F acting on the cutter. It has been fully calibrated by the manufacture with the cutter holder mounted on it and the force applied at the tip of the cutter. The complete acquisition ligne (sensor, amplifier, AtoD converter) achieves 0.5% cross-talk and about 0.5 N of precision over the entire measurement range [0-4000 N]. The scanning rate is typically set at 25 samples per millimeter. The main characteristics of the experimental setup are summarized in Table 1.

Table 1 : Characteristics of the RSD and experimental procedure

θ	w (mm)	v (mm/s)	d (mm)	L (mm)	m (kg)	F_s,F_n (N)
15	10	4 - 10	0.1 - 1	200 – 1000	35 – 75	0 - 4000

II - Cutting Modes

Experiments indicate that rock cutting is associated with a ductile or a brittle mode of failure depending on the depth of cut.

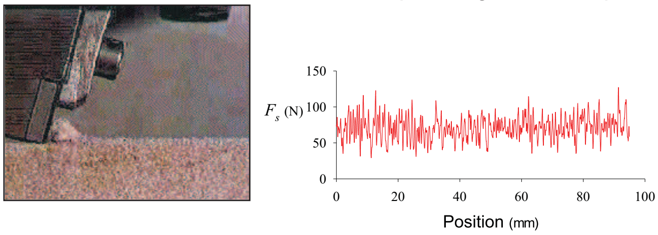


Figure 4 : Ductile mode

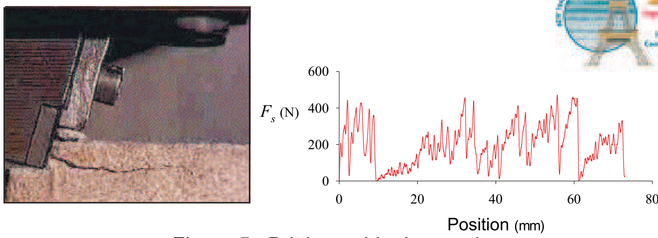


Figure 5 : Brittle or chipping mode

The ductile mode takes place at shallow depth of cut and is associated with plastic flow. The force signal may be viewed as a white noise.

The brittle mode occurs above a threshold depth of cut and is characterized by the propagation of tensile crack. The force signal presents a marked sawtooth pattern. The abrupt drop of the force after a peak is associated with unstable propagation of the crack leading ultimately to the formation of a chip.

III - Cutting Model within ductile mode

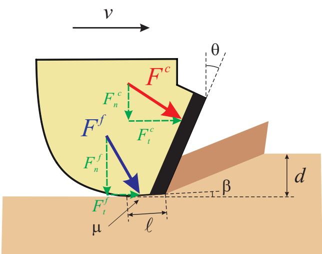


Figure 6 : Independance of pure cutting and frictional contact

Two contributions :

1. Pure cutting on the cutting face ;
2. Friction underneath the cutter.

$$F = F^c + F^f$$

Both contributions have been prooved to be independant.

1. Pure cutting - sharp cutter

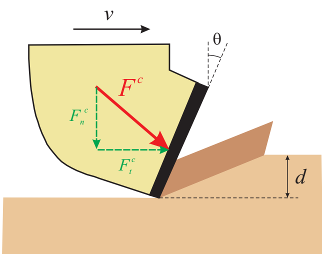


Figure 7 : Force acting on a sharp cutter

Within the ductile mode, the force acting on the cutting face is found to be proportional to the cross sectional area of the groove being traced. The coefficient of proportionality is called the intrinsic specific energy.

$$F_t^c = \varepsilon w d$$

$$F_n^c = \zeta \varepsilon w d$$

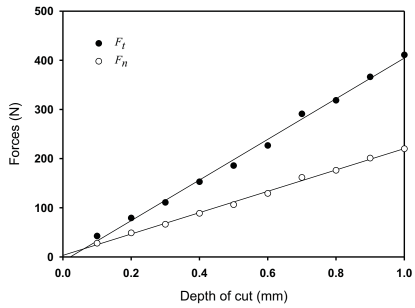


Figure 8 : Evolution of F_t and F_n with wd, w = 10 mm, Lens Limestone.

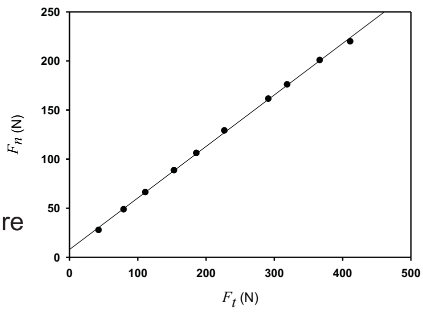


Figure 9 : Evolution of F_n with F_t, w = 10 mm, Lens Limestone.

2. Frictional contact on the wear flat

The normal and tangential components of the frictional force are related according to a friction law :

$$F_t^f = \mu F_n^f$$

3. Cutting response of a cutter

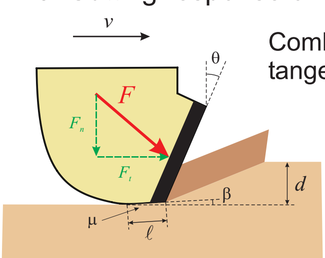


Figure 10 : Force acting on a blunt cutter

Combining the two processes (pure cutting and frictional contact), the relationship between the tangential and normal components of the total force acting on the cutter is given by :

$$F_t = (1-\mu\zeta)\varepsilon w d + \mu F_n$$

Defining the specific energy E and the drilling strength S respectively as :

$$E = F_t/wd \quad \text{and} \quad S = F_n/wd$$

The constraint on the cutter response is given by :

$$E = (1-\mu\zeta)\varepsilon + \mu S$$

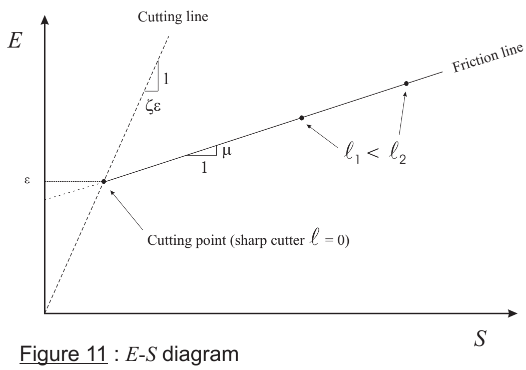


Figure 11 : E-S diagram

IV - Interests of the scratching test

CORRELATION OF MEASURED SCRATCHING PROPERTIES WITH ROCK PROPERTIES

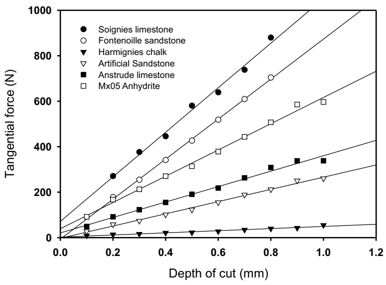


Figure 12 : Evolution of the tangential force with *wd* for 6 different rock materials, $w = 10$ mm.

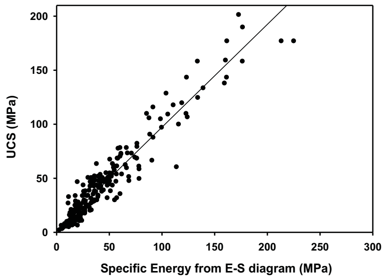


Figure 13 : Correlation between intrinsic specific energy and uniaxial compressive strength.

Experiments show that ε varies with the material strength as illustrated in figure 12. These results were a motivation to build a correlation between the intrinsic specific energy and a standard material strength property such as the uniaxial compressive strength. Numerous scratching tests were conducted on more than 250 different rock materials. Intrinsic specific energy ε appears to be well correlated to the uniaxial compressive strength (figure 13).

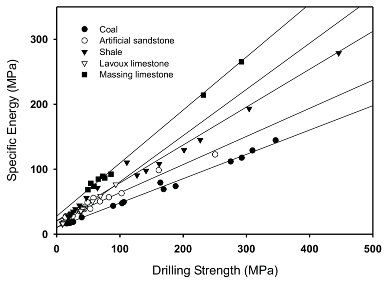


Figure 14 : *E-S* diagram for 5 different rock materials, $w = 10$ mm.

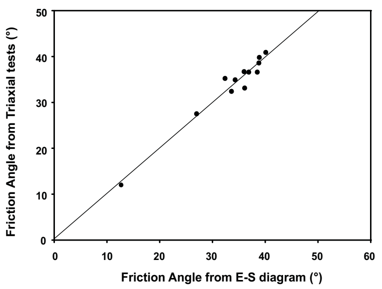


Figure 15 : Correlation between friction angle atan μ and the internal friction angle of the rock determined based on triaxial tests.

Experiments show that friction angle on the wear flat atan μ varies with materials as illustrated in figure 14. Scratching tests were conducted on 12 different rock materials which were also tested in a triaxial press. The friction angle on the wear flat appears to be equal to the internal friction angle of the rock (figure 15).

V - Characteristics of the scratching test

1. Repeatability of the measurements

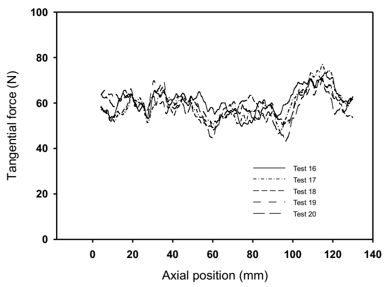


Figure 16 : Force signal recorded for different tests performed in the same conditions in the same sample of Vosges Sandstone.

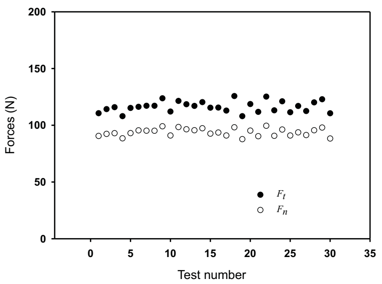


Figure 17 : Average of the force signals recorded for 30 different tests performed in the same conditions in the same sample of Vosges Sandstone.

The high degree of repeatability of the test is illustrated in figures 16 and 17. Several scratching tests (30) were conducted in identical conditions on a very homogeneous sample of Vosges sandstone, the forces recorded while testing (figure 16) and the forces averaged over the entire cutting length (figure 17) display strong degree of repeatability.

2. Advantages of the method

- The test is fast and simple ;
- The test is semi-destructive, since the depth of cut remains shallow. The sample can most often undergo other destructive or non-destructive testing afterwards (figure 18) ;
- The test requires minimum sample preparation. Any geometry of sample (as long as fixation is possible) can be tested (figure 19). Core sample of diameter down to 15 mm diameter have been tested successfully (figure 20) ;
- The test has a unique ability of providing a precise continuous measure of material properties with a wide range of applications petroleum, mining and civil engineering ;
- The test can be performed on site ;
- The test is not influenced by the natural fracturation of the core samples or the RQD.

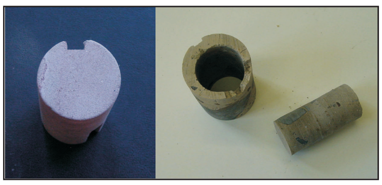


Figure 18 : Test semi-destructive. The sample can undergo other testing after the scartching test.

Figure 19 : Any geometry can be tested.

Figure 20 : Core diameter down to 15 mm can be tested.

VI - Applications

1. Geomaterials properties characterization

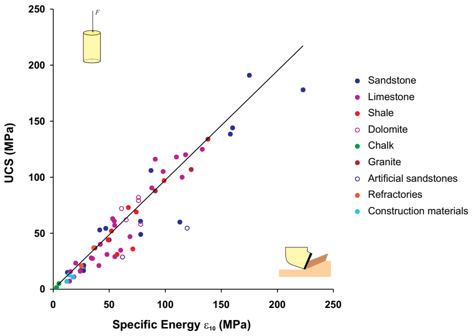


Figure 21 : Strength determination in rock materials

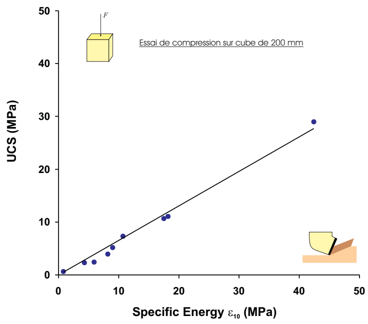


Figure 22 : Strength determination in cements

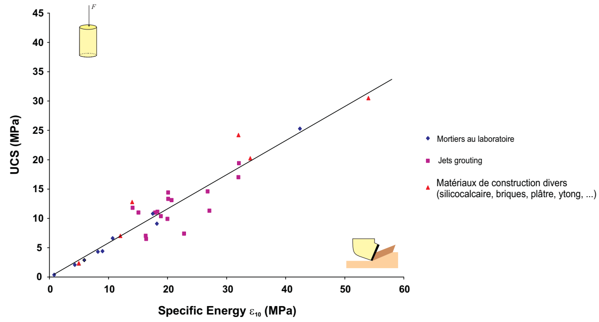
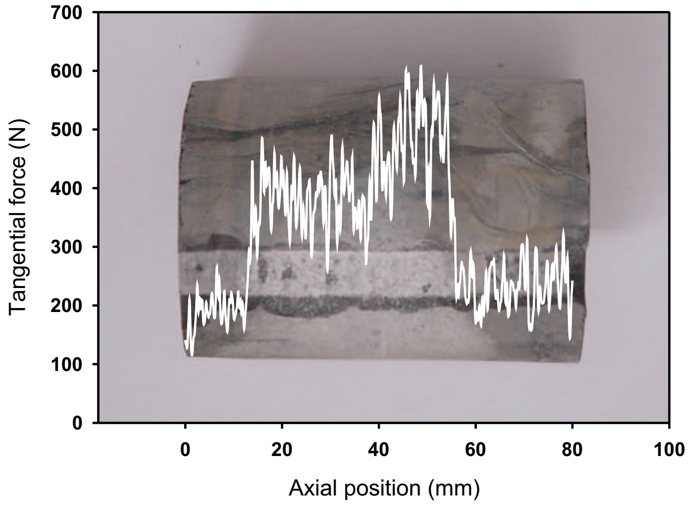


Figure 23 : Strength determination in building materials in general (concrete, mortars, jet grouting, ...)

2. Core logging : heterogenity, anisotropy and damage detection



Changes of lithology are easily detected along the groove. The example displayed in figure 24 shows three well defined regions characterized by different specific energy.

Figure 24 : Log of the specific energy on a material with three distinct zones

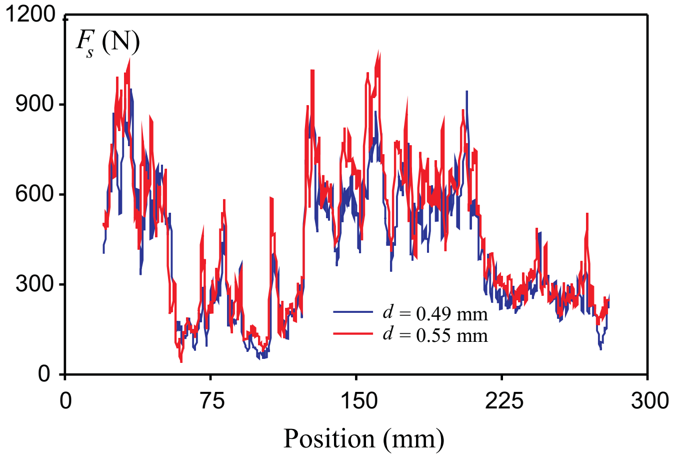
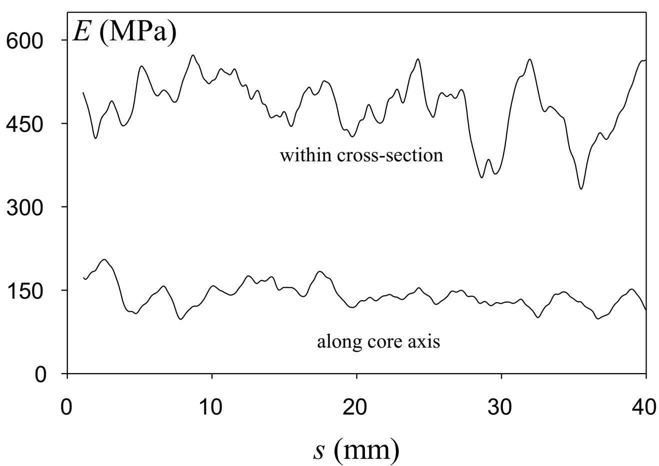


Figure 25 : Evidence of heterogeneity in a sample of layered Shale.



The test can capture to some degree anisotropy in material properties. Specific enrgy recorded along the core axis or within the cross-section of a sample of Martelange slate are significantly different as illustrated in figure 26.

Figure 26 : Evidence of anisotropy in a sample of slate of Matelange.

VII - Field cases

1. Petroleum Engineering : Detection of weak reservoir sections with high potential for sanding production.

The RSD may be of particular interest to the petroleum industry : it provides a direct, real time and simple means of logging of the variation of rock strength along the core. It can be used as A TOOL TO DETECT WEAK RESERVOIR SECTIONS WITH HIGH POTENTIAL FOR SANDING PRODUCTION OR TO CALIBRATE LOG DERIVED MECHANICAL PROPERTIES as illustrated in figures 27 to 29.

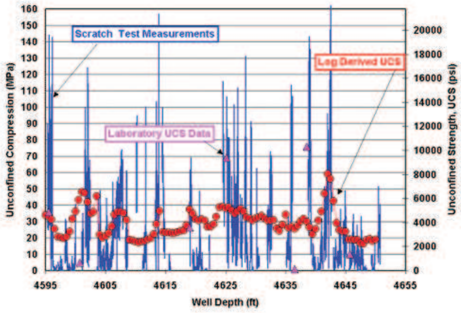


Figure 27

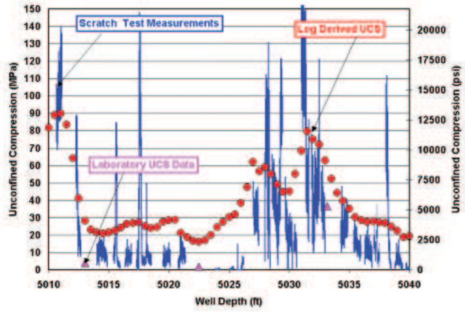


Figure 28

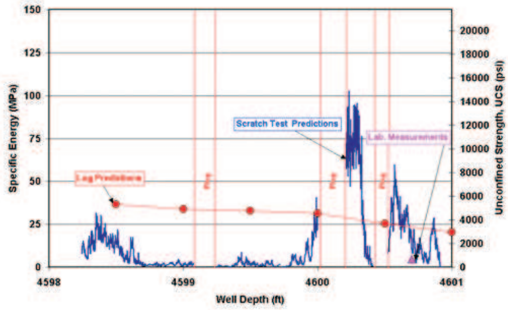


Figure 29

2. Civil Engineering : Characterization of damaged historical mortars


Figure 30


Figure 31

The purpose of the scratching test in this particular field application was the individual characterization of different historical mortars (figure 30) used in the foundation, based on very poor core samples (figure 31).

3. Civil Engineering : Jet grouting analysis


Figure 32

In this particular field application, the scratching test has been performed on samples cored in foundations (figure 32) to check the properties of the jet grouting. Data are presented in figure 23.

THE SCRATCHING TEST MAY BE PERFORMED FOR QUALITY CONTROL ON CONSTRUCTION MATERIAL LIKE CEMENT, BRICK, PLASTER, FOUNDATIONS,...

4. Characterization of damaged materials

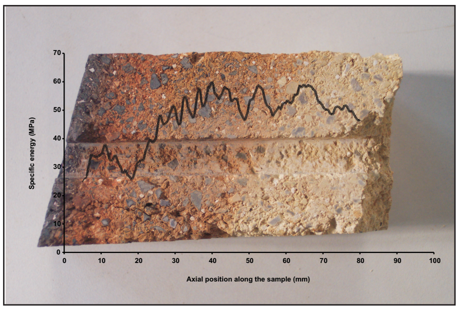


Figure 33

The scratching test has been performed in this application in order to detect any mechanical damage in refractories. A refractory brick of which one face has been exposed to the interior of a chimney conduit was tested on the RSD. The specific energy signal clearly captures a zone of lower strength due to thermal damage undergone by the brick over the 25 first mm of the sample.

THE SCRATCHING TEST CAN BE USED FOR THE DETECTION AND THE MEASURE OF MECHANICAL DAMAGE DUE TO CORING, POLLUTION, FLUID, HEAT, ETC.

VIII - References

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