Brittleness and drillability

by H.G. Denkhaus

Comment on 'The evaluation of rock brittleness concept on rotary blast hole drills'

in the *Journal* of SAIMM, vol 102. no. 1. pp. 61–66

Comment on 'Correlation of specific energy with rock brittleness concepts on rock cutting'

in the *Journal* of SAIMM, vol 103. no. 3. pp. 163–171

by R. Altindag

Foreword

Some thirty years ago it was almost customary that articles in South African technical and scientific journals were followed up by discussions in which the reader(s) expressed criticism and/or added to the information contained in the article. This custom has obviously died out, be it that the articles are nowadays of such a high standard that nothing can be added or be it that the receivers of the *Journal* suffer from an information inflation and do not read the articles any more. I now have the temerity to offer a discussion to an article that recently appeared in the journal, namely 'The evaluation of rock brittleness concept on rotary blast hole drills' by R. Altindag (J.S. Afr. Inst.Min.Metall., vol, 102 (2002), pp. 61–66.

Brittleness

Contrary to the still widespread but wrong belief, brittleness (or its counterpart, ductility) is not a property of the material but a term describing the type of fracture. When a fracture is accompanied by plastic deformation, it is called, a 'ductile fracture' and when plastic deformation is absent (i.e. when the total strain at fracture is elastic), it is called a 'brittle fracture'.

Since fractures are seldom purely ductile or purely brittle, the scale of brittleness (or ductility, for that matter) must be arbitrarily defined, e.g. by the ratio of elastic strain at fracture to plastic strain at fracture ($B=\varepsilon_{Be}/\varepsilon_{Bp}$). The higher this ratio, the higher the brittleness of the fracture and the lower its ductility. Another parameter is the ratio of plastic deformation to total deformation; the higher this ratio, the more ductile the fracture and the less brittle it is. Brittleness may also be defined in terms of the ratio of (specific) elastic strain energy at fracture to total (specific) strain energy at fracture, i.e. by the ratio of the two areas under the stress-strain curves indicated in Figure 1.

In the article 'The evaluation of rock brittleness concept on rotary blast hole drills', the author, R. Altindag, investigates the relationship between drillability and two parameters, namely $B1=\sigma_e/\sigma_t$, i.e. the ratio of uniaxial compressive to uniaxial tensile strength, and $B2= \sigma_c/\sigma_t$, the area under a curve of uniaxial compressive strength versus uniaxial tensile strength. It is, of course, permissible and perhaps even useful to investigate the influence of the ratio (B1) or the product (B2) of the uniaxial compressive and tensile strength of rock upon its drillability, but these parameters should not be called 'brittleness', because they have got nothing to do with the relation of elastic to plastic strain. The approach is purely phenomenological and the physical meaning of the product $\sigma_c\sigma_t$ is not clear.

Brittleness depends upon a number of factors such as temperature, the multi-axiality of the stress, the rate of stressing, the material and the shape and size of the system fractured.

Brittleness fracture can occur on structures of carbon steel, which is usually regarded as a 'ductile material' at normal temperature when the state of stress becomes multiaxial; this occurs at notches, rapid changes of cross-section (fillets), and other irregularities of the shape of the structure. Apart from the state of stress, low temperatures and high rates of straining (impact) have an influence on the brittleness of a fracture, and all structures made of structural (carbon) steel are prone to brittle fracture under unfavourable conditions, although their fracture is ductile

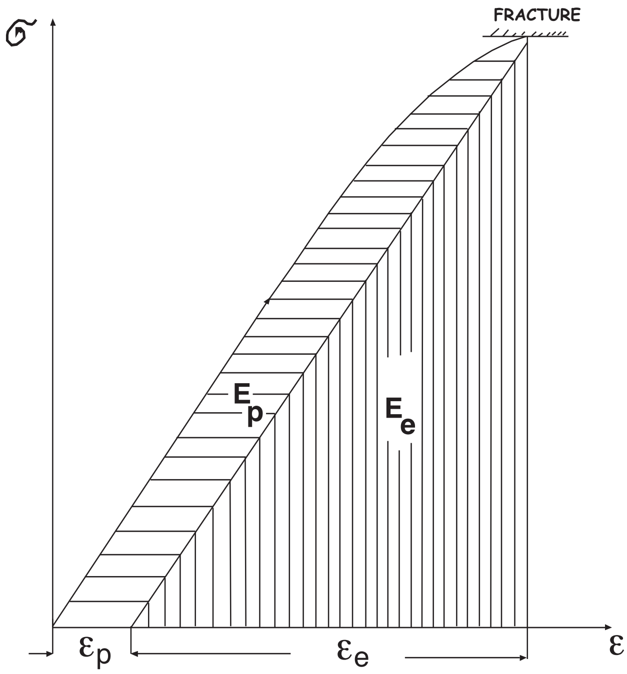

Figure 1

under normal conditions. In the history of modern engineering, the problem of brittle fracture, especially of welded structures, came to the fore in 1938 when fractures occurred on welded beams of steel bridges in Germany and Belgium. In the United States sudden brittle failures occurred in about 1000 welded 'Liberty' ships and tankers during 1942 to 1946. More than 100 of these failures were severe; the tanker 'Schenectady' broke in half while in port. All these incidents occurred in winter time (at low temperatures!) at welds (where the state of stress is multiaxial) on large structures (bridges and ships) made of carbon steel which under normal conditions fractures in a ductile fashion.

Marble, for instance, is colloquially considered as one of the most 'brittle materials'. This, however, is only true for 'normal size', i.e. when the marble piece has dimensions larger than about 2.5 mm. If the effective specimen size is small, then the fracture of marble is extremely ductile, i.e. shows a lot of plastic deformation: If, for instance, a hardness test with a diamond indentor is carried out with an impression load of 0.1 to 0.15 N, the impressions show cracks, which means that the fracture is brittle. With an impression load of 0.05 N, however, the impression is crackfree, the fracture is ductile because the affected region of the 'marble system' is small. Thus, the brittleness (or ductility, for that matter) is influenced by the specimen size. This is also the reason why marble can be ground or cut by tools because the cutting chips are small so that the fracture (breaking away of the chips during cutting) is ductile. The fracture of marble, by the way, is brittle (i.e. without plastic deformation) only under uniaxial compression or tension, but it is quite ductile under differential triaxial stress.

Drillability

The cost of drilling is a major item of the total production costs of mining and quarry operations. Production demands therefore call for increased drilling rates. The determination of the drillability of a certain type of rock—preferably *in situ*—is therefore of prime importance.

In 1965 the then Transvaal and Orange Free State Chamber of Mines appointed a Rock Drilling Panel which commissioned the Rock Mechanics Division of the then National Mechanical Engineering Research Institute of the CSIR to investigate various drillability indices with the aim to recommend the most suitable. The project led to the issue of two reports[1,2], which may be very briefly summarized here.

A literature survey led to the conclusion that there are two main schools of investigators. The one group tries to arrive at a drillability index by determining several physical properties of rock in the laboratory (it appears that R. Altindag subscribes to this concept by determining the tensile and compressive strengths). The other group uses actual drilling tests with a standard machine and standard drilling bits and thereby avoids the uncertain determination of the relationship between drillability and rock properties, which are difficult to establish. Both types of investigation include the inconvenience of long and difficult transportation of rock specimens, in the one case, or drilling equipment in the other. The whole test procedure is time consuming and costly.

It was then thought that a rebound technique applied *in situ* to determine rock drillability would have merit. The so-called Schmidt hammer test, which originally was developed for testing concrete, makes use of the rebound technique to determine strength but was also used for testing coal strength in German mines. Suitable experiments were carried out and it was found that the Schmidt hammer rebound number RN represents a reliable index of drillability, when it is applied with due consideration to the petrography and the geological origin of the rock, as illustrated in Figures 2 and 3. ◆

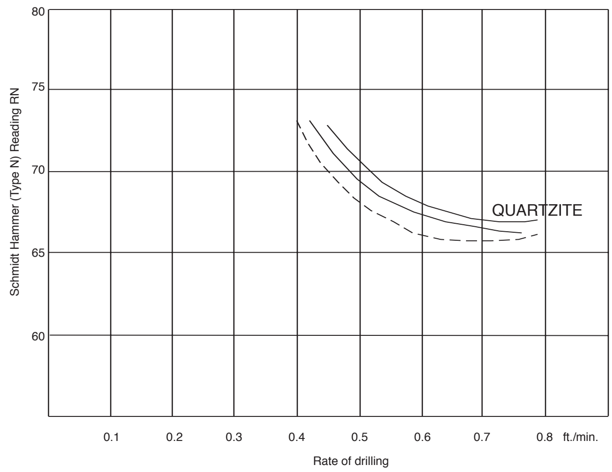

Figure 2

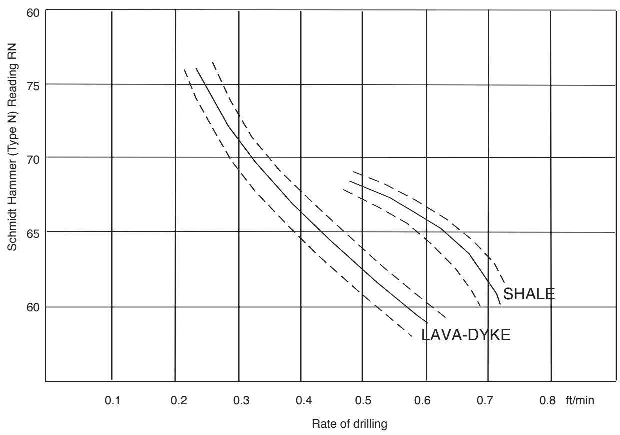

Figure 3

(1) National Mechanical Engineering Research Institute (Project Leader: H.U.Ressmann): Determination of an index of rock drillability (Literature survey). CSIR Report No. MEG 393, Pretoria, September 1965.
(2) National Mechanical Engineering Research Institute (Project Leader: H.U. Ressmann): Final Report on Determination of an index of rock drillability for percussion drilling. CSIR Report No. MEG 451, Pretoria, June 1966.