

[3]. However, it is suggested that even  $K_{gl}$  normalized to  $\beta = 1$  represents only a comparable experimental parameter, without any deep physical meaning. This is the case, since the  $T_g$  values determined by DSC fail to be the real glass formation temperatures for glasses obtained at  $R \gg \beta$  (e.g. splats). In this case the glass transition temperature determined by DSC represents the low-temperature edge of the transformation region, being lower than the real glass formation temperature [3], whereas the  $T_x$  value is the real temperature of the onset of devitrification (being a measure of the thermal stability of glassy state). These  $T_x$  values also have to be normalized to  $\beta = 1$ , for comparison of the thermal stability of various materials.

The assumption about the constancy of the melting temperature,  $T_m$ , seems to be of a general nature. In the present calculations of  $K_{gl}$  for Te-Ge alloy, the value of  $T_m$  was taken from the equilibrium diagram, and confirmed experimentally. Variations in  $T_m$  within the whole scanning rate range do not exceed the experimental error, while those for  $T_g$  and  $T_x$  amount to  $27^\circ$  and  $42^\circ$ , respectively.

In summary, it is suggested that the  $K_{gl}$  parameter, normalized to  $\beta = 1$ , is accepted as a comparable measure of the vitrification tendency of various materials, although no strictly defined physical meaning can be attributed to  $K_{gl}$ . The

normalized value of  $K_{gl}$  for the eutectic Te-Ge alloy was found to be 0.18.

The present results were obtained on the occasion of systematic studies on transformations in glassy Te-Ge alloy; the results of the latter investigations will be published separately [4].

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### *On the influence of the flushing fluid during diamond drilling*

Since the work of Rehbinder and co-workers became widely known in the late forties [1, 2], there has been a continued interest in the effect of a surrounding liquid environment on the mechanical properties of both metals and non-metals (see for example a recent review by Westwood [3]). In particular, it has been suggested that simple inorganic salts, soaps and other surfactants may be added to the flushing water when drilling rocks in order to produce substantial increases in the rate of penetration. Such increases have indeed been reported by many workers [1, 4-7], but there is some conflicting evidence (8, 9), and no additive is yet used in commercial practice with the specific purpose of exploiting the "Rehbinder effect". The

effect was originally explained [1, 2] in terms of a reduction of the fracture surface energy of the rock by an adsorbed ion or compound, but subsequent workers [3, 6] have shown that the explanation may be more complex, and that inter alia, dislocation mobility in the material being drilled may be either increased or decreased by the additive.

In an attempt to clarify this question, we have made simple experiments on both marble (from Lasa, Ticino, Switzerland) and a pink granite (from Bohus, Sweden) with a standard 10 mm diamond-impregnated core drill, using a variety of liquids recommended in the literature. In diamond drilling, the instantaneous speed of advance is approximately proportional to the rotation speed and to the feed pressure, provided that adequate flushing is maintained. This is very important

when drilling at the rates of advance common in commercial practice (30 to 100 mm min<sup>-1</sup> in marble, 10 to 60 mm min<sup>-1</sup> in granite) for if the liquid flow is interrupted the bit will be melted in a few seconds. When drilling in marble, the diamond is worn away only very slowly, and many metres may be drilled with negligible change in the bit characteristics. This means that different flushing liquids may be compared directly, since the sharpness of the diamonds remains constant from test to test.

In the case of granite, however, there is a steady wear of the diamonds under all drilling conditions, and the drill must be periodically dressed to expose new diamonds. The rate of wear is very dependent on the feed force, being greatest when the feed force is least. Space does not permit an

exhaustive discussion of this behaviour, but it can be understood in terms of the tendency of the diamonds to "skate" on the surface of the rock under light loading, and for the cutting points to be polished away. Since the feed force is low, and the diamonds are not forced deeply into the rock under these conditions, the removal of only a small amount of material from the cutting points is sufficient to drastically reduce the rate of penetration of the drill. Examples of the rate of drilling under applied loads of 100 and 400 N (2.7 and 10.6 N mm<sup>-2</sup> of bit surface, respectively) are shown in Fig. 1.

Optimum drilling conditions for both rocks are, therefore, to be found in working as close to the upper limit of feed force as is practical without choking the drill, both because of the requirement

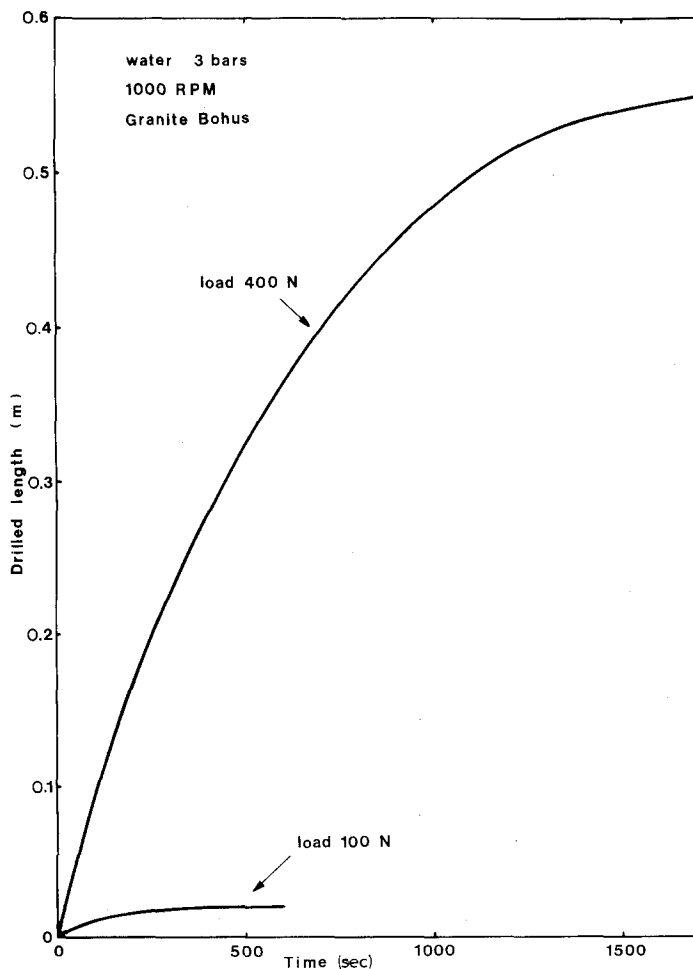


Figure 1 Rate of penetration as a function of time in Bohus granite. Note not only the much reduced rate of penetration with low feed force, but also the much greater rate of wear.

for rapid penetration, and, in the case of granite, to minimize wear. We therefore took as our "standard conditions" 150 N feed force, a flushing pressure of 3 bar and speeds of 1000 to 3300 rpm for marble, and 400 N feed force, a flushing pressure of 3 bar and 1000 rpm for granite. These values correspond well with commercial practice

With marble, we drilled at speeds between 1000 and 3300 rpm using the following solutions in water:  $\text{AlCl}_3$ , 0.5, 0.75 and 1%,  $\text{Na}_2\text{CO}_3$ , 0.2, 0.33, 0.5 and 1%,  $\text{NaOH}$ , 0.025, 0.05, 0.1 and 0.25%, "QUAT 316" (dodecyl ethyl dimethyl ammonium bromide)  $10^{-3}$  and  $10^{-2}$   $\text{mol l}^{-1}$ , and a commercial liquid soap containing 21% salts of fatty acids and 5% sulphonated compounds as its active constituents diluted to 0.25 and 0.5%. The results are shown in Fig. 2, from

which we conclude that none of the additives produced any increase or decrease in the drilling rate detectable against the experimental scatter. As mentioned above, when drilling marble, the rate of wear is negligible.

In the case of granite, where the bit wears continuously, we show the average rate of penetration over consecutive advances of 26 mm. For this series of experiments, we used the series of straight-chain aliphatic alcohols,  $\text{CH}_3(\text{CH}_2)_n\text{OH}$  from methanol to decanol, since these have been previously reported as having a very large influence on the rate of drilling in granite [3]. The results are shown in Fig. 3, alternating with results obtained using water as the flushing medium. Overall, the figure shows a generally decreasing rate of penetration with distance drilled, as the

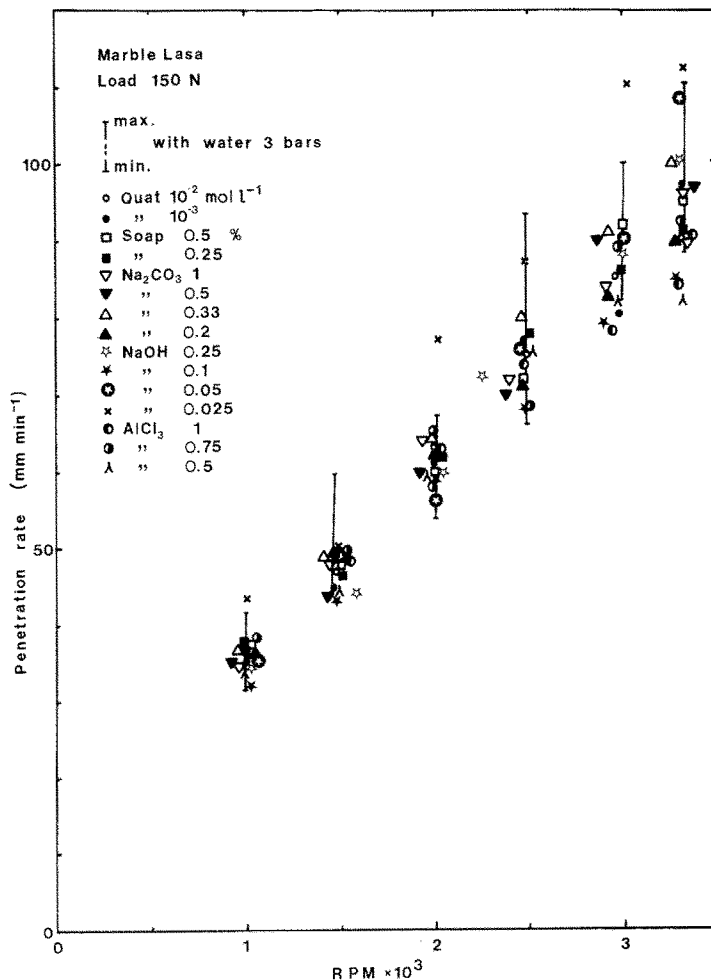


Figure 2 The effect of various additives on the drilling rate in marble. No additive produces penetration rates which are significantly different from those obtained using water alone.

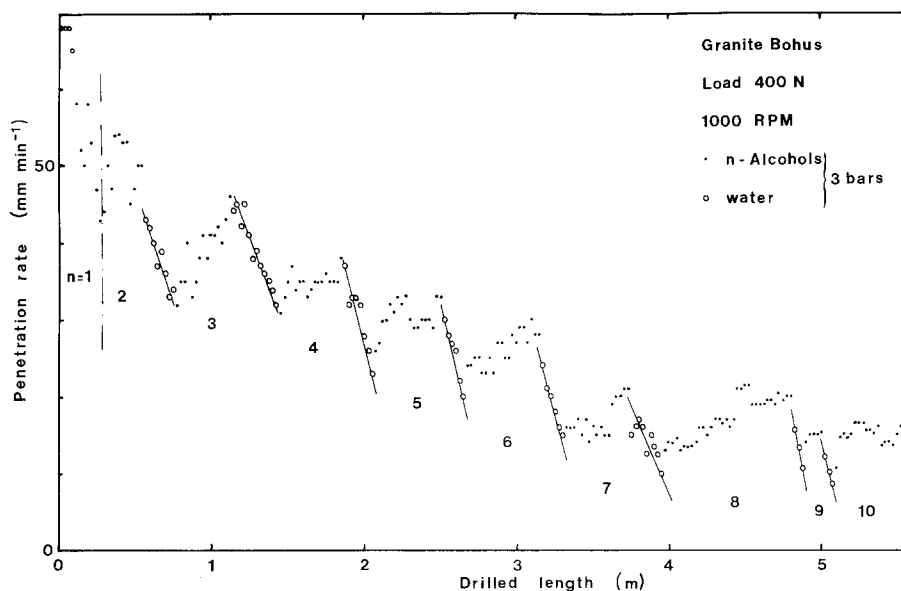


Figure 3 The effect of different aliphatic alcohols on the rate of penetration in granite, alternating with water.  $n$  represents the number of carbon atoms in the molecule (1 = methanol, 2 = ethanol, etc).

diamonds slowly wear down. Superimposed on this trend, however, one notices two remarkable features, firstly, that there is no dramatic change in penetration rate when changing from an alcohol to water or vice versa, but secondly, that the rate of wear while drilling with water is distinctly greater than that obtained with any of the alcohols.

We interpret our results by supposing that at these drilling rates, the influence of the environment in strengthening or weakening the rock is very much less than at the very low penetration rates quoted by Westwood of  $0.72 \text{ mm min}^{-1}$  (water),  $0.24 \text{ mm min}^{-1}$  (propanol) and  $1.68 \text{ mm min}^{-1}$  (decanol) [3]. On the other hand, we note the strong difference in the rates of wear when using water or any of the alcohols. We believe that the wear behaviour is composed of three interacting mechanisms, namely the blunting of the diamonds, the abrasive wear of the matrix by exposure to the slurry of rock fragments in the flushing liquid, and the tearing-out of diamonds from the bit surface. The balance of these three factors determines the behaviour of the drill in any given conditions. In the cases where water was used as the flushing liquid, we suppose that the blunting of the diamonds was dominant. Had we continued drilling with water for a sufficient

time, the diamonds would have become so blunt that they would have ceased to cut the rock, and since, under these conditions, there would have been no production of abrasive particles to wear down the matrix, this wear mechanism would have ceased also. Finally, since the wear of the matrix had ceased, there would have been no exposure of new diamonds, and the drill would ultimately have ceased to advance. In the case of the alcohols, we suppose the wear of the diamonds to be much reduced. Under these conditions, the production of abrasive particles is maintained, and so is the wear of the matrix. This wear is reflected in a better exposure of the diamonds, leading to a steady improvement in the performance. This upward trend is overlaid with periodic stepwise changes in drilling rate as individual diamonds (sharp or blunt) are torn out of the matrix. (In such a bit, about one hundred diamonds are visible in the cutting face at any time, although how much each contributes to the cutting process is uncertain).

Having these three wear processes in mind, inspection of the data shows that if we had conducted the experiments by taking a new bit each time and had measured the length of time required to drill, say, 500 mm in any one environment, we would have obtained striking differences

between the average penetration rates in water and the different alcohols. Such was not the case when we measured the performance over the much shorter distance of 26 mm. We therefore suggest that this observation may help in explaining some of the conflicting results already published, namely that in cases where measurements of performance are made over a significant fraction of the bit life, differences in average rate of penetration are likely to be found, but they can just as well be attributed to a change in the rate of wear of the bit as to any hardening or softening of the rock being drilled.

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*Q-band esr spectra of  $\gamma$ -irradiated Pyrex*

Previous electron spin resonance (esr) work on  $\gamma$ -irradiated Pyrex at X-band (9.4 GHz) has revealed the well-known boron–oxygen hole centre (BOHC) spectrum and a narrow resonance at  $g = 2.0008$  which has been ascribed to the  $E_1'$  electron centre [1] in sub-microscopic helices or chains of silica existing separately within the bulk borosilicate structure [2]. The narrow resonance was identified as the  $E_1'$  line by its lineshape, linewidth and  $g$ -value, and by the fact that it saturated easily with microwave power.

In an attempt to confirm this identification, the spectra were investigated at Q-band (35 GHz). Fig. 1 shows the first derivative signal obtained at liquid nitrogen temperature, 77 K, of a Pyrex sample having had a gamma dose of 8598 Mrad ( $85980 \text{ J g}^{-1}$ ). This spectrum has been numerically smoothed twice, according to the equation

$$A_H = \frac{1}{2}A'_H + \frac{1}{4}A'_{H+\Delta} + \frac{1}{4}A'_{H-\Delta}$$

where  $A_H$  is the amplitude of the plotted derivative curve at a magnetic field  $H$ ,  $A'_H$  is the amplitude of the measured derivative curve at a magnetic field  $H$ , and  $\Delta$  is the magnetic field increment, in this case 0.03 mT. A microwave power of

0.01 mW was used at a frequency of 34.91 GHz, and the derivative curve obtained in the usual way with 160 kHz modulation and phase-sensitive demodulation.

Fig. 1 has two main components, a broad line of width  $\Delta H_{ms} \approx 5 \text{ mT}$  and a narrow, complex resonance of overall width  $\approx 1.2 \text{ mT}$ . The broad line can be readily ascribed to the BOHC, which has been shown [3] to possess orthorhombic symmetry, while the lineshape over the central and high-field regions is produced by overlapping the four-line hyperfine components centred on

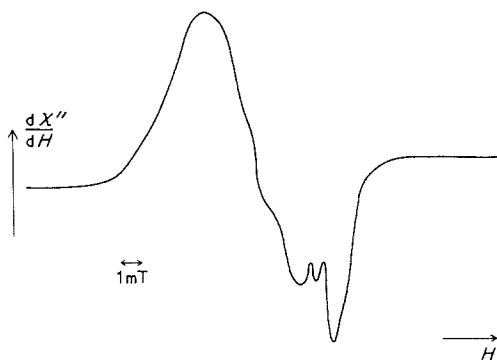


Figure 1 Q-band spectrum obtained from  $\gamma$ -irradiated Pyrex. Microwave power 0.01 mW, temperature 77 K.