Contribution to the mechanism of core discing

by T. R. STACEY*, Pr. Eng., D.Sc. (Eng.), M.S.A.I.M.M., M.I.M.M.

SYNOPSIS

Previous investigations of stress conditions under which core discing occurs have concentrated on shear stress as the cause of this phenomenon. In this paper it is suggested that discing initiates as a result of extension strain, which develops in the field of triaxially compressive stress ahead of the borehole end.

SAMEVATTING

Vorige ondersoeke van die spanningstoestande waaronder skyfbreuke van boorkerns plaasvind, was toegespits op skuifspanning. In hierdie referaat word daar aangevoer dat skyfbreuke begin as gevolg van ekstensievervorming wat in die veld van die drieasdrukspanning voor die ent van die boorgat ontwikkel.

Introduction

As is commonly known, it is often impossible to obtain significant lengths of rock core by diamond drilling in areas of high stress. The core breaks up spontaneously into discs, which are usually curved, the centre of curvature being towards the collar of the hole. In some cases, the core is intact but contains a number of regularly spaced circumferential fractures. The occurrence of discing has been investigated by Jaeger and Cook[1], Obert and Stephenson[2], and Durelli *et al*[3]. The first authors conducted a number of experiments, which showed that a projecting core stub broke off over a curved surface when a lateral stress was applied to the rock. They also found from experimental drilling into stressed rock that, the higher the applied lateral stress, the thinner the resulting discs. They observed that the fracture surfaces appeared clean and unsheared, suggesting a tension failure. It was also suggested, from their observations, that failure may start near the centre of the core.

Obert and Stephenson's observations were essentially similar. However, they found that, in both laboratory and field tests, the failure initiated on the exterior surface of the core. On the basis of a linear relationship between the shear strength of the rock and the lateral stress required to produce discing at zero axial stress, they suggested that discing is initiated by, or is completely the result of, shear stress. This appears to contradict the former authors' observations of clean unsheared surfaces.

Durelli *et al.*[3] used three-dimensional photoelastic models to analyse the stress distribution at the end of a borehole with a short projecting core stub. By comparing their results with those of Obert and Stephenson[2], they inferred that discing initiated at the point of maximum shear stress near the bottom of the kerf area. However, the magnitude of the shear stress required to produce failure appeared to be much larger than the shear strength of the rock, which was determined by the testing of rock samples in triaxial compression.

Hast[4] discusses core discing in relation to *in situ* stress measurement. According to him, the expansion of the core stub is counteracted by the shearing force acting in the plane of the base of the drill groove. When the length of the core stub is such that the expanding force exceeds the resisting shearing force, a disc shears off. This contradicts the observations of Jaeger and Cook[1].

Suggested Mechanism and Analysis

The end of a borehole in stressed rock is generally an area of biaxial or triaxial compressive stress. Tensile stresses of small magnitude can be expected to occur, depending on the geometry of the borehole end, but they would not be sufficient to cause tensile failure of the rock. Jaeger and Cook[1] observed the disc surfaces to be clean and unsheared, suggesting a tension failure. However, for a surface of this nature to be formed, it is not necessary for tensile stresses to be present. As shown by Bridgman[5,6] and Griggs and Handin[7], an extension fracture can be generated by a state of triaxial compressive stress. Further to this, a simple criterion of extension-strain fracture was developed[8], which states that fractures initiate in brittle rock when the extension strain exceeds a critical value characteristic for the rock type. From the results of laboratory tests, it appeared that, for brittle rocks such as quartzite, this critical value could represent a low magnitude of strain. Extension fractures can be generated under triaxial compressive stress of very large magnitude[5].

It is postulated in this paper that the development of discing in rock core is the result of extension fracturing of the rock and that this mechanism can be explained by means of a simple criterion[8] of extension-strain fracture. A simple model based on the experimental work of Jaeger and Cook[1] and Obert and Stephenson[2] was chosen for analysis. This is shown in Fig. 1 and consists of a cylinder of rock containing a borehole. The model was analysed using axisymmetric finite elements, with the application of a radial compressive stress and several values of axial compressive stress in turn. Several different lengths of core stub were also taken into account. The material properties chosen for the model were a modulus of elasticity of 35 GPa and a Poisson's ratio of 0,11. These are typical values for quartzite, a rock type in which discing commonly occurs.

Results of the Analyses

Twelve analyses were carried out for the model geometry shown in Fig. 1. The maximum extension strain was calculated from the equation

$$\epsilon_3 = \frac{\sigma_1 1}{\sigma_1 E}[\sigma_3 - \nu(\sigma_1 + \sigma_2)],$$

* Steffen, Robertson and Kirsten, P.O. Box 8856, Johannesburg 2000.

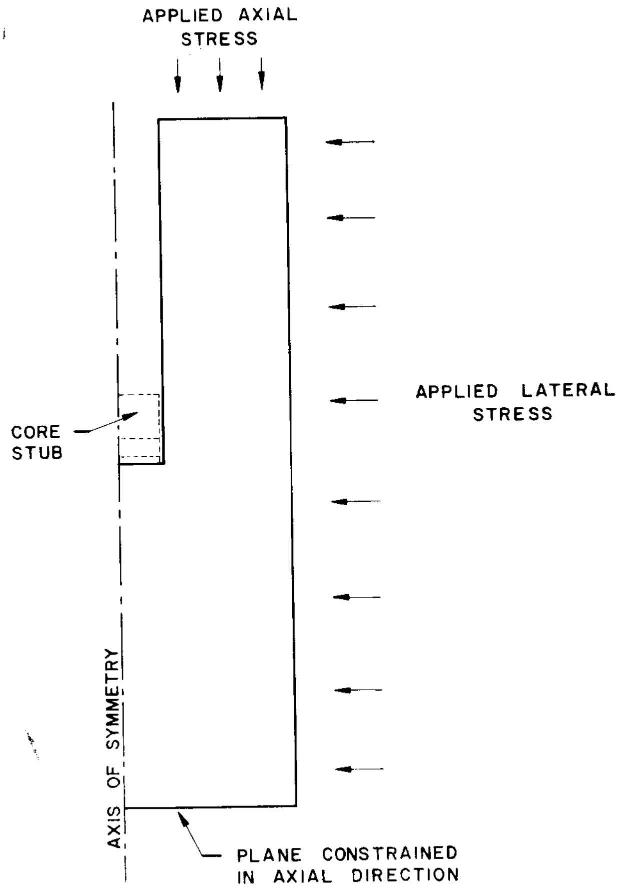

Fig. 1—The model used for stress analysis

where σ_1, σ_2, σ_3 are principal stresses,
E is the modulus of elasticity, and
ν is Poisson's ratio.

The results of these analyses are presented in the form of contour plots of extension strain in the region of the borehole end in Fig. 2. The plots are arranged in this diagram to permit a ready comparison of the results. The following observations can be made from the results of the analyses.

(i) Under the applied compressive stresses, extension strains of considerable magnitude develop in the region of the borehole end. To put these numbers into perspective, a rock such as quartzite would typically have a tensile strength of about one-tenth of the compressive strength, i.e. approximately 20 MPa. The tensile strain at failure in a direct tensile test would thus be about 200 to 300 microstrain. The minimum extension strain contour plotted in Fig. 2 is the 200 microstrain contour.

(ii) The effect of an applied axial compressive stress is generally to reduce the magnitude of the extension strain at a point. This does not apply in all cases, however. When a significant core stub is present, the extension strain level near the outer boundary of the stub, fairly close to the base of the drill groove, increases with an increase in the axial compressive stress. The extension strain in all other areas decreases.
The level of axial stress has very little influence on the location of the point of maximum extension strain. This can be clearly seen by a comparison of the relevant plots in Fig. 2.

(iii) Both the magnitude of the extension strain at a point and the location of the point of maximum extension strain are affected very significantly by the length of the core stub. For example, with no stub the maximum extension strain occurs at the face in the corner formed by the borehole end and the borehole wall. As the stub length increases, the point of maximum extension strain moves from the corner towards the axis of the core. Finally, as the stub lengthens further, a point of high magnitude remains in this region near the core axis, but a maximum point develops near the outer boundary of the core close to the base of the drill groove. This behaviour is similar for all levels of axial stress applied.

(iv) The geometry of the drill groove also has an influence on the distribution of extension strain. This is illustrated by the extension strain contours shown in Fig. 3 for a model with a wider drill groove. When compared with the corresponding model in Fig. 2(c), it can be seen that the location of the point of maximum extension no longer occurs close to the outer boundary of the core stub. Further, the pattern of the contours around the base of the drill groove changes considerably.

(v) The criterion[8] of extension-strain fracture predicts that fractures will form in a plane normal to the direction of the minor principal strain. In the zone ahead of the borehole end, these planes are generally oriented at angles of between 80° and 90° to the core axis.

(vi) The stresses in the region ahead of the borehole end are triaxially compressive. The maximum shear stress occurs near the centre of the base of the drill groove. This agrees with the results obtained by Durelli *et al.*[3] from photoelastic stress analysis.
As the core stub lengthens, a zone of low-magnitude tensile stress develops near the outer surface of the core stub. Initially, this tensile stress acts only in the axial direction, but, with a lengthening stub, biaxial tension occurs. The magnitudes of the tensile stresses increase as the stub length of the core increases and develop to values in the axial direction that exceed the probable tensile strength. The magnitudes are also slightly greater for higher axial compressive stresses.

Interpretation of Discing Observations

The actual magnitudes of the contours in Fig. 2 should not be considered, but rather the locations of the maximum extension strain and the relative magnitudes for the different geometries and applied stress conditions.

(i) *Development of discing*
Jaeger and Cook[1] suggest that discing failure may start near the axis of the core whereas Obert and Stephenson[2] observed that fracture initiates on the exterior surface of the core. The results in Fig. 2 indicate that both of these conclusions may be

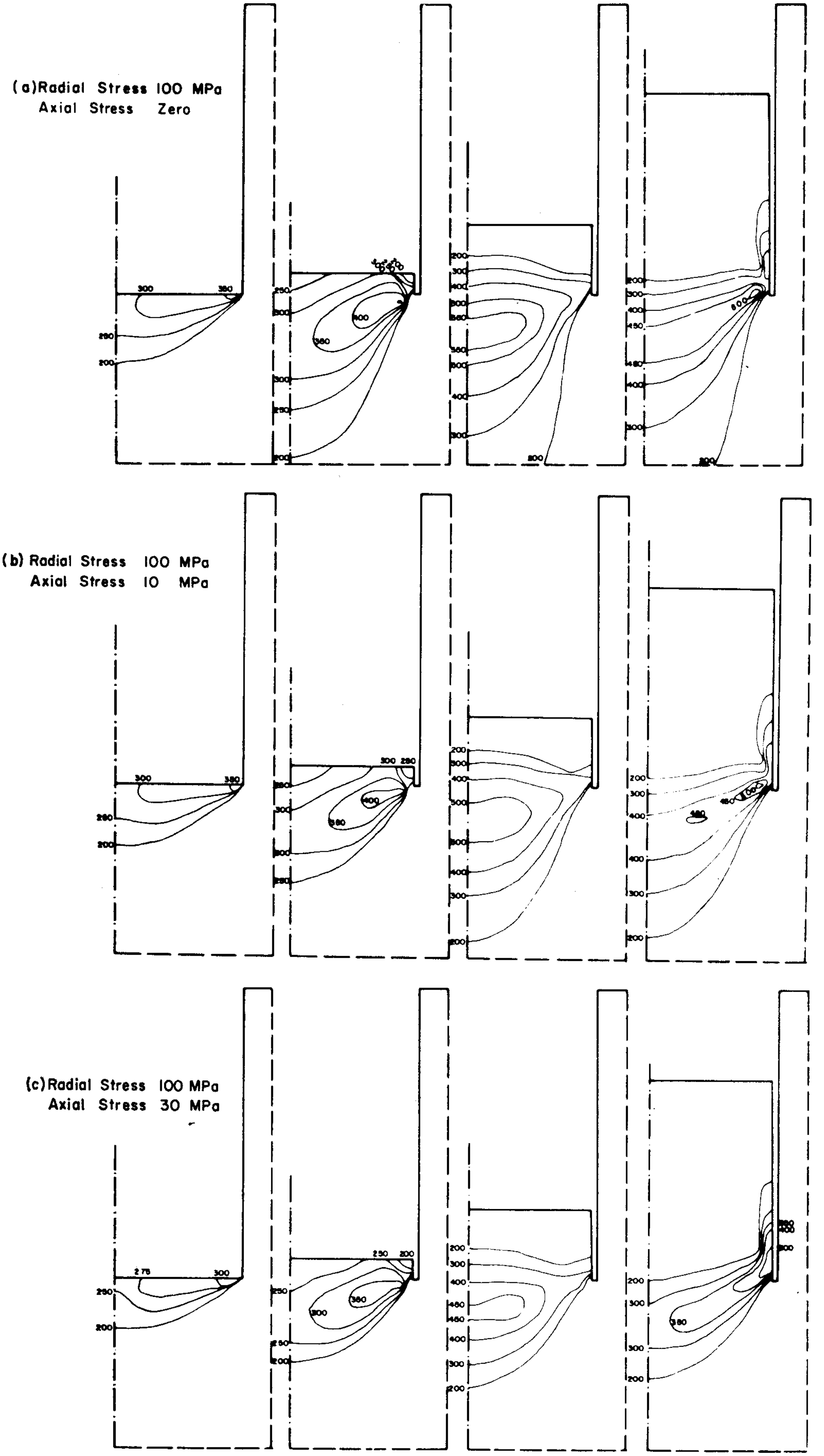

Fig. 2—Contours of extension strain

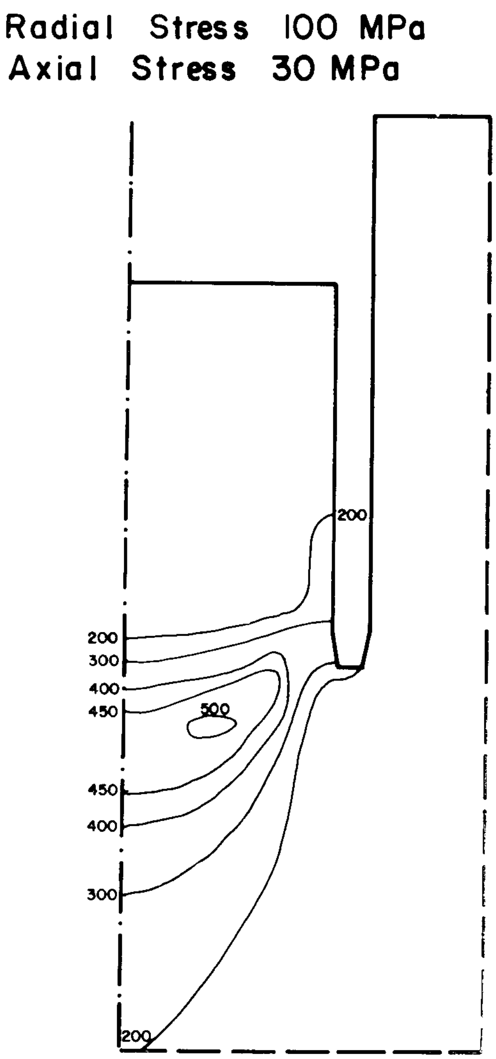

Fig. 3—Contours of extension strain for a wider drill groove

correct, depending on the geometry of the effective core stub and drill groove. With no stub, the maximum extension strain is always located just inside the borehole end at the outer extremity of the borehole diameter. As the stub lengthens, the location of the maximum moves towards the axis of the core ahead of the borehole end. At the same time, the magnitude of the maximum extension strain increases. With further lengthening of the stub, an extension strain of high magnitude remains in the central portion of the core, but the maximum value develops on the outer boundary of the stub in the region of biaxial tensile stress. With a wider geometry of drill groove, the latter maximum zone does not occur.

Based on the above observations, the following procedures in the development of core discing are suggested.

(*a*) Under conditions of very high lateral stress, discing would be initiated from the external boundary just ahead of the face of the borehole end. This would occur before a stub had begun to form, and hence the discs would be very thin.

(*b*) Under lateral stress conditions lower than in (*a*), when a short length of core stub had actually formed, discing would be initiated in the solid rock ahead of the borehole end but close to the future outer surface of the core. Fractures would therefore probably be observed in the outer surface of the 'intact' core. The discs would be thicker than in (*a*).
Fig. 4 shows a section cut through an 'intact' core. The presence of fractures in the outer section of the core, discontinuous through to the centre of the core, indicate that, in this case, the fractures initiated in this outer section.

(*c*) With yet lower lateral stresses, the discing would be initiated close to the axis of the core, and the core might appear to be solid.

(*d*) Finally, with stress conditions that would permit the formation of significant lengths of core, extension fractures might form on the outer boundary of the core, and the appearance would be as in (*b*).

(*e*) As illustrated by Hallbauer *et al.*[9] in core specimens loaded in triaxial compression, a multitude of small extension fractures would form, rather than a single fracture plane. The disc surface that developed would be a concatenation of these small fractures. The locus of the development of this surface would depend on the changing stress distribution resulting from the advance of the drill and the progressive development of fractures. The surface of the discing fracture would remain extension in character. As a result of the progressive development of fractures, it is probable that an 'effective' length of core stub would be defined that would differ from the apparent length.

(ii) *Effect of axial stress*

The higher the axial compressive stress, the lower the magnitude of the extension strain, except if the core stub is long. As stated previously, a zone of biaxial tension develops on the outer boundary of the core in this case, leading to large extension strains. However, in general a higher axial compressive stress leads to lower extension strains, with a consequent reduction in the incidence of discing.

(iii) *Curvature of discs*

The major principal stresses, and hence the orientations of potential extension fractures, are generally inclined at angles of greater than 80° to the axial direction of the core. The path of the maximum extension strains in the zone ahead of the borehole end is clear for each model. The actual discing surface is likely to follow this path partially, but will be modified by the changing geometry and stress distribution as the drill barrel advances. The disc surface will be formed by the concatenation of numerous extension fractures.

The variation in the radius of curvature of the discs was not investigated. It is likely to be affected by numerous factors such as the shape of the previous disc surface, the stress level, the brittleness of the rock, the geometry of the drill groove, the

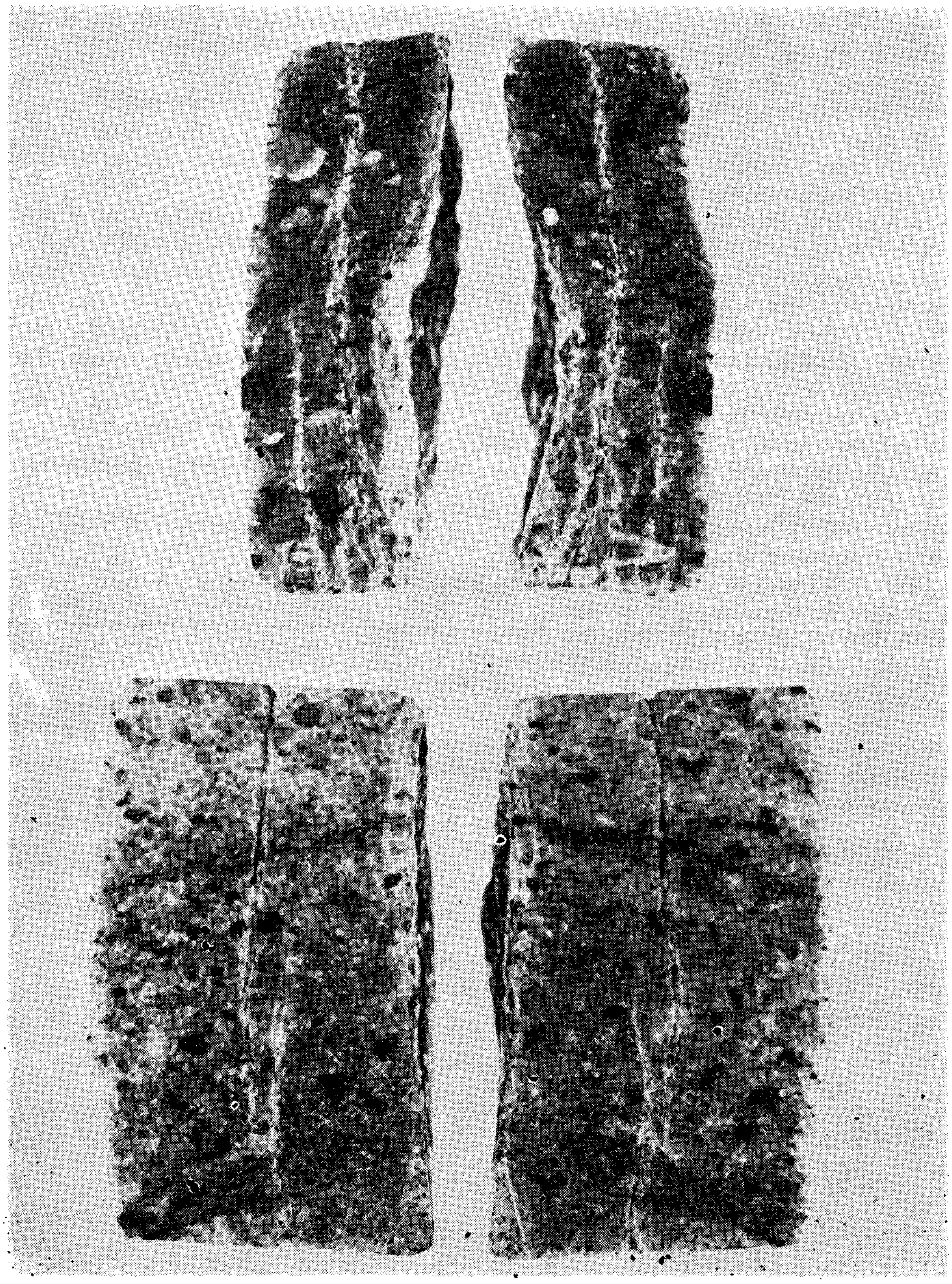

Fig. 4—Fractures in 'intact' core

effective length of the core stub, and the rate of drill penetration.

(iv) *Other effects*

The stress level at which a disc is formed will depend on the time-dependent behaviour of the rock. For example, in Jaeger and Cook's core stub test[1], the stress level at which the stub broke off would be dependent on the rate of load application: the slower this rate, the longer the time available for the individual fractures to join up and form a continuous surface. This was observed to happen during a large-diameter coring operation[10] in which a disc suddenly burst off more than an hour after drilling had stopped. The results of the analyses described earlier suggest that, in this case, the discing fracture would start close to the core axis, and would then progress both towards and away from the axis.

The criterion of extension fracture for predicting fracture initiation is applicable to brittle rock types. For more ductile rock, it is possible that fractures may be initiated by a different mechanism such as shear. It is suggested that this explains the inability of Obert and Stephenson[2] to produce discing in chalk. It is probable that the extension-strain threshold in the core stub of chalk was not reached before the shear strength on the wall of the borehole and in the core was exceeded.

Discussion

The phenomenon of discing of core has been used to estimate the magnitude of the *in situ* stress field[11]. However, based on the results in this paper, the discing phenomenon will not provide a reliable estimate of the absolute stress magnitude. Discing is dependent on the properties of the rock, as well as on the stress level, and will not be present at all in non-brittle rock. It is also dependent on the stress acting in the axial direction of the borehole, and consequently discing can give only a qualitative indication of stress magnitude, as suggested by Leeman[12].

The partial or complete formation of discs could also have a very significant influence on the validity of the results of *in situ* stress measurements using, for example, the doorstopper technique or other overcoring methods. If discing fractures are present in the core or overcore, measurements of strain relief will be recorded on partially stress-relieved rock and the corresponding *in situ* values calculated will be incorrect.

It is suggested that the results given in this paper could be used in the consideration of any cutting or boring process in highly stressed rock, and in the optimization of performance and minimization of bit or cutter wear. For example, if it can be established in advance that discing conditions may occur in a boring operation, the designs of the cutter and chute can be altered to accommodate large, loose blocks rather than small cuttings from the intact, unloosened rock.

Acknowledgements

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