E. Zaayman

The fracture of diamond.

University of Cambridge (UK)

Contact : smw14@phy.cam.ac.uk

The fracture of diamond is not only of economic but also academic importance, as it represents an almost perfectly brittle material. The study of the fracture properties of diamond can be roughly divided into two areas: static and dynamic. Static studies have focused on indentation methods following the work by Roessler on glass to determine the fracture surface energy of diamond and other key elements of brittle fracture such as the occurrence of the Auerbach region. Dynamic experiments have investigated potential rate effects in diamond, both in terms of changes to the fracture load, and to the angle of the cone formed.

This research ties together the existing body of information and extends it to include indentation near to edges and corners and the final failure of a spherical diamond particle.

A comparison of experiments performed with a light gas gun and Instron show that there are no significant rate effects in diamond under normal atmospheric conditions. The light gas gun set-up was also used to determine the damage threshold for a diamond particle impacting on various materials. The most important damage conditions with diamond is when two diamonds impact each other. This is because of the extreme rigidity of diamond.

Indentation loading is described as blunt (when the material behaves elastically), or sharp (when the material behaves plastically). In indentation experiments with both sharp and blunt indenters, diamond always behaved elastically. It is concluded that the geometry of the indenter has little effect on the response of the diamond. A sharp indenter simply fractures and the situation reduces to that of blunt indentation. The only geometric effects observed were alterations in the damage cone angle due to changes in the stress field, brought about by deforming indenters.

Indentation experiments have the added advantage that they are not sensitive to the surface finish, in either initiation or growth, as is the case with usual mode I loading. Initiation of a cone crack is not sensitive to the surface finish, since the stress field under an indenter does not extend very deep into the material and therefore only samples cracks at the small end of the flaw distribution. Since the propagation of a well formed crack is stable, the initial flaws do not have a significant effect on the depth of the final crack and this was confirmed. It is also shown that there is a minor effect of increasing the radius of the initial ring crack for indentation on a rougher surface.

The research by Almond and McCormick and Morrel and Gant on edge flaking in brittle materials is extended to diamond and new observations are made. While the edge flakes do have a constant geometry, they are deeper and wider than expected and diamond has a higher edge toughness than predicted. Fracture is dominated by cleavage along the {111} planes, evident from scanning electron microscope (SEM) micrographs. The difference in edge toughness for {110} and {100} surfaces is not as great as the deviation of diamond from the observed behaviour of other materials. This points to factors other than the dominance of the easy cleavage plane being responsible for the deviation from expected behaviour. It is therefore hypothesised that the extraordinarily low Poisson ratio for diamond is a major factor. It is further hypothesised that the shape of the edge flake in a material is dependent on the Poisson ratio. Indentation near to corners and in close proximity to all three edges shows that these scenarios result in greater degrees of damage.

The final set of experiments determined the threshold of a diamond to failure, where failure is defined at the point at which a particle breaks into 2 or more pieces. Uniaxial compressive loading of spherical diamond particles showed three distinct mechanisms of failure for different failure loads (Pc). Pc was found to increase as the orientation of the easy cleavage plane moved away from parallel to the applied load. It is hypothesised that failure is as a result of one of 3 stresses:

1. Crushing stress within the particle leading to failure into orange-like segments.
2. The tensile stress at the boundary of the contact region (Hertzian stress) leading to failure by the extension of a Hertzian cone crack.
3. Surface stresses along the equator of the sphere which in conjunction with the crushing stress lead to failure of the sphere into halved orange segments.

Further it is hypothesised that many brittle materials will fail by this crushing mechanism rather than as a result of dislocation motion and shear below the indenter.

This research therefore quantifies the damage done to a diamond exposed to a given stress. These data are summarised as a fracture mechanism map. This information is of value to anyone interested in a concise guide to the failure of diamond particles/stones including those trying to quantify the damage done to a stone in the final stages of mining and sorting.