Energetic developments in fracture

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Cracks travel more slowly than standard theory predicts, and finding out why may lead to safer materials and engineering. The answer appears to be in the way a speeding crack branches.

WHAT drives physicists to study cracks? There is certainly some attraction in being able to tell the children one is getting paid to break things. There is also a perverse pleasure in learning the physical laws underlying irreversible change, decay and destruction. Eran Sharon, Steven Gross and Jay Fineberg[1] have just given an answer to an old and deceptively simple question, "How fast do things break, and why?".

The first scientific attempts to answer this question go back to research by Hubert Schardin and Wolfgang Struth in 1937, who used sparks to take photographs of cracks in less than one millionth of a second[2]. They concluded that "the maximum velocity of propagation of glass fractures is to be considered a physical constant", and they measured crack speeds that were approximately a quarter of the speed of sound in many different glasses.

Some time after these experiments came theories of crack motion, which firmly insisted that cracks should move at about twice the speed observed. The classic theory[3] left little room for uncertainty. Cracks leave two new surfaces behind them, and the speed at which vibrations travel across a free surface is the Rayleigh wave speed — the speed of sound produced when one raps one's knuckles on the top of a table, or the speed at which earthquakes travel on the surface of the Earth. Cracks, said the theory, should move at this Rayleigh wave speed too — but it does not happen. In Plexiglas, for example, the Rayleigh wave speed is around 1,000 metres per second, but cracks never exceed 600 metres per second. This discrepancy was widely acknowledged to be rather puzzling, but there was the consolation that it was probably rather unimportant. After all, if a wing is falling off an aeroplane, who has time to wonder whether the crack is moving at 600 or 1,000 metres per second?

In 1991, Fineberg, Gross, Harry Swinney and others developed a method of looking at the motion of cracks, by depositing a very thin layer of aluminium on the surface of a Plexiglas or glass sample, and then monitoring the electrical resistance of the aluminium as a crack raced through it. This technique made it possible to measure the velocity of a crack on timescales much shorter than a millionth of a second, hundreds of thousands of times in succession. With this abundance of new information came many clues about the crack's stubborn refusal to obey a perfectly good theory and accelerate to the proper speed.

The most important clue was found in velocity traces, such as the one on the left of Fig. 1. After accelerating rapidly in its youth, a crack driven hard enough suffers a mid-life crisis at a speed of 340 metres per second, and the smooth motion of the earlier times degenerates into very rough oscillations in velocity.

A large number of different theoretical ideas was proposed to explain these experiments. However, one set of ideas is particularly supported by the recent work[1]. From this point of view, one regards a crack in its early stages as a thin blade, one atom wide, slicing through a piece of brittle material. The effective sharpness of the blade depends upon the power with which it presses through material: press too hard and it blunts, presenting enormous resistance to speeding

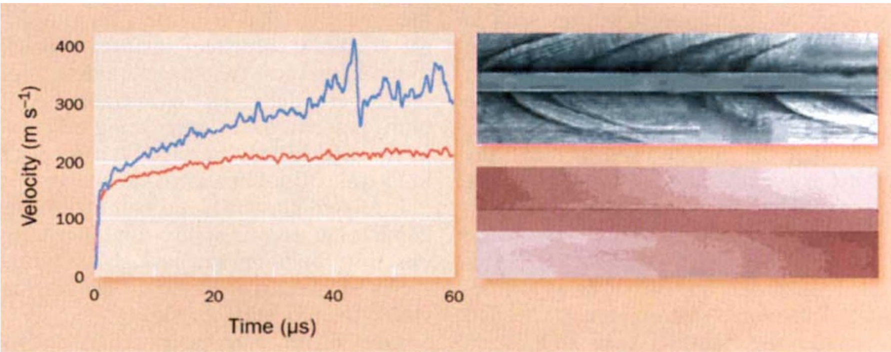

FIG. 1 A crack in Plexiglas, travelling at less than the critical velocity of 340 m s^{-1}, moves calmly and leaves smooth surface in its wake (bottom right). Above this velocity, the crack bucks and plunges, leaving a branching structure beneath the surface (top right). Left, Crack velocity versus time for two experimental runs. (Data courtesy of Sharon, Gross and Fineberg.)

Planes and boats and sticky ends

THE scientific study of breakage originates with Galileo. His *Dialogues on Two New Sciences* begin in a shipyard, where the questioners ask what is "the resistance of solid bodies to separation", and proceed to lay out a sequence of problems to occupy mechanics and solid-state physics for the next three hundred and fifty years. Progress has usually been spurred by disasters. In 1919, a molasses tank 50 feet high and 90 feet wide burst in Boston, killing twelve people and several horses. The court auditor concluded that the only rock to which he could safely cling was the obvious fact that at least half of the scientists must be wrong. Better understanding became particularly crucial during the Second World War, when demands for rapid production led to all-welded ships, and no fewer than 88 examples of the first version of the 'Liberty ship' freighter broke beyond repair, sometimes while sitting in port. New methods of testing materials and procedures for designing ships soon emerged from these failures. Several aeroplane crashes in the following decade were attributed to cracks, which led to systematic inspection procedures. If an engineer is told how much energy it takes to make a crack move forward, he or she can now design ships and planes that will be safe if properly inspected. However, the problem of understanding why a crack needs a certain dose of energy to move, and of calculating when it will do so, is often still mysterious. M. M.