

with analysing the effects of existing modes in more realistic geometry. There was also an interesting and welcome trend in that theoreticians were attempting to compare their predictions with experimental results.

The Oak Ridge theoretical group gave an analysis of the flux-conserved tokamak equilibrium. These equilibria are attained by increasing the plasma pressure in a time which is short compared with the magnetic field diffusion time. In this manner  $\beta$  values of the order of 0.3 are achieved. The current profile of this type of equilibrium has not yet been examined; nevertheless, if a tokamak can be operated at a high  $\beta$  then the reactor economics of the device will be greatly improved. □

## Environmental stress cracking

from P. D. Calvert

WHEN the bottom of a polyethylene bucket splits after six months use the cause is probably environmental stress cracking. The action of detergent solutions and residual stresses from the moulding process cause the slow growth of a crack which usually follows the boundaries of the polyethylene spherulites. Fifteen years ago this was a matter of great industrial concern as coverings on underground cables were prone to crack at bends. It was found, however, that the problem could be largely eliminated by suitable control of the grade of polymer and moulding conditions and the level of industrial interest decreased. But some progress has since been made on the more academic question of why this cracking occurs.

The phenomenon of environmental stress cracking has been extensively reviewed (see Howard, *Soc. Plastics Eng. J.*, 397; 1959; *Engineering Design for Plastics* (ed. Baer, E., Krieger, Basel; 1964)). Cracking is sensitive to the molecular weight distribution of the sample and in particular cracking resistance is improved by removal of the lowest molecular weight species (Herman and Biesenberger, *Polymer Engineering Sci.*, 6, 341; 1966), which probably segregate to the spherulite boundaries and weaken them. Tests for stress cracking measure the time to fracture of a sample either bent and immersed in a liquid, or held under constant load in the liquid.

High density polyethylene is more resistant than low density to stress cracking under a constant load, but the situation is reversed when bent samples are tested. Fire polishing improves re-

sistance to stress cracking, presumably by removing small surface flaws.

The liquids which cause stress cracking in polyethylene tend to be of low viscosity and to be surface active. Non-ionic detergents are quite effective, as are silicone oils, mineral oils and alcohols, but not ethylene glycol, glycerol or water. The liquid does not have to be a solvent or swelling agent for the polymer.

From a series of recent studies we now know that the mechanism of environmental stress cracking at low loads, involves void growth and depends on the ability of the liquid to penetrate from the sample surface to the crack tip.

In 1974 Hannon (*J. appl. Polymer Sci.*, 18, 3761) showed that the fracture surfaces consist of small smooth areas surrounded by zones where the polymer has been drawn out. He pointed out that this resembles the situation in ductile fracture surfaces of metals where fracture starts by the growth of voids around particulate inclusions and ends when the voids grow large enough to join up. In polyethylene the voids must start at locally weak regions. Addition of detergent to the testing environment results in larger voids with less deformed material. Berg (*J. Res. NBS*, 76C, 33; 1972) discussed theoretically the process of cavity growth in metals and suggested that this could be applied to stress cracking in polymers.

At high loads the crack velocity can become sufficiently large that the progress of the crack tip is limited by the ability of the liquid to flow in. On this basis Williams and Marshall (*Proc. R. Soc.*, A342, 55; 1975) made a fracture mechanics analysis of stress cracking and predicted a change in the stress dependence of crack speed, which they observed to occur at about  $3 \times 10^{-7} \text{ m s}^{-1}$  in a detergent. Shanahan and Schultz (*J. Polymer Sci.*, (Phys), 14, 1567; 1976) have now established this change by measuring fracture times of polyethylene samples in a series of silicone oils of different viscosity. At low loads the time to failure is independent of viscosity but for each viscosity a critical rate is reached above which the failure time changes only slowly with load. This critical time to failure is roughly proportional to the fluid viscosity. The most obvious interpretation of this is that the total time to fracture is the time it takes the crack to grow, but Shanahan and Schultz make the rather more elaborate assumption that when, by creep, a critical strain of 15% is reached, fracture occurs rapidly at a rate proportional to the creep rate. This, however, is a point which ought to be easily cleared up.

Although this gives us a good idea of how the fracture occurs it does not

help to explain why polyethylene is the only polymer in which it happens and why some liquids are more effective than others. Spendal (*J. appl. Polymer Sci.*, 16, 2375; 1972) has shown that the addition of 10% rubber can dramatically improve stress crack resistance, presumably by toughening the boundary regions. With rather more subtlety Schonhorn *et al.* (*J. Polymer Sci. (Phys)*, 11, 1013; 1973) have shown that the addition of silanes to polyethylene can improve stress crack resistance and base their arguments on the ways in which the interfacial energies of polymer-polymer and polymer-liquid are modified.

There are many other cases where polymers do form voids under stress both with and without environmental agents; the phenomenon is generally called crazing. Why this should be so common amongst polymers and why only polyethylene is vulnerable to the peculiar form of voiding discussed above is not known although Haward (*The Physics of Glassy Polymers* Applied Science, 1975) has discussed the question in some detail. But the solution to this problem is unlikely to help the humble plastic bucket. □

## Serpentinite in the oceanic crust?

from Peter J. Smith

IT is now more than 14 years since Hess (in *Petrologic Studies*, Geological Society of America, 1962) suggested that serpentinised peridotite is the major constituent of seismic layer 3 of the oceanic crust. In the debate that has gone on throughout most of the intervening period, arguments have been adduced both for and against the proposal, although the balance of belief now seems to be against it. As the serpentinisation of peridotite can only occur below 500 °C, Hess envisaged the hydration of upper mantle peridotite taking place upon the latter's moving upwards through the 500 °C isotherm beneath an oceanic ridge; but as Fowler (*Geophys. J.*, 47, 459; 1976) has recently pointed out, the depth and proximity of layer 3 to the ridge axis combined with a reasonable thermal model of the crust militate against widespread serpentinisation. Moreover, as Cann (*Geophys. J.*, 15, 321; 1968) has noted, the very small scatter of layer 3 seismic velocities would imply an unacceptably high uniformity of serpentinisation throughout the layer.

Cann's alternative suggestion is that the lower oceanic crust consists largely of gabbros and metagabbros. But even so, it does not follow that serpentinite