Contact damage reduction by a hard coating

Good erosion resistance combined with good optical properties in the (far) infra-red region are the prime requirements for window materials in new electro-optical devices to be used in aviation. Most of these materials are brittle and are therefore susceptible to contact damage. The aim of this study is to investigate the possibility of increasing the (rain) erosion resistance of zinc sulphide and other infra-red transparent materials by the application of a coating. Thorium oxide was chosen as the coating material because of its transparency in the infra-red and its mechanical and chemical properties. Quasi-static ball indentations have shown that the threshold load for contact damage in zinc sulphide can be doubled by a thorium oxide coating of sufficient thickness.

In the experiments, an 800 μm diameter tungsten carbide ball was loaded onto uncoated and "thorium oxide"-coated zinc sulphide. The thorium oxide coating and the zinc sulphide substrate were both produced by a chemical vapour deposition process. The thickness of the thorium oxide coating was about 3.0 to 3.5 μm. Radial cracks were formed around the indentations. At high loads (about 100 N) lateral as well as radial cracks were observed. The processes involved in the nucleation and propagation of these crack systems in zinc sulphide have been described in detail elsewhere [1].

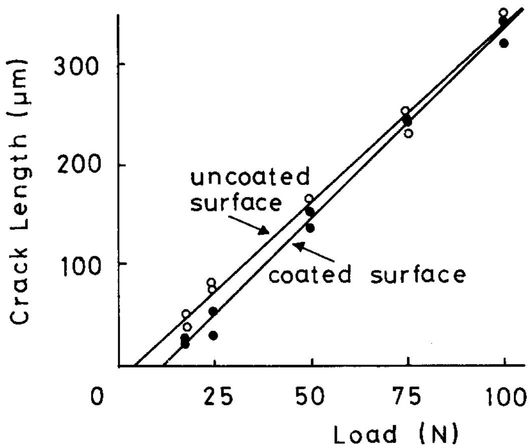

Figure 1 Plot of radial crack length against applied load.

The length of the radial cracks as a function of the applied load is plotted in Fig. 1 for both the coated and the uncoated surface of the specimen. A significant reduction in the average crack length at loads below 50 N is observed. The beneficial effect of the coating on the contact damage is however negligible for loads in excess of 100 N. Extrapolation of the linear relationship [2] between radial crack length and the applied load towards low loads indicated that for this coating thickness the critical load for crack nucleation is about twice that for the uncoated surface. At low loads the coating not only reduces the average length of the cracks but also the number of cracks nucleated. At a load of 18 N, 6 to 8 radial cracks are observed around an indentation on uncoated

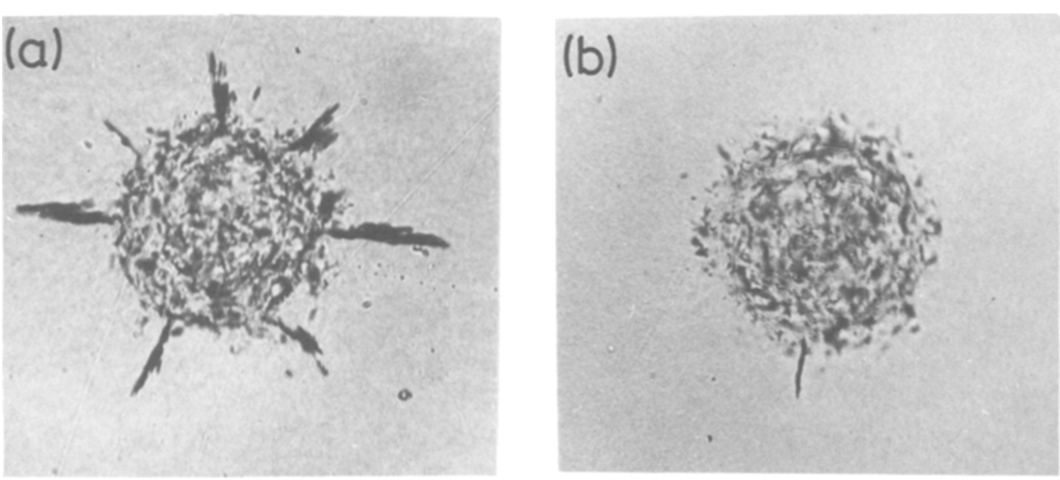

Figure 2 Radial cracks around a spherical indentation, (a) uncoated surface and (b) coated surface, (× 238).

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zinc sulphide, while only 1 to 2 cracks are nucleated around indentations on the coated surface (Fig. 2). The size of the plastic impression is however the same in both cases. Examination of the coating surface showed that the cracks do not, or only partially, extend into the coating surface, indicating that the crack is nucleated *in the substrate*. It should be pointed out that the protection offered by the coating depends on its thickness. No statistically significant reduction in the radial crack length, nor in the number of cracks nucleated, was observed for specimens coated with a 2 μm thick thorium oxide coating.

Two explanations can be put forward to explain the observed reduction of the radial crack length due to the thorium oxide coating.

(1) Since the thermal expansion coefficient of thorium oxide is lower than that for zinc sulphide, compressive stresses are generated in the composite structure on cooling down from the deposition temperature. This beneficial effect will disappear at high indenter loads, where the magnitude of the pre-existing stresses is small compared with the induced stresses.

(2) The presence of a "stiffer" coating with a high interfacial strength will reduce the displacements in the coating–substrate interface, providing the coating does not fail at lower stress levels than the substrate. This will reduce the tensile stresses responsible for crack propagation.

A theoretical model is being developed to calculate the effect of various coating parameters on the stress field generated by localized loading conditions.

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Normal and anomalous fatigue crack propagation (FCP) of thermoplastic polymers

As a result of the increasing use of thermoplastic polymers as structural components in the past ten years, increasing interest has been shown in their fatigue crack propagation (FCP) behaviour. Most of the work conducted in this area was concentrated on amorphous polymers such as polystyrene (PS) or polymethylmethacrylate (PMMA). The most important result is the validity of a relation of the type

$$\frac{\mathrm{d}a}{\mathrm{d}N} = A\Delta G^n = A\left(\frac{\Delta K^2}{E}\right)^n, \qquad (1)$$

where $\mathrm{d}a/\mathrm{d}N$ is the crack growth rate, A and n are empirical constants, ΔG is the energy release rate, ΔK is the stress intensity and E is Young's modulus.

On the other hand, only limited knowledge is available on the behaviour of semicrystalline materials. Hertzberg *et al.* [2, 3] have shown that significant differences exist between amorphous and crystalline polymers. Crystallinity clearly provides a higher resistance against the growth of fatigue cracks.

The purpose of this investigation is to obtain a more detailed insight into the fatigue properties of semicrystalline polymers. Therefore FCP-tests with a constant triangular load amplitude ΔF were conducted with low molecular weight polyethylene (LMWPE) (molecular weight, $\bar{M}_w = 100\,000$), high molecular weight polyethylene (HMWPE) ($\bar{M}_w = 450\,000$), polyamid-6 (PA6),

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