developed by Sato and Toth [5, 6] for Cu–Au alloys, has recently been found applicable to the two-dimensional long-period superstructures in hexagonal Cu–Sb [7] and Au–Cd [8] alloys. The low temperature instability of the long-period structures in cobalt sulphide, which is also quite common in metallic alloys, is thought to be due to the temperature dependence of the antiphase boundary energy.

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Received 29 August
and accepted 5 September 1974

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Large work of fracture values in wire reinforced, brittle-matrix composites

The purpose of this note is to draw attention to a feature of the pull-out of ductile fibres from brittle-matrix composite materials, which may lead to large values of the work of fracture of the composite.

In the course of an investigation into the pull-out of long metal wires from epoxy resin and cement matrices, the behaviour of work-hardened nickel wires was compared with that of annealed nickel wires of the same diameter. The experimental arrangement is shown in Fig. 1. A completely cracked matrix was simulated by dividing the cast resin at some point along the length of the wire with a thin flake of mica. A cement of epoxy resin matrix surrounding the wire was produced by casting cement or resin into a cavity machined in a resin block. This facilitated alignment of the wire and subsequent gripping of the specimen. The wires in the resin matrix were in general inclined at some angle $\pm\ \theta$ to the normal to the simulated crack but for brevity in this note we will describe only results for $\theta = 0$, i.e. with the wires normal to the simulated crack and parallel to the tensile stress during pull-out. Qualitatively, the comparison of the behaviour of cold-worked and annealed nickel wires described below for $\theta = 0$ holds for other values of θ, although variation of θ introduces significant quantitative variations, which will be described in another place.

In the pull-out tests, the work-hardened wire fractured when its shorter embedded length exceeded a critical value, whereas the annealed wire invariably pulled out of the matrix, even when its shorter embedded length was five times the critical length of the work-hardened wire (Fig. 2). To check that this difference did not arise from a change in the surface condition of the wire during annealing, the results of annealing in air and in argon and of etching the wire in acid after annealing were compared. These variations had no effect on the pull-out behaviour of the annealed wire. Closely similar results were obtained when the wires were embedded in a cement matrix (Fig. 3).

The force needed to pull an annealed nickel wire from a resin matrix as a function of the separation of the two halves of the specimen is shown in Fig. 4, for a wire of 55 mm shorter embedded length. The force remains constant (subject to minor fluctuations) for a substantial fraction of the total separation. Because of this feature, and because the length of wire embedded can be increased indefinitely without leading to

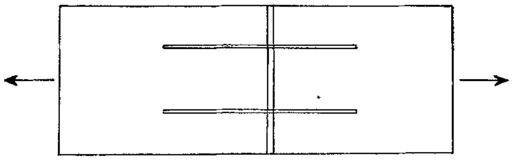

Figure 1 Specimen consisting of a pair of nickel wires embedded in an epoxy resin or cement matrix containing a simulated crack.

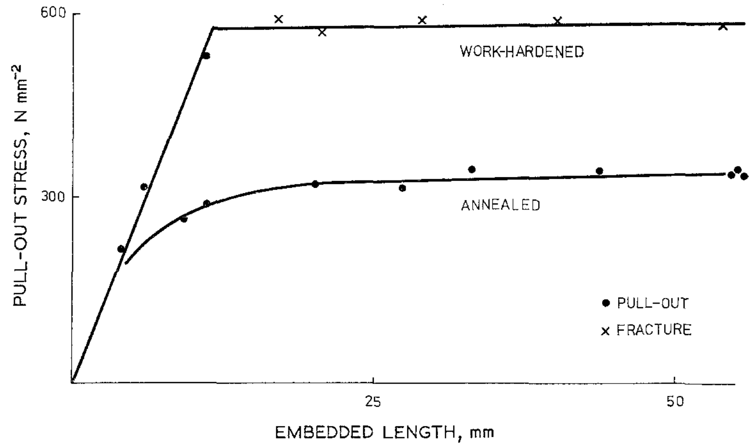

Figure 2 Maximum tensile stress exerted on a wire at the position of the simulated crack, as a function of the shorter initial embedded length – resin matrix.

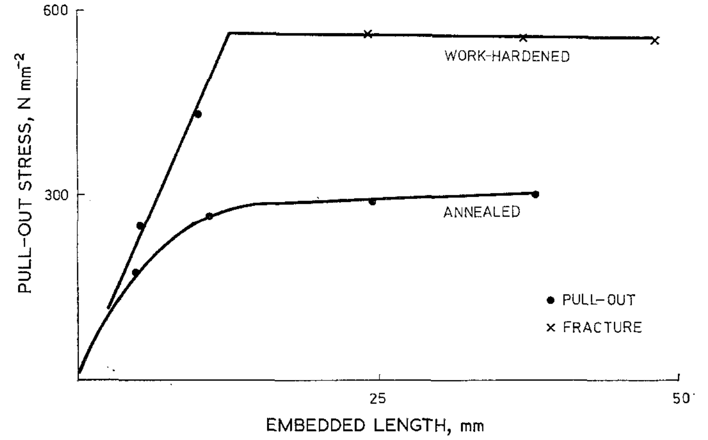

Figure 3 Maximum tensile stress exerted on a wire at the position of the simulated crack, as a function of the shorter initial embedded length – cement matrix.

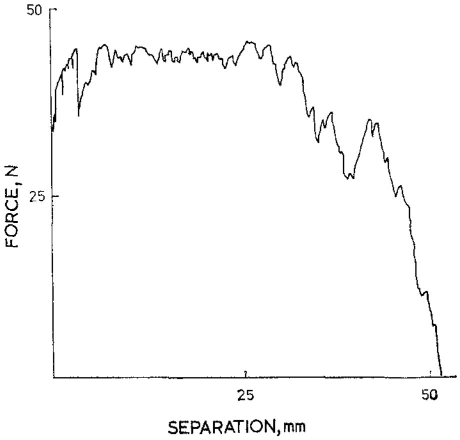

Figure 4 Chart record of pull-out force versus separation of the two halves of the specimen – annealed nickel wire in resin matrix.

the fracture of the wire, the total work of fracture of the model composite increases approximately in proportion to the length of wire initially embedded, and has no upper limit. This is quite different from the behaviour expected of a wire whose pull-out is resisted by a constant interfacial shear stress. There, the work of fracture per wire increases as the square of the fibre length, up to a maximum value at a wire length just less than the critical length at which the wire fractures [1].

The explanation of the behaviour of the annealed nickel wire lies in its abilty to undergo substantial uniform plastic elongation. A wire which is too long to be pulled out at a stress below its yield stress elongates plastically with an accompanying lateral contraction which releases it from the grip of the resin or cement matrix. (Both resin and cement matrices shrink during setting and subject the wires to a radial compression. It is the frictional force acting on the wire as a result of this compression, rather than any bond formed between the wire and the matrix, which supplies the maximum force opposing pull-out in our specimens.) This process of "plastic release" then propagates along the wire towards the embedded end until the wire is able to pull out. The residual length of wire that is strongly gripped by the matrix remains constant as the wire is pulled out, up to the point where it reaches the simulated crack, so that the pull-out force also remains constant up to this point. This behaviour resembles that proposed for the pull-out of a long elastic fibre by Takaku and Arridge [2], where the lateral contraction of the wire given by Poisson's ratio serves to release it from the matrix and sets a limiting value to the force required to pull the fibre out. We suggest that when the limiting pull-out stress given by Takaku and Arridge exceeds the yield stress of a wire which is capable of substantial uniform plastic elongation, the wire is released by plastic deformation and pulled out at a limiting stress given by the flow stress at the plastic strain needed to obtain release. For nickel wires in our cases the limiting pull-out stress for elastic behaviour exceeds the ultimate tensile strength of the wire, and the work-hardened wire, which is not capable of sufficient further uniform plastic elongation to release it from the matrix, fractures when a critical length is exceeded.

To check the above explanation, the lengths and stress-strain curves of the pulled-out portions of the annealed nickel wire, pulled from the resin matrix, were measured. Increases in length of between 4% and 5% occurred, and the yield stress in tension was equal to the flow stress of an annealed wire at a plastic strain of 7%. The nominal stress at yield of a pulled-out wire, 305 N mm^{-2} was somewhat less than the limiting pull-out nominal stress of 350 N mm^{-2} (Fig. 2). These results suggest that the wire undergoes an inhomogeneous plastic elongation during pull-out, most severe at the crack position, so that the tensile test sampling a region of wire between the crack position and the end records a slightly lower yield stress than the pull-out stress. If the hardening of the wire at the crack position is attributed entirely to plastic elongation, a strain of about 9% at this point is implied.

The observations described in this note suggest in designing composites of the wire-reinforced cement type, there may be advantage in employing wires having a high work-hardening rate and a uniform elongation to failure of, say, 10%, in order to maximize the work of fracture of the composite.

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Received 29 August
and accepted 9 September 1974

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The optical reflection transform method

The purpose of this short note is to present a simple diffraction explanation for the patterns created when a collimated beam of light is reflected back from a material having a crystallographic topography. At its simplest, the technique is a direct copy of the back-reflection Läue technique with the X-ray beam replaced by a light beam.

The technique has a long history, dating back to its conception by Chalmers [1] who used it to measure the angle of twinning in deforming tin crystals. Later workers, among them Cocks *et al.* [2] and Yagi *et al.* [3], have used the method and have coined various terms such as "laser reflectogram", "light figure method" and "reflection pattern method" to describe it, but have, it is felt here, incorrectly or incompletely interpreted the resulting patterns. From the simple analysis presented here the term, if a term is necessary at all, "optical reflection transform method" would appear to be more appropriate.

Purely to illustrate the inadequate interpretation of the reflected light patterns that Cocks *et al.* and other workers have made, reference is made to Fig. 2 of the article on the laser reflectogram method by Cocks *et al.* [2]. They were studying the crystallographic nature of the pits created by etching in crystals of silicon carbide. Cocks *et al.*