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Concluding Remarks

Peter Hirsch

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Concluding remarks

By Sir Peter Hirsch, F.R.S.
Department of Metallurgy and Science of Materials, Parks Road, Oxford OX1 3PH, U.K.

The original objective of this meeting was to assess how fracture mechanics is now being used in practice, both in design and service, in different industries, and the extent to which it is now established as a reliable tool. It was hoped to bring together engineers and scientists with experience in different applications of fracture mechanics.

My own impressions of some of the important conclusions that have emerged from this meeting are as follows.

1. The simple concept of a constant fracture toughness controlling unstable fracture under nearly l.e.f.m. and quasi-static loading conditions seems to work remarkably well for a variety of materials, including alloys, plastics and composites (see Professor Williams's paper). But when plastic deformation becomes significant, there are complications, in particular the effects of triaxiality of the stress system, a point stressed by Professor Burdekin, and also of high rates of strain, which must be taken into account in applying toughness values obtained from laboratory tests to actual structures in service.

2. There is now some understanding of the dependence of fracture toughness on microstructure (see Dr Knott's paper), but this is an area where much work remains to be done, particularly in respect of quantitative modelling. While the engineer can proceed without this detailed micro-mechanistic understanding, he must at least be aware of the differences in microstructure and properties of different parts of the structures, effects of heat treatment, etc., and of possible changes of fracture mechanisms under different conditions (a point made by Professor Bilby).

3. Subcritical crack growth rates (see Dr Tomkins's paper) can also be usefully correlated with stress intensity factors, but the relative simplicity of the application of fracture mechanics to the problem of unstable fracture is to some extent lost here, since other important parameters have to be taken into account, e.g. the mean stress in fatigue crack growth or the nature of the corrosive environment. The difficulties in relying in practice on threshold values of ΔK, when a range of transients of different severity may be encountered, have been emphasized.

This appears to be an area where much remains to be done to improve our understanding and to elucidate principles, and the engineer must work closely with the metallurgist or materials scientist to appreciate the strong interaction between microstructure, stress and environment.

4. As regards the use of fracture mechanics in design, the régime in which elastic–plastic analysis has to be applied is most important. Various methods have been suggested for interpolating between the l.e.f.m. and plastic collapse régimes, all of which have a common basis in terms of the J integral, and, to quote Professor Turner, give the same results to within a factor 2 ± 1. As Professor Bilby warned the conference, the measured values of J, may not actually correspond to any of the three theoretical definitions of J.

Practical design guides, e.g. the failure assessment diagram of the C.E.G.B. (Dr Milne's paper), or the c.o.d. method developed by the Welding Institute (Professor Burdekin's paper), are *empirical*, albeit theoretically inspired, interpolations between the l.e.f.m. and plastic collapse régimes, and their validity depends on how well they work out in practice for different conditions of stress, toughness and extent of plasticity.

5. Probabilistic fracture mechanics (see Dr Rau's paper) appears to be an important step forward, in that risk can be assessed quantitatively in terms of probability of failure, which depends on probability distributions of toughness, stress, defect sizes (modified by inspection), etc. Good input data are needed, and separate analyses are probably required for different geometric parts of a structure, e.g. nozzles in pressure vessels, a point made by Dr Nichols. In principle, design specifications could be given in terms of acceptable probabilities of failures, but in practice the usefulness of this approach is limited by a lack of knowledge of the various probability distribution functions.

6. Design based on fracture mechanics will increasingly have to take into account the need for inspection, both during fabrication and service, e.g. by ultrasonics, and the limited sensitivity of the inspection techniques will have to be taken into account (e.g. 2 mm in the ultrasonic inspection of steels, a figure given by Dr Coffey).

There is clearly scope for review of the engineering design codes in the light of new assessment methods based on fracture mechanics and inspection techniques (see Mr Poynor's paper).

7. It is clear from the examples described by representatives of different industries (petroleum, gas, rubber, wood, nuclear, C.E.G.B.) that fracture mechanics is being applied successfully not only in design, but also in service. Dr Williams (C.E.G.B.) reported impressive savings in replacement costs by extending the time that a component with a defect can be left in service, resulting from fracture mechanics, assessments. The use of micro-fractography of failed components in providing data on subcritical crack growth mechanisms and rates was emphasized.

8. A number of 'problem' areas emerged, which require further work and discussion, including:

(*a*) uncertainty regarding the magnitudes and effects of residual and thermal stresses;

(*b*) the need for attention to repair procedures (emphasized by one of Dr Cotton's examples);

(*c*) the conditions for crack arrest (see Mr Smedley's examples);

(*d*) the need to predict transients, and to calculate stresses and transients, accurately – in pressure vessels the uncertainty here may be greater than that regarding the value of toughness;

(*e*) the unpredictability of welds – in Professor Cotton's words, if enough are tested, a bad one will eventually be found!;

(*f*) the possible virtues of warm prestressing.

9. Finally, there appears to be a need for the engineers and theoreticians to get together to define the problems that should be tackled to extend elastic–plastic analysis to actual engineering structures.

To quote a comment made by Professor Cotton at the Rosenhain Centenary meeting in 1975 (published in *Phil. Trans. R. Soc. Lond.* A **282**, 53-64 (1976)): 'Not only are specific answers required to specific questions but general principles need to be revealed and communicated to engineers in language which they can understand.'

Bearing in mind the widely different background experience of some of those attending this meeting, it cannot be expected that all speakers were understood equally well by everyone. This must remain an important challenge for the future. There is little doubt that if the communication gap could be bridged, the benefits of fracture mechanics could be reaped by many more industries, and perhaps even BP might find it useful to add to the small, but obviously very successful, number (three?) of fracture mechanics experts on their staff to support a £1000M investment programme!

Those of you who have read the recent account in the popular press of the Tay Bridge disaster, which occurred about 100 years ago, will no doubt agree that quite outstanding progress has been made since then in engineering design, and the considerable developments in fracture mechanics and non-destructive testing, discussed during this meeting, have made their contribution to this advance.

It remains for me to thank all speakers for their stimulating contributions, the Royal Society for supporting the meeting and Miss Christine Johnson for organizing the conference so effectively.