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STRESS WAVE EMISSION: DETECTION CAPABILITY AND ASSESSMENT

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INTRODUCTION

Stress wave emission monitoring has perhaps greater potential as an NDT and diagnostic tool than any other technique yet devised but, in many ways, progress with the development of these techniques has been slow. This is very unfortunate since if the techniques could be suitably developed they would make a major contribution to ensuring the safety of oil rigs, nuclear power plant and many thousand of other structures and assemblies.

Euphoria has been generated by the potential of stress wave emission monitoring, but an adverse reaction has resulted, both from an initial over-sell and from very variable results in practice. The net effect has been to cloud the processes in mists of uncertainty, but these mists are now beginning to clear, in that the situation is taking a more definable pattern, which should eventually allow resolution of the controversies over the viability of the techniques, of the assessment and calibration procedures and the location of emission sources.

It can now be seen that emission is detected in some instances (satisfactory sources) in sufficient quantity and sufficiently consistently to give confidence in the techniques provided rational assessment approaches are used (1-5). In other cases (6) emission is not detected or that detected is too sparse or too inconsistent to allow meaningful interpretation (unsatisfactory sources). If this pattern of behaviour can be rationalised the viability of the techniques when they are applied will be enhanced and the areas where further effort is required will be more clearly defined. This paper first discusses the detectability aspect and then its significance with regard to assessment before briefly noting the current situation with regard to other important aspects.

DETECTION OF EMISSION

Stress waves are vibrations generated by dynamic events within materials and are an essential part of those reactions. Consequently, emission should be detected from all rupture and deformation mechanisms, from many phase change reactions and from some ancillary effects such as fretting.

The main interest is in rupture and deformation since the greatest potential for application of stress wave emission techniques lies in (i) Fabrication monitoring, (ii) Preservice and proof load monitoring, (iii) In service monitoring.

If viable, the techniques are theoretically applicable to anything from small components to large structures.

The essential requirements of any viable monitoring approach (whether pure assessment or based on source location) (6,7,8,9) are (i) An adequate detection capability and (ii) A rational assessment technique.

Stress waves have a very wide dynamic range (amplitude) (1,2,3, 9) which is to be expected (6,7,10) since they are generated by events with from microscopically small to macroscopically large dimensions (Fig.1). Thus, detection systems require both ultimate sensitivity and dynamic range, sensitivity being possibly more important since much of the interest is centred on finer events, where other inspection or NDT techniques are unsuitable. Here usable sensitivity is achieved by using (i) The inherent sensitivity of piezo-electric transducers (especially at their resonant frequency), (ii) High gain, low noise, amplification systems of restricted bandwidth and (iii) Sufficient shielding etc. to give a high level of immunity to electrical interference.

With regard to items 2 and 3, the AML team have set a very high standard (11,12,13) and it is doubtful whether any lower standard should be tolerated, in view of the dynamic range required and the need to detect fine events.

Work by the Harwell team (14) has shown that transducer sensitivity is high, for example amplitudes of 10^{-14}m which are orders of magnitude below the interatomic distances, may be detected. Even with high gain amplification systems and no noise problems, however, the amount of emission detected is sometimes virtually non-existent. For example, using systems produced following the AML approach, fatigue tests on aluminium alloys have been monitored at The Welding Institute with no emission being recorded over prolonged periods of visible crack extension (2). Also, the fact that more emission is normally associated with the minor deformation at yield stress or at the limit of proportionality, than with subsequent major plastic deformation is a cause for concern.

One of the few guides to the amount of emission which ought to be detected is the copious emission associated with some cracking events which, when suitably assessed, can give an approximate direct correlation between the assessed value and the extent of the source event (1,2,3). Examples of these events are lamellar tearing, stress corrosion cracking in some aluminium alloys and brittle short transverse failure in some aluminium alloys. Here, extrapolation of the data obtained indicates that an arbitrary unit emission (generating a 1 V signal at the input to the pre-amplifier and selected for convenience) if generated by cracking would be equivalent to a jump of 10^{-6} to 10^{-10}mm^2 depending upon material and event. Assuming that the minimum individual crack jump will be 10^{-5} to 10^{-6}mm^2, many of the smaller emissions detected, e.g: generating 3 V to say 30 V, will be associated with deformation or other events. This is reasonable since most deformation mechanisms would be expected to generate emissions equivalent to those for crack jumps within the 10^{-6} to 10^{-10}mm^2 size range (if the latter actually occurred). Consequently it would be reasonable to expect that copious detectable emission would be generated by all cracking mechanisms and by any significant volume of material undergoing deformation. The pattern emerging from practical experience appears to be:- (i) Brittle fracture mechanisms generate large amounts of detectable emission giving correlation between the assessed value (suitable assessment technique) and the crack area. (ii) Ductile fracture mechanism can give little or no detectable emission by comparison with case (i). (iii) Emission detected in association with deformation varies considerably but is usually sparse or very sparse im relation to case (i), especially where dislocation as opposed to shear deformation mechanisms are involved. (iv) Shear transformation tends to give copious emission (another indication of the amount of emission which should be detected), while the situation with diffusion controlled transformation is ill defined.

Thus (Fig.2), it is mainly events which are generally classified as fast or brittle which tend to generate detectable emission in large quantities. It is in these circumstances that a viable correlation between the assessed value and the magnitude of the events has been shown. With events normally classified as ductile or slow, however, the amounts of emission detected are mainly small or non-existent compared with those classified as brittle. Here, therefore, there is considerable cause for concern. Clearly in many cases (e.g. with a specimen being uniformly deformed), only a small proportion of the source events are generating detectable emissions. The important unknowns are why these few sources in one specimen do and others do not generate detectable emissions and to what extent the proportion of sources which do generate detectable emissions is constant.

EMISSION ASSESSMENT.

Where emission has been detected in sufficient quantities to give confidence in these techniques, it has been possible to define assessment requirements and to produce equipment which meets those requirements as defined to date (7,9). Where too little emission is detected, it is highly dangerous to rely on assessment, since the probable outcomes are either unnecessary deformation of the technique or, a catastrophic failure of a structure.

Although use can be made of qualitative assessment, stress wave emission monitoring should normally only be considered when adequate quantitative interpretation (e.g. on basis, crack area = constant x assessed value of emission detected) can successfully be made. The major factors associated with quantitative assessment are (i) The basic assessment technique, (ii) The dynamic range of the system and (iii) The capability for coping with various amplitude distributions etc.

Various assessment techniques are used notably ring counting, even counting and $\sum A^2$ or energy assessment (1,2,3,7,8,9). Of these only $\sum A^2$ or energy assessment has withstood theoretical scrutiny and the tests of practical experience. The others cannot cope with either the dynamic range or the variation in amplitude distributions encountered in practical applications (7). For some if not all event types, e.g. stress corrosion cracking in a given material, emission energy is likely to be a direct function of the magnitude or significance of the source. A practical approach to measuring emission energy, which is applicable to the full dynamic range is to sum the squares of the peak emission amplitudes. The dynamic range of emission significance (or amplitude squared values) must extend from that for the largest single crack jump down to well below that for the smallest individual crack jump. Thus with crack jumps extending say from $10^4 mm^2$ down to $10^{-5} mm^2$ a dynamic range of 10^9 is obtained. This range must be extended downwards by perhaps 2 or 3 orders of magnitude to cater for finer events and widened to cover variation, with material or event type, in the coefficient relating the sum of squares of the amplitudes to the source magnitude. Thus a 10^{12} (or perhaps greater) range of emission energies needs to be covered, which is equivalent to a 10^6 range of emission amplitudes. Experience has shown (7) that although with controlled laboratory experiments amplitude distributions can be gaussian and reproducible, in practice any distribution can be expected and equipment must function satisfactorily irrespective of the amplitude distribution encountered. The Welding Institute have developed equipment to meet these needs as they have been defined (7 & 9). Detection and amplification systems have been based on the developments of the AML team. The simplest system has a single ΣA^2 readout and this is suitable for routine work once a monitoring approach has been established. At the present stage of development of the techniques however, this equipment is too simple for research purposes and therefore a combined amplitude sorter (counting the emissions within each amplitude range) and two channel ΣA^2 readout system has been produced. This system has proved satisfactory when background mechanical noise levels have been high, as well as for quiet tests. With extremes of both sensitivity and dynamic range to cope with, calibration of stress wave emission monitoring systems is important but until recently has been quite difficult. Reciprocity (stimulating one transducer with another face to face) and spark bar techniques (the production of a shock wave in a bar by discharging a spark onto it) are amongst the more common techniques which have been used for transducer calibration (15) but these are far from satisfactory and the calibration units 'dB referred to 1V per microbar' are not convenient to use. Now, however, the Harwell team have developed a direct amplitude calibration system using laser interferometry (14) and a gas jet system has been developed in Canada (16) for more routine and spectral calibration.

DISCUSSION

It is now becoming apparent that events generating emission can be divided into two groups. The first covers mainly events normally classified as brittle or rapid which generate copious detectable emissions. The second covers mainly events normally classified as ductile or slow, where the amount of emission detected varies, but is usually sufficiently low to cause concern. This means that rapid progress towards industrial application should be possible with the former but much more work is required before application to the latter can be considered as a viable proposition. Definition of which sources belong to which group is more difficult than might be expected. This is because what may appear to be essentially similar events are in fact sufficiently different for them to act as sources of different types. For example, stress corrosion cracking has different modes which can give different source types, while hydrogen cracking as a result of artificially stressing specimens gives sources of one type (satisfactory), but in naturally stressed weldments gives the other. Additionally, the variability in the amount of emission detected from unsatisfactory sources can cause difficulty with definition of to which group a source belongs, if in initial studies copious emission is detected.

With satisfactory sources it ought to be possible to establish quite readily the viability of detection and assessment procedures since emission from such sources can be readily assessed using suitable equipment (1,2,3,7,8,9). Although such equipment has to meet exacting requirements (7) it can now be produced. Once procedures have been established industrial application should quickly follow. Unfortunately with metals these areas where early application might be expected are somewhat restricted but would include some forms of stress corrosion cracking, lamellar tearing (provided that crack extension occurred rather than the opening of pre-existing lamellar separations) proof load monitoring of dissimilar metal joints to detect the presence of particular types of defects. Additionally, monitoring for the occurrence of particular ancillary noises, e.g. stick/break noise from fatigue cracks appears to be a usable approach. These suggested early application areas have naturally been subjected to qualification but it must be remembered that any NDT technique should only be used where appropriate, none are universally applicable. With non-metals e.g. reinforced plastics and metal/non-metal joints, however, the scope for early applications should be much wider.

Some of the 'unsatisfactory' group of emission sources are most important and included amongst these are those relevant to areas where the application of stress wave emission monitoring is most needed, i.e. oil rigs, nuclear power plants etc. where materials, selection and design are aimed at avoiding brittle forms of failure in the event of overload or mishap. At present the value of assessing emission, which is detected in inadequate quantities, is doubtful although it is commonly attempted in practice. The danger is that the proportion of emission detected to that actually generated may change without the operators knowledge, (especially when changing from laboratory tests to practical applications) and a false interpretation of the situation may be made. The options with regard to improving the situation in relation to unsatisfactory sources are to increase detection capability or, if this is impossible, to establish the extent to which the emission actually detected can be validly assessed. Effort should be directed towards improving detection capability, since it is a more positive approach and the alternative would be very difficult and expensive in view of the need to ensure that the amounts of emission currently detected were both consistent and representative of a given situation (if they were not, catastrophic failures could result from misinterpretation).

Both detection and emission assessment are important in relation to source location. Although at least two laboratories are now examining A^2 weighting, normal practice is to weight emission sources according to the number of events detected from each. In view of the dynamic range of significance of individual emissions, this approach is considered untenable. The approach of weighting on the basis of only the number of emissions, is being followed because emission assessment and source location have been divorced aspects of stress wave emission monitoring. It is now time that source location techniques were combined with rational weighting of the located sources as a matter of course. Location is however often applied to structures where failure is expected by ductile or slow deformation and rupture mechanisms (where assessment is most difficult), because of the need for monitoring on many such structures. The use of location for such application needs to be reconsidered most carefully until the 'unsatisfactory source' situation is resolved, in view of the possibilities of misinterpretation.

CONCLUSIONS

1. The sources of stress waves can be considered in two groups : (a) those giving copious detectable emission which can be readily assessed in a quantitative manner with suitable equipment and (b) those giving too little detectable emission such that the value of attempting to assess it is questionable.
2. Group (a) comprises mainly events normally considered as brittle or rapid, while group (b) comprises mainly events normally considered as slow or ductile.
3. The paucity of detectable emission with slow or ductile events may be a major set-back since many of the major potential applications involve structures designed to fail in a ductile rather than a brittle manner.
4. Improvements in the detection capability with regard to emission from slow/ductile events is the approach requiring most effort.
5. As far as possible location systems should only be used when they weight the located sources in a rational manner.

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STRESS WAVE EMISSION

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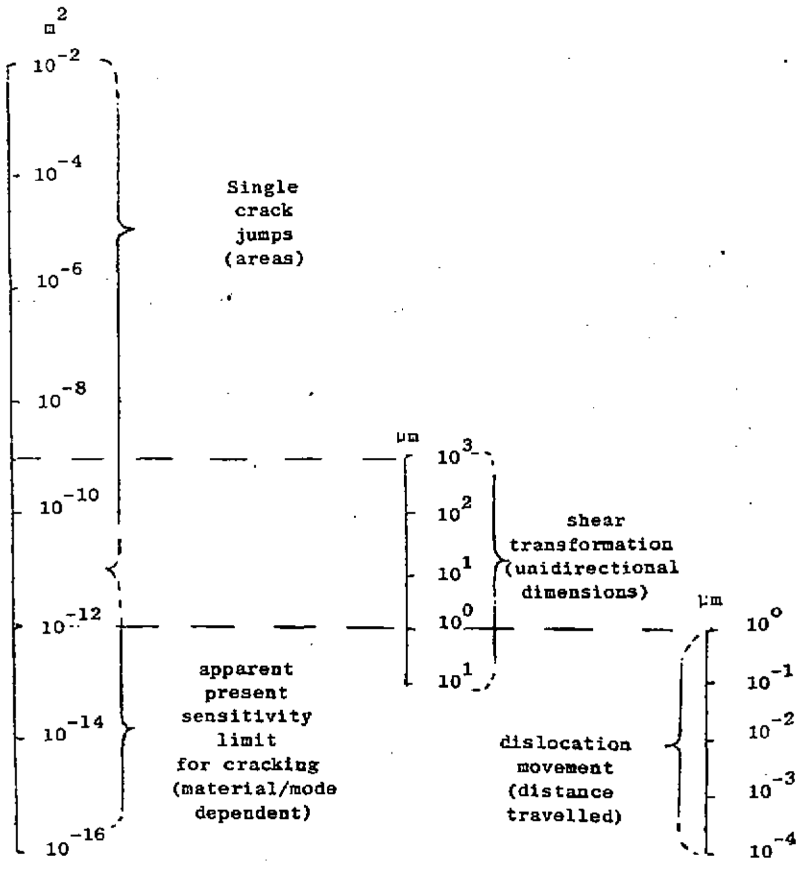
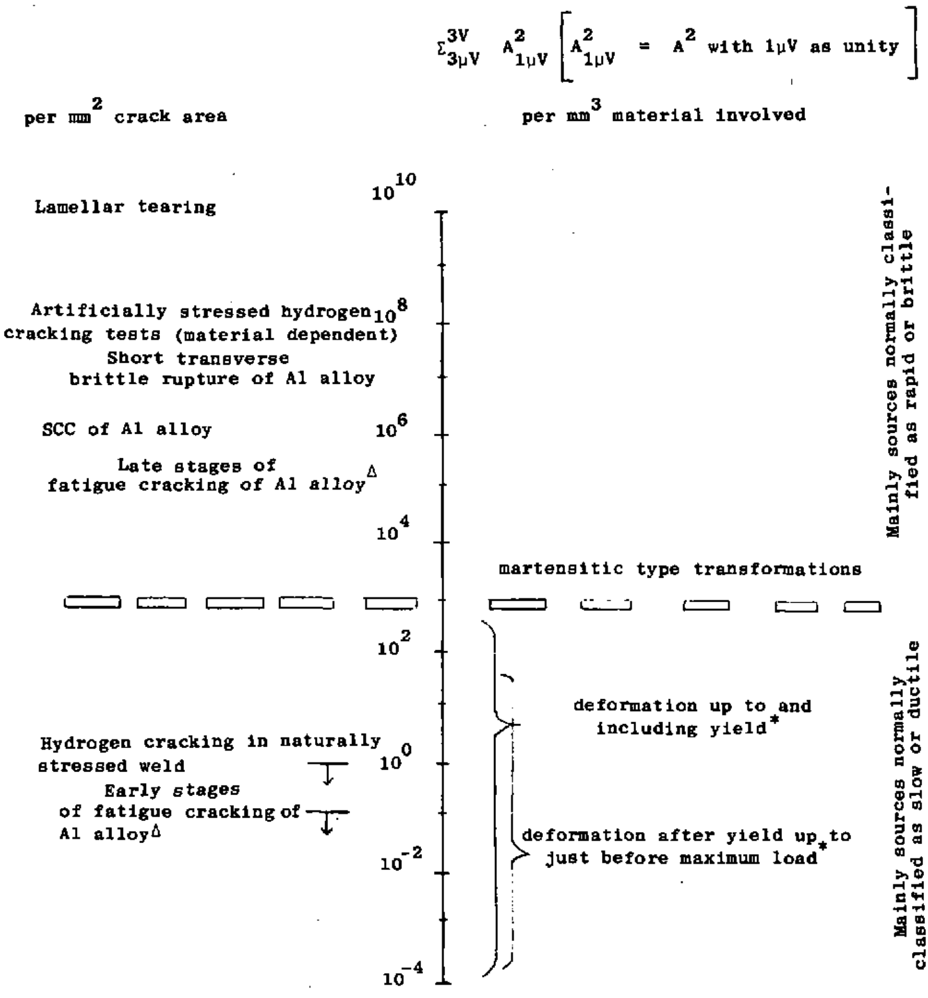


Fig 1 Examples of dimensions involved in emission sources

STRESS WAVE EMISSION



Δ same specimen

* series of tensile tests on strong diffusion bonded joints in mild steel.

Fig. 2. Examples of correlations between assessed values of the emission detected and area or volume of source. NB in view of the present state of the art and the variations shown, too much reliance should not be placed on the absolute values quoted.