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RECENT WORK ON STRESS WAVE EMISSION - A REVIEW.

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Audible Sounds may be heard sometimes in the mechanical deformation of materials as for example when bending a sheet of tin the characteristic noise known as the <u>cry of tin</u> is generated. Any deformation of a material if sufficiently abrupt, in which one region is displaced with respect to another, could result in a small fraction of the energy involved being released in the form of a stress wave. This phenomenon is known as stress-wave emission or acoustic (or sonic) emission and in most cases the vibrational amplitude is too low or the frequency too high for it to be detected by ear so that special equipment is required. The deformation leading to the emission could emanate from slip, or in the formation or growth of cracks, whereby the local equilibrium is disturbed and is restored by the outward propagation of stress waves.

Stress-wave emission gives information about the actual creation of disturbances within a body and the doctor's stethoscope is probably the first example of its practical application, It differs from the usual ultrasonic flow detection techniques, which inject acoustic energy into the specimen to detect the presence of mainly static defects.

A wide diversity of materials and systems have been investigated such as bridge integrity, seismic disturbances, missile casings, single metallic crystals and rock bursts; mention of the latter draws attention to the considerable current interest of applying emission techniques in rock mechanical studies. The analysis of the mechanical waves generated by earthquakes, a large scale emission, has been used to define the fault movement in terms of location, depth and energy release. The <u>cry of tin</u> has been attributed to crystal twinning, while during the heat treatment of steel audible clicks have been heard which are associated with a martensitic transformation. In liquid media the bubble formation on boiling and the consequent detection of the acoustic waves emitted on collapse play a significant part in the monitoring of reactors.

In homogeneous metal specimens subjected to tensile stress the emission is broadly characterised by a continuous low-level component, which is associated with plastic deformation, at comparatively small strains and initially increases in amplitude with increased loading but decreases after the yield point has been reached. The other component, the so-called burst emission, now becomes of greater consequence and is usually of greater amplitude than the continuous emission. Its discontinuous nature has been related to micro-crack formation and twinning which occur at the large plastic strains prevailing just before the specimen fails.

The peak in the count rate near the yield point (Fig. 1) confirms the amplitude fall-off. The use of some aspect of sonic emission to give advanced warning of the ultimate mechanical failure of a system has been one of the chief objectives for many investigations. Despite the often large statistical fluctuations observed in the emission count rate (N) there are certain general patterns which are discernible Schofield conducted quite a comprehensive programme of emission experiments, including work on aluminium single crystals, and concluded from these that there were many variables which influenced the count rate, such as strain rate, crystal orientation and previous stress history. He sought to find a correlation between a mechanical deformation parameter and the count rate and found that the strain rate gave a simple relationship. The frequency response characteristics of a specimen will be dependent on any imposed restricting forces as well as on its elastic properties and its geometry. Hence loading a specimen will alter its frequency signature. The mass of the detecting transducer itself is also of consequence and the main frequencies of the observed emission signal will include the natural frequencies (and harmonics) of the specimen, transducer and the coupling medium.

<u>The Loading System</u>. In laboratory type testing the loading system demands careful attention since the signals detected by the transducer will probably include extraneous noise such as that produced by the loading apparatus - noise generated at rubbing surfaces, hydraulic valves (and even cavitation noise in hydrodynamic systems), gear trains, misalignment in loading machine etc., and additionally there may be environmental noise comparable with low-level acoustic emission. In order to minimise the loading noise, buoyancy systems have been used, the load being applied by emptying a water tank in which ballast is floating. In hydraulic systems reciprocating pumps must be avoided. These 'silent' techniques are usually restricted to small loading and the applied strain rate is slow and fixed. Manual screw loading has been employed and being relatively stiff in operation do permit an easy controllable rate of strain. This may also be achieved with conventional loading machines by use of hydraulic accumulators etc. Vibration propagated through the testing machine may be minimised by suitable introduction of damping materials in the conduction paths. It is always possible to detect acoustic emission even in the presence of noise by suitable filtering techniques e.g., Hutton has detected acoustic emission in the presence of bydraulic noise and cavitation by using the frequency band 750KHz to 3MHz as most of this unwanted noise is below 1MHz. This was a notable advance in experimental procedure and obviated the need for elaborate sound-proofing arrangements arrangements. Electrical interference problems can arise from stray r.f. signals which may be overcome usually by suitable earthing of electronic system.

<u>Instrumentation</u>. The basic requirements are the means for signal detection, amplification, recording and analysis, and a typical lay-out is shown schematically in Fig. 2. Much of the work to date has been concerned with the count or pulse rate, each time a fixed amplitude threshold is exceeded a count being registered. Other electronic instrumentation may be employed to measure such parameters as frequency content, amplitude distribution and various derived parameters such as energy content, but a limitation often with this instrumentation is range and inability to handle very fast phenomena. Alternative to the counter are amplifiers with logarithmic outputs, a satisfactory range of sampling times and a suitable range of frequency response and they are capable of accommodating the wide range of emission occurrence rates - four or five orders of magnitude. In processing emission data on-line computers have been used or alternatively high-speed tape recorders have recorded data on parallel channels for off-line processing, or for using other means of processing. In general the essentials of the required information may be obtained more simply from the counter system by feeding into a digital to analogue converter having an output voltage which is proportional to count rate (or total count). This

output is then fed with a mechanical variable, stress or strain, to an X - Y recorder (see Fig. 2) which provides a display useful for quality control testing of materials by stress wave emission characteristics.

The most important 'cog' in the recording system is the transducer for converting mechanical into electrical signals. The type most favoured is the PZT 5 polarised ceramic which has a low impedance and may be employed as an accelerometer, when a flat frequency response is required, or as a mechanically resonant device giving a greater sensitivity, the choice being governed by the needs of experiment. In rock or seismic studies, where the attenuated signal mainly comprises very low audio frequencies electrodynamic transducers (geophones) are used. In amplifying the output signal from the transducer a greater flexibility and improvement in low frequency response is obtained by the use of a charge amplif-ier. Transducers are sensitive only to the small area of the specimen upon which they are placed and usually only to motion in a specific direction, although Egle and Tatro showed that their transducers were affected by flexural as well as longitudinal waves. On comparing their energies, the former were much larger which suggests that the source primarily generates distortional and not dilational waves. This observation supports Schofield's suggestion that stress wave emission is associated with slip line formation which is a shear-type deformation. Magnetic tape recording is simple, although with conventional speeds high frequency linearity is lost, but may be overcome by using a rotating recording head, as employed in video-tape recorders. The conventional recording techniques, pen or sensitised paper, mirror galvanometer and oscilloscope photography may be used according to the frequency range required. Large scale structures such as pressure vessels may be monitored by several transducers and assuming a knowledge of the wave velocity and using a triangulation technique it should be possible to locate the source by comparing the various arrival times of the stress wave emission bursts, which should have preferably sharp leading edges.

General Comments. There is a choice amongst a number of possible emission parameters dependent upon the type of information desired The waveform, frequency spectrum and amplitude for example give an indication respectively of the fine structure, the nature and the energy of the source event. On the other hand the amplitude distribution and the rate of emissions will be associated with the type and the rate of occurrence of the observed damage. In tests on overlap-type adhesive bonds of metallic specimens (SS) of the form shown in Fig. 3, with the transducer (T) mounted close to the bond (B) the recorded emissions (two are shown in Fig. 4) revealed three main excitation frequencies, the lower at 10 kHz corresponding to the lowest transverse mode of the specimen. A frequency analysis thus appears to provide a means of differentiating between different types of vibration and consequently different sources of deformation. It seems that several different types of source event could be involved in the bond testing, such as the cracking of the adhesive and also its peeling from the metal strip. A general consideration of the possible form of the source stress waveform leads to the conclusion (*) that it is fundamentally a pulse-like function of stress and the broad features of such a model are consistent with practical experience. Fig. 5 illustrates the Kaiser effect, named after the first serious worker in the field. It is to be noted after unloading the specimen from a maximum stress S, and then reapplying the load, that no emission occurs until S, has been exceeded. Recent observations by Hill and Kim suggest that the effect does not always hold in fibre composites. The effect has received application in a device to give prior warning of over-pressurisation (i.e. exceeding a pre-determined stress S_2) of a system, such as a boiler in operation. Furthermore, if operating below S_2 any crack extension or fresh formation should be readily recognised.

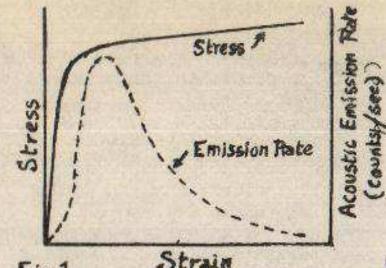

Fig 1.

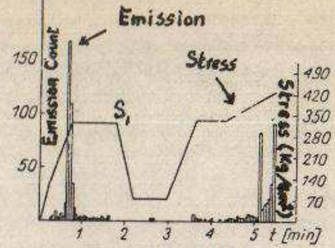

Fig Emission activity during a typical test of adhesive bond.

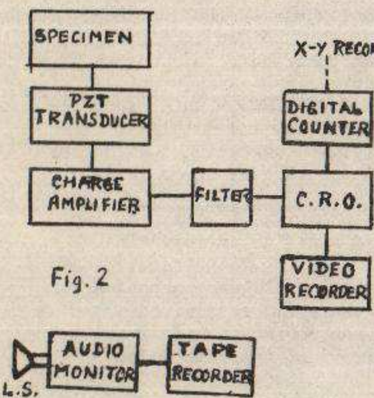

Fig. 2

Fig

OSCILLOSCOPE RECORD OF EMISSIONS FROM ADHESIVE BOND (POLLOCK)

Fig

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