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ACOUSTIC EMISSION FROM STRUCTURAL STEELS

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ABSTRACT

Tensile studies have been conducted in longitudinal, transverse and short trans-verse directions, upon steels of varying carbide content and morphology, yield points and cleanliness. The results indicate that emissions will only be detec-table at the yield point if the opportunities for dislocation multiplication and motion and the associated activation stress are large enough, that the cracking of carbide in these steels cannot generally be detected, and that inclusion cracking or debonding will only be detectable if the inclusions are relatively large and frequent and suitably disposed relative to the directions of strain and fracture. It was found that yielding in ferrite/pearlite mild steel could generate more energetic emissions than cleavage cracking in a medium carbon Widmanstatten structure, that Luders band formation could be intrinsically quiet, and that the spectral content of emissions from plastic deformation contained more low frequency components than that attributed to the formation of micro-cracks or the fracture of non-metallic inclusions. This has important consequences for the detection of acoustic emission from propagating fractures, since if the major contribution to detectable emission activity arises directly from localised yield phenomena, the observed activity will undergo a reduction as the fracture mode changes from plane stress to plane strain (as a direct con-sequence of the reduction in plastic zone size). In addition, if the steel contains sufficient non-metallic inclusions so oriented with respect to the local deformation phenomena that they are fractured, their contribution to observed emission activity will be large and may exceed that of matrix yield, and it may only be possible to detect defect extension in a particular matrix morphology through this secondary mechanism.

INTRODUCTION

Many workers have reported qualitative and/or quantitative relationships between acoustic activity and particular events, such as an increment of growth of crack area[1] or plastic zone size[2] or volume. However, our studies indicate that there may not be a general relationship between AE and any parameter such as increment of crack growth, etc, unless the partition process[3] involved is identical; hence the intrinsic difficulty of translating results from specimens to structures. In particular, environmental influences can dominate the partition process (e.g. stress- corrosion cracking, which may give rise to emissions under hydrogen assisted cracking, but not for active path dissolution[4]). Similarly, the relaxation time will govern the spectral content of the emission, since transformation to the frequency domain to reconstruct the spectral content of energy distribution (i.e. the Fourier transform) will require the addition of higher frequency components.

We speculate that microcrack processes may generate higher Fourier components than slip processes, and hence we investigated a range of steels of varying yield point, cleanliness, microstructure and orientation.

EXPERIMENTAL TECHNIQUE

Tensile tests were conducted upon parallel unnotched tensile specimens of ten steels, five using cylindrical specimens with threaded ends, and five using preloaded ring clamped end fixings which earlier work had shown to be apparently quiet during loading. AML acoustic emission instrumentation having high immunity to electrical interference was used at centre frequencies of 150 and 400 kHz* (± 20 kHz for 3 dB points) the former recorded as pseudo RMSØ and the latter as zero offset (or "ring") count rate, together with peak amplitude analysis. Each channel was set to count on background noise but the actual numbers obtained are less important than the indication of the presence or absence of acoustic activity, for reasons discussed elsewhere(5).

The first five steels were chosen in discussion with Gladman(6) as representative of materials in which carbide cracking induced during post yield strain would occur at differing strains, in order to determine whether AE activity could be correlated with the anticipated stress-dependent carbide cracking; the remaining five steels (described in the table) were chosen by Bentley(7) for his M.Sc study of the effect of yield point, microstructure, cleanliness and orientation on the acoustic response of steel.

RESULTS AND DISCUSSION

None of the tests upon the first five steels resulted in the detection of significant emission activity during strain-hardening to failure, suggesting that carbide cracking during tensile loading of such steels may not be detectable with present techniques.

Typical results from longitudinal tensile tests are illustrated for each of the latter five steels, showing little detectable activity in either channel for two of the steels, and that as the yield stress increased, the acoustic activity passed through a peak, noticeable in both channels but particularly in the lower frequency pseudo RMS channel, for steel C.

Further, in steel D, the AE activity was more prevalent in the higher frequency channel for the first part of the test, and vice versa, indicating a possible predominance of relatively short duration events during the pre-UTS region and more relatively slow events associated with the final stages of deformation leading to fracture.

Four of these steels were also tested in the transverse direction with the results shown. Comparison indicates that there is no direct correlation between distributed events during the tensile life of longitudinal and transverse specimens other than that associated with yield. In the low frequency channel, the general emission response of steels A, C and E was broadly similar to that observed for the longitudinal direction, but the response of steel D no longer displayed an increase in activity towards the end of the test. In the higher frequency channel there was rather more activity, generally distributed over the first half of the tensile test, and particularly noticeable around yield in steel E, a result we attribute to the fracture of non-metallic inclusions.

* Only 400 kHz was used for the tests on the first five steels.

Ø Detected output from HP spectrum analyser into a chart recorder of 500 mS time constant.

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Only two of the steels could be tested in the short transverse (or Z) direction, with the results shown, which indicate similar behaviour to that of the longitudinal specimens for steel C, but for steel D there was again no evidence of AE activity towards the end of the test in the lower frequency channel, and a marked increase in activity in the higher frequency channel from just before yield to the UTS of the material, a result we attribute to a significant increase in the rate of formation of small micro-cracks, a view consistent with the final cleavage failure, but for which we have so far failed to produce metallographic evidence.

CONCLUSIONS

These results lead us to conclude that:-
(1) Tensile tests of unnotched specimens of differing orientation, microstructure and cleanliness yield differing AE response, generally explicable in terms of well established metallurgical knowledge.
(2) The cracking of individual plates of carbide may not be detectable.
(3) The partition process indicates variables involved in the acoustic response of a material.
(4) The acoustic activity associated with yield increases until the restrictions imposed upon the opportunity for dislocation multiplication and slip supervene, when it decreases.
(5) The acoustic activity is very dependent upon orientation in hot worked material containing significant quantities of non-metallic inclusions, but not for relatively clean materials (or, presumably, cast or scarcely worked materials).
(6) There is some evidence to suggest that yield processes produce more energy at low frequencies whereas fracture/debonding of non-metallic inclusions or the production of matrix micro-cracks produces more activity at higher frequencies, supporting the simple stress relaxation model proposed.
(7) For structural applications, it is necessary to establish the acoustic response of a material to the nature and orientation of crack growth, noting that the acoustic response may change as the fracture regime passes from plane stress to plane strain.

ACKNOWLEDGEMENTS

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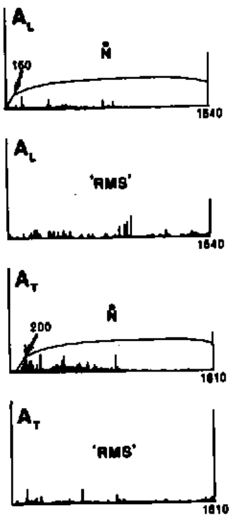
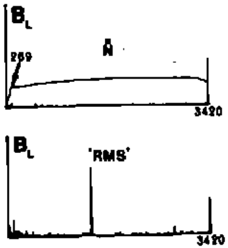
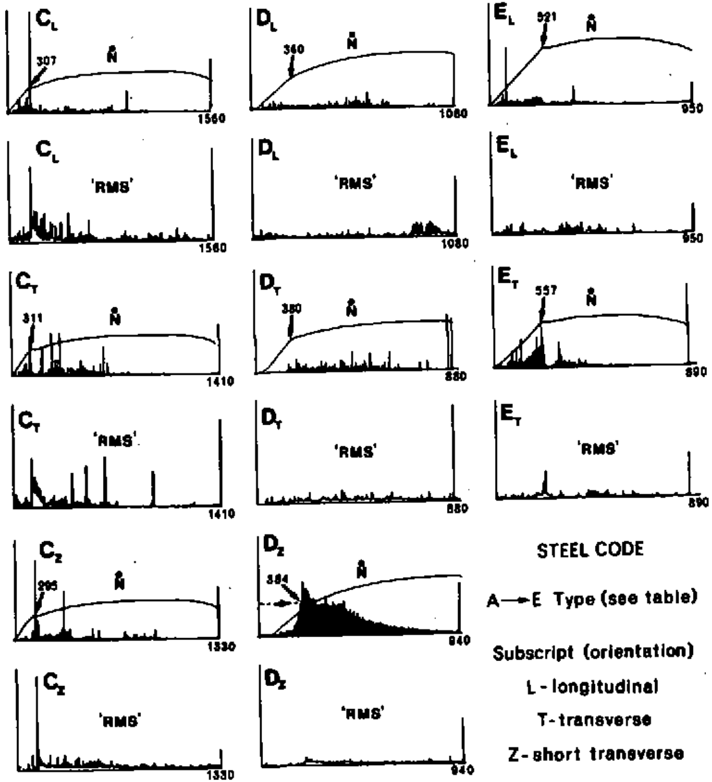




KEY

Vertical:–
Sensitivity full scale
$\dot{N}$ 10^4 counts/sec (400 kH_z)
RMS 1volt linear (150 kH_z)
Load 5000kg (values are 'yield' MN m^{-2})
Horizontal:–
Values are full scale time to failure. Crosshead deflection 0·05cm/min



STEEL	TYPE	MICROSTRUCTURE	FRACTURE
A	0·18% C, 1·2% Mn. (mild steel)	ferrite/pearlite	ductile
★ B	0·1% C, 0·3% Mn. (low carbon)	ferrite plus some boundary carbide	ductile
★ C	0·16% C, 1·5% Mn. (off–shore structural steel)	ferrite/pearlite	ductile
D	0·4% C, 0·9% Mn. (medium carbon)	Widmanstatten	cleavage
E	0·15% C, 1% Mn. 1% Ni, 1% Cr. (weldable low alloy)	bainitic	ductile

★ 'clean steels'

STEEL CODE

A → E Type (see table)

Subscript (orientation)

L - longitudinal

T - transverse

Z - short transverse

TENSILE/ACOUSTIC RESPONSE FOR DIFFERING ORIENTATIONS OF FIVE STEELS