ACOUSTIC EMISSION MONITORING OF BUCKLING BEHAVIOUR IN IMPACT-DAMAGED COMPOSITE PLATES.

K.M. Holford, C.A. Featherston, R. Pullinand M. J. Eaton

School of Engineering, Cardiff University, UK

Key Words: Acoustic Emission, Buckling, Composite Plates

Abstract

In composite structures subjected to compressive loads, impact damage is a major problem as it promotes delamination, which severely reduces the buckling strength. The problem is further complicated by the fact that internal defects cannot be detected by a visual inspection. In order to assess the effect on a component of any damage it is desirable to determine the behaviour of a defect during the loading of the component.

In this work, epoxy glass fibre specimens were damaged at various levels using a drop impact technique. All specimens were tested to failure under a buckling load and monitored by Acoustic Emission (AE). Test data show that the compression strength of composite structures is significantly reduced by low-speed damage even at levels where damage can not be detected by visual inspection

Defects in the panels due to impact damage were successfully located by Acoustic Emission using a linear time-of arrival technique to an accuracy of 30 mm. It was possible to identify damage using AE even where the damage was not discernibly visible. A relationship was established between AE parameters, such as peak amplitude, counts and rise time, and levels of damage in the specimens.

Introduction

Composite materials offer many advantages over more conventional materials such as steel and aluminium. They do however have some serious limitations, most significantly their response to localized impact loading. A feature of impact loading is the promotion of delamination (Cantwell and Morton 1991), which severely reduces the residual strength of a component. Most notably when subject to in-plane compression the residual strength may be reduced by up to 30% (Abrate 1994).

Due to the nature of this damage it is possible to have sizable areas of delamination that are not visible from the surface. Given the severe reduction in strength this is not a desirable situation. Current non-destructive damage assessment techniques include X-ray and C-scanning, however these techniques cannot be used to assess a defect under loading.

Lindahl and Knuuttila (1999) used AE to monitor Carbon Fibre Reinforced Plastic (CFRP) wings and vertical stabilisers of the JAS 39 Gripen aircraft during proof testing. The AE was able to detect and locate damage of the wings and stabilisers at an early stage and prevented unexpected failure. Areas of damage were confirmed using conventional NDT techniques. This paper reports on the use of AE to detect and locate induced damage in composite plates. It is hoped this technique will eventually be used not only as an inspection method for composite materials but also to predict buckling modes of failure.

Experimental Procedure

Five composite specimens were manufactured from SP Systems pre-impregnated SE84LV RE292 E-glass epoxy. The glass fibres are plain woven (0º/90º) and layed up to give an orthotropic 8 ply specimen.

Figure 1 shows the instrumentation and loading arrangement of the composite plates in the buckling test rig. All sides of the specimen are simply supported; the two vertical (unloaded) edges are supported in knife edges with the two horizontal (loaded) edges supported in roller supports. Due to the design of the buckling test rig, specimen dimensions are 430x400mm although the actual buckling area is 400x400mm. All specimens were loaded at a 2mm.min^{-1} loading rate until failure.

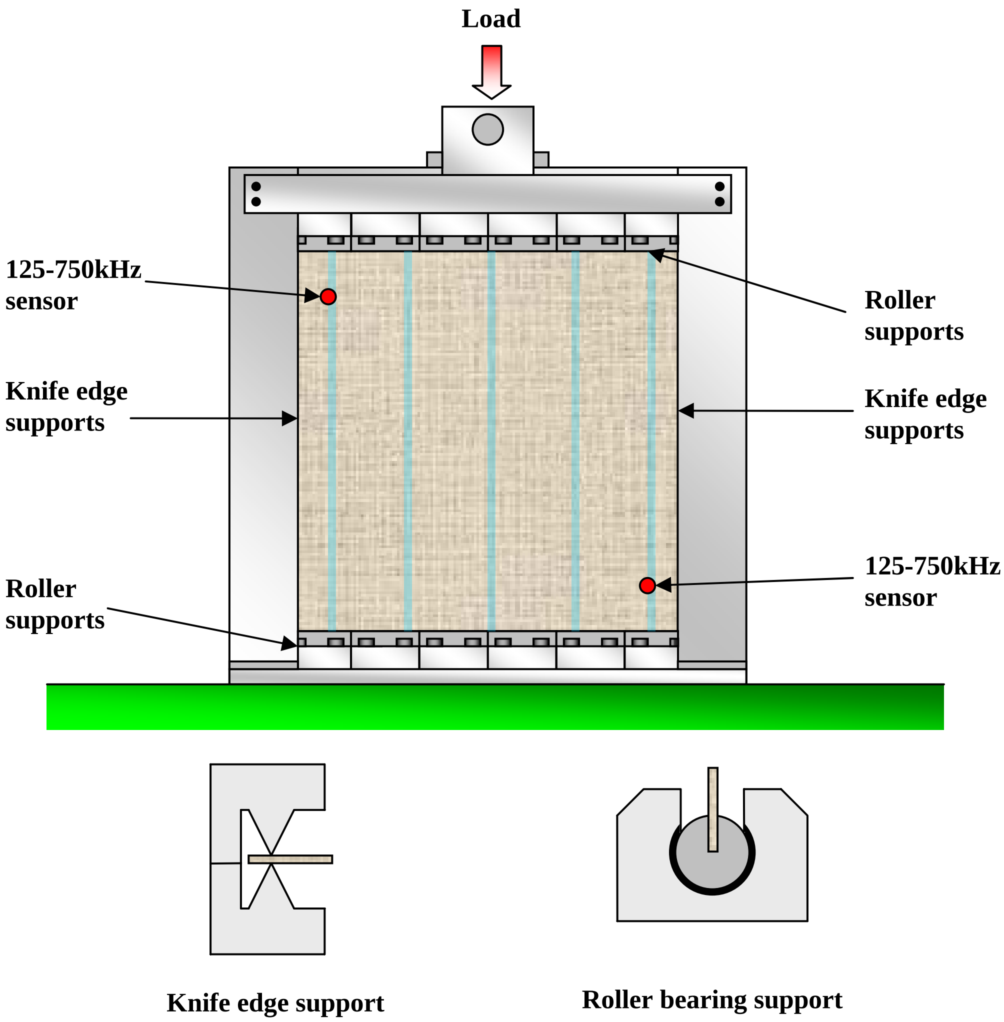

Figure 1: Test specimen and instrumentation

Damage was introduced into four of the composite plates using a drop impact test. A weight of known mass is dropped from a known height onto the specimen. The four specimens were damaged to levels of 2.5J, 5J, 7.5J and 10J, respectively, at the centre. One plate remained undamaged. The 2.5J level of induced damage was not visibly detectable.

Two sensors were attached to the composite plate using a hot melt glue gun. The glue acts as an acoustic couplant. The sensors (operating frequency range of 125-750 kHz) were positioned in opposing corners, 400mm apart, to locate damage at the centre of the plate.

Sensor response, attenuation and signal location were evaluated using the pencil lead fractures (PLFs) technique (Hsu and Breckenbridge 1979 and ASTM 1994). Signals resulting from the PLF adjacent to each sensor were recorded to evaluate response. To assess attenuation a PLF adjacent to sensor 1 was recorded by sensor 2 and sensor 1 using a synchronised trigger. Location accuracy was completed using PLFs at the centre of the plate. The specimens were monitored for the entire loading at a threshold of 65dB for feature data and waveforms.

Results and Discussion

The response of all sensors to PLFs adjacent to the sensor was above 97dB. This demonstrates that all sensors were attached correctly. The loss of signal was 25dB over 400mm, allowing a threshold of 65dB to be used. The velocity of sound in the specimens was measured at 3800ms^{-1}. Figure 2 shows the results of the PLF test to establish the accuracy of the time of arrival location method. The results indicate that the location of damage will be accurate to within 30mm.

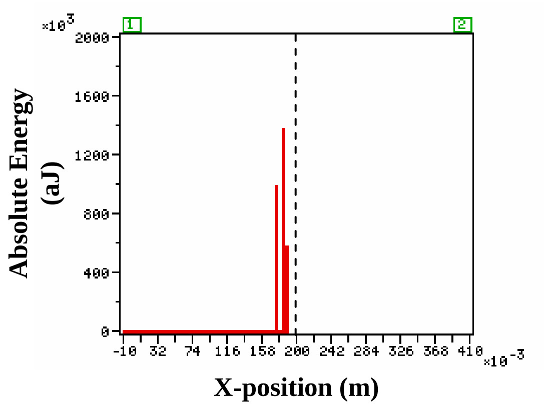

Figure 2: Location of pencil lead fractures from centre of specimen

All specimens experienced their final failure at the top corners of the plates. The loading used was greater than the capacity of the bearings, which restricted the rotation of the plates, leading to eventual failure at the upper corners.

Figure 3 shows the activity of the plates in terms of the amount of energy detected on all sensors. The plots show that there is a large increase in absolute energy at the end of the test coinciding with the failure of the plate, demonstrating that AE is detecting the damage of the plate.

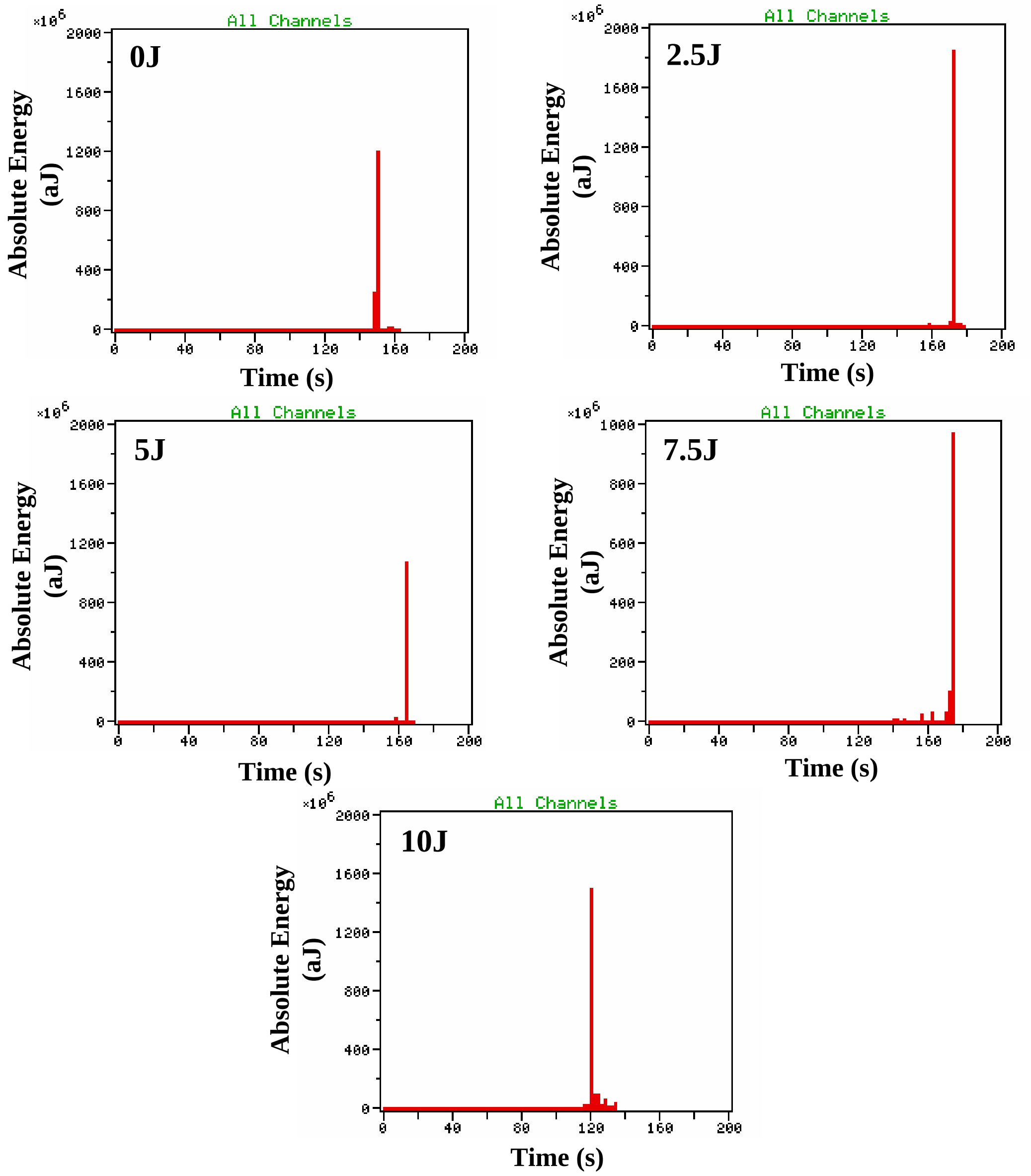

Figure 3: Activity of composite plates during loading

Figure 4 shows the location of signals detected during the loading for the five specimens. The location of the failure at the corner is detected at the extremes of the array. The location of inflicted damage due to prior impact is also observed. Energy detected and located 30mm either side of the centre (error in location is 30mm) is presented in Table 1. It can be seen that as the level of damage increases the level of detected energy increases at the central location point. It is noted that there are a number of peaks associated with the location at the centre of the 10J and the 7.5J model and these peaks are combined. Energy is detected from the central location from the undamaged plate and it is believed this is either cracking in the matrix or delamination of the layers due to induced buckling. This cannot be currently verified without C-scanning the plate. The results suggest it may be possible to calculate the amount of induced damage in a composite plate by the detected AE.

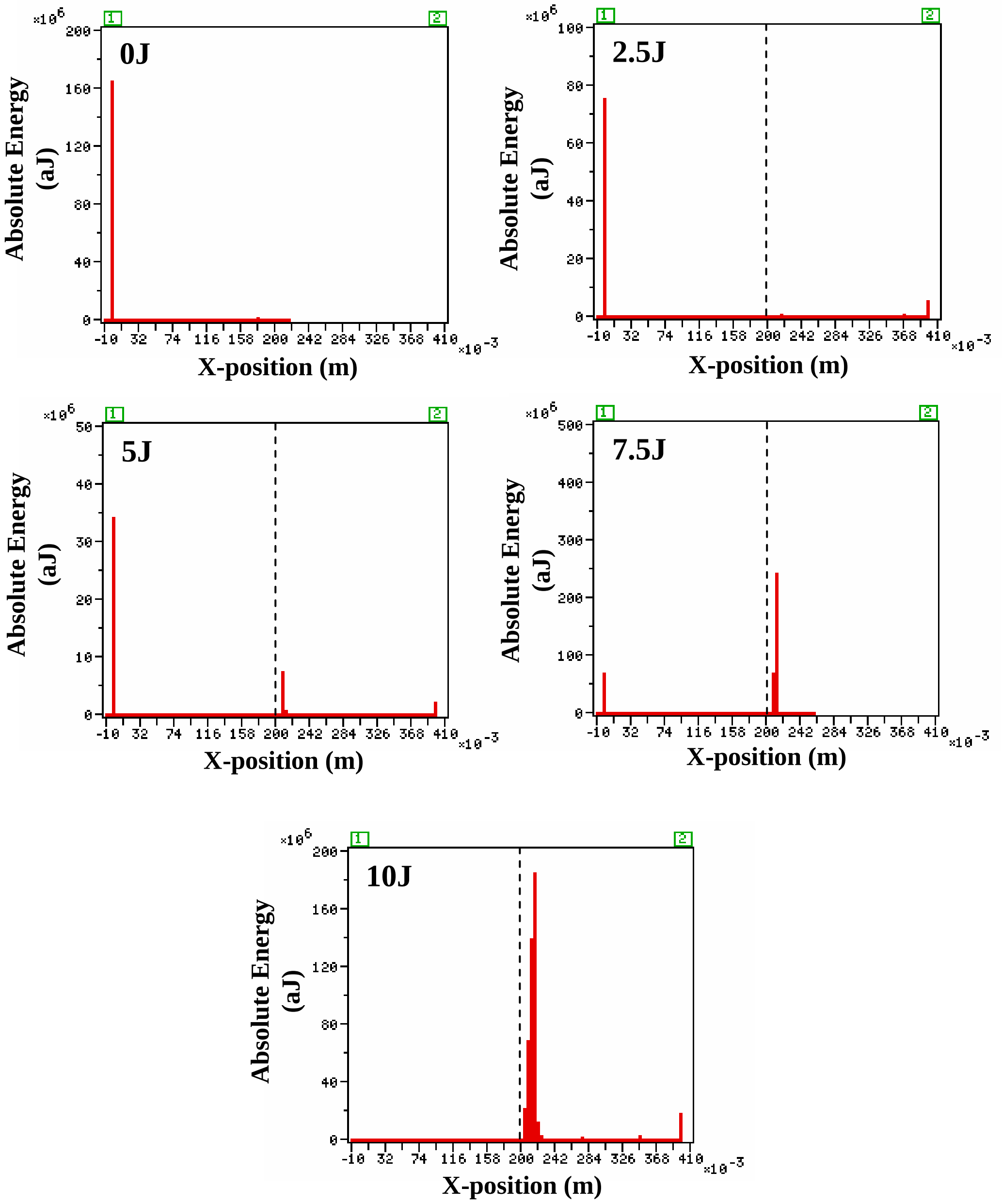

Figure 4: Location of signals from composite plates during loading

Table 1: Energy detected 30mm either side of damaged area.

Damage Level (J)	Detected AE at Centre of Panel (aJ)
0	0.2×10^6
2.5	1.2×10^6
5	93×10^6
7.5	310×10^6
10	410×10^6

Figure 5 presents the characteristics of the data recorded in the central location for the damaged specimens in terms of counts and rise time against amplitude. The plots show that the peak amplitude increases as the level of induced damage increases (2.5J-87dB, 5J-96dB, 7.5J-98dB and 10J-99dB) and that there is an increase in the number of detected hits. This suggests that there is a possible relationship between the level of induced damage and recorded AE. Further data is needed to ensure that this is not experimental scatter. Comparing the rise time and counts between the levels of induced damage shows little difference in pattern apart from an increase in number of detections. This suggests that the detected emissions are from the same type of source, either cracking in the matrix or delamination, and that with increased induced damage there is an increase in detected damage by the AE.

Future work needs to be completed on a broader range of plates with a greater number of plate samples and differing levels of induced damage. The results contained in this paper are based on only five plates and do not allow for experimental scatter. It is also envisaged that as a plate starts to buckle the deflections will cause cracking of the matrix or delamination which will cause AE events which can then be located. This would allow AE to identify the buckling nature of a composite plate. In addition the buckling effect of the plates will be modelled using a finite model. This will be compared with AE results and also confirm that the current loading conditions are correct.

Acknowledgements

The authors wish to express their gratitude to the technician staff of the Engineering Department.

Conclusions

Five epoxy glass fibre specimens were manufactured and damaged using an impact test. The specimens were loading to induce buckling until failure. Using AE the induced damage was detected to within 30mm. Levels of energy detected increased with the level of induced damage. Results suggested that there was a relationship between peak amplitude and levels of induced damage.

References

Cartwell, W. J. and Morton, J., 1991. “The Impact Resistance of Composite Materials – a Review”, Composites, Vol. 22 (1991) pp 347-362

Abrate, S., 1994. “Impact on Laminate Composites: Recent Advances”, Applied Mechanics Review, Vol. 47 (1994) pp 517-544

Hsu, N. N. and Breckenbridge, F.R. (1979). “Characterisation and Calibration of Acoustic Emission Sensors”, Material Evaluation, Vol. 39 pp 60-68

ASTM (1994). “Standard Guide for Determining the Reproducibility of Acoustic Emission Sensor Response”, American Society of Tseting and Materials, E976.

Lindahl, D. and Knuuttila, M., (1999). “Acoustic Emission Monitoring of the JAS39 Gripen Combat Aircraft”, Conference of USAF Aircraft Structural Integrity Program, 30 Nov – 2 Dec 1999.

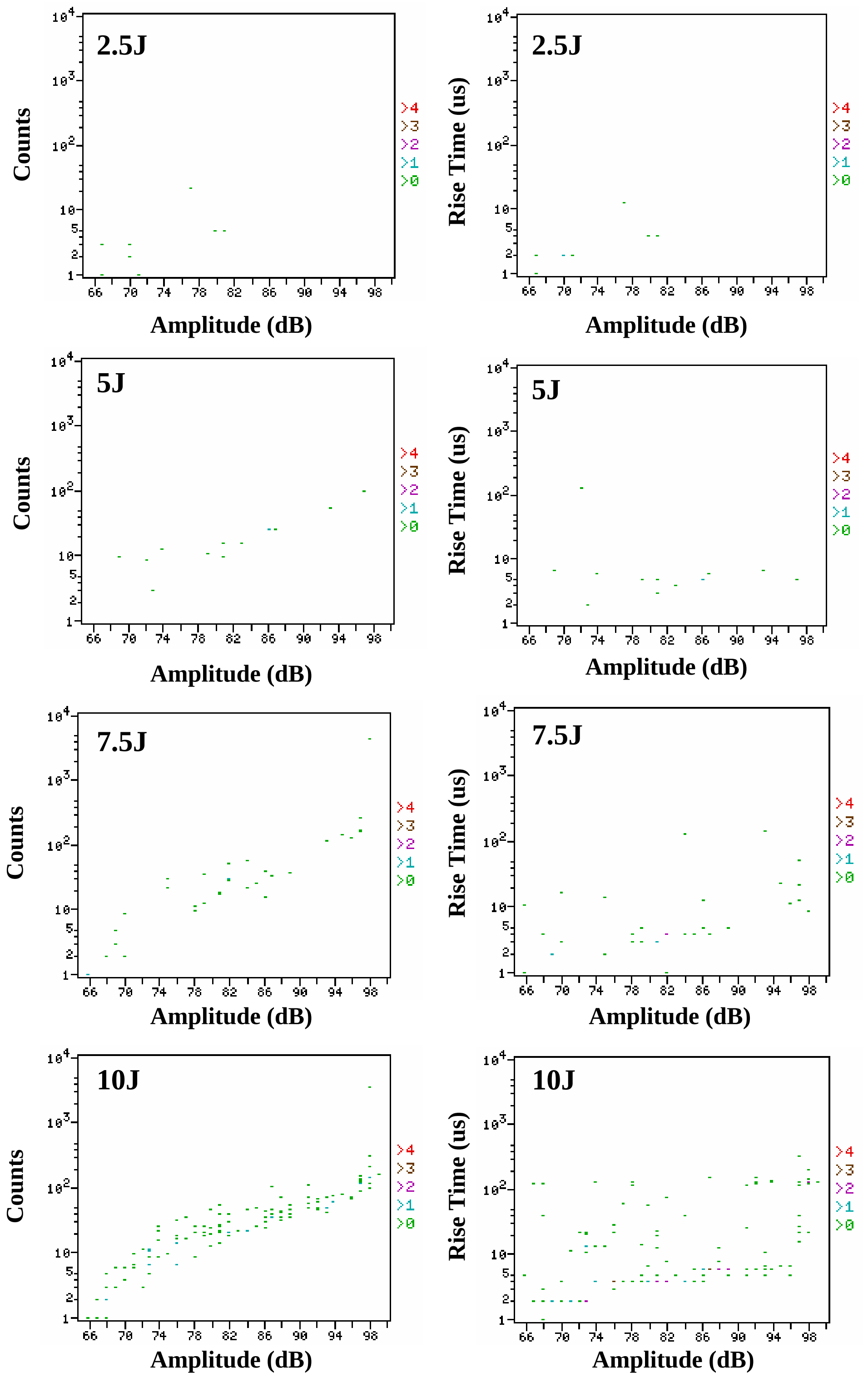

Figure 5: Characterisation of signals from damaged specimens