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Determination of Damage Levels of Composite Plates After Low Velocity Impacts Using Acoustic Emission

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Abstract. Eight composite plates 400x410x2.15mm were fabricated from carbon/epoxy in $((0,90)_4)_s$ lay-up. To ensure there was no damage in the plates prior to the impact investigations the plates were C-scanned. A drop test rig was used to apply a low velocity impact to the undamaged plates. A rebound mechanism was employed to prevent secondary impacts.

AE sensors were selected for frequency and size due to the limited space on the test rig. Super glue was used both as a couplant and also to secure the sensors in position. During the impact wave streaming, time driven data and hit driven data were used to record the impact simultaneously. One test was conducted on each sample with two impacts completed at 5J, 6J, 8J and 10J (total of 8 samples). The impacts were designed to allow only slight visible impact damage to be formed. After completion of the impact investigation the plates were C-scanned to determine the area of debonded material. Analysis of the data showed the complete record of the impact event from the wave streaming, while the hit driven and time driven absolute energy data provided increasing correlations with the area of composite damaged.

Introduction

The response of carbon fibre composites to low velocity impact loadings, such as a dropped tool, is an area of great concern. The large areas of inter-ply debonding produced by an impact event are often hard to identify by visual inspection and can substantially reduce a component's mechanical properties (Abrate, 1994). This can lead to unexpected premature failure of a component that is operating within its design limits.

Acoustic Emission (AE) has been used successfully to assess post-impact damage in continuous fibre composites subject to three-point bending (Santulli, 2001) and buckling (Holford et al, 2004). Liu et al (1999) showed poor correlation between damage area and AE energy and counts (recorded as discrete waveform feature data) from impact events on carbon fibre panels.

This work forms part of a larger investigation on the monitoring of impact damage in composite panels under buckling loads. Experiments subjecting eight carbon fibre / epoxy panels to low velocity impacts of varying energies, from a drop weight impactor, are reported. AE equipment was used to monitor the specimens during the impact events and C-scan images were taken to assess the area of debond induced. Absolute energy, recorded as discrete waveform feature data and as time driven data, were correlated with the debond area.

Experimental Procedure

The composite specimens were manufactured from Advanced Composite Groups HTM45/HTS5631(12k)135-134% pre-impregnated unidirectional carbon fiber/epoxy tape. A 16 ply $((0,90)_4)_s$ lay up was used, which provided a nominal thickness of 2.15mm and the overall dimensions were 400x410mm. To ensure flatness the specimens were placed between two aluminium plates before vacuum bagging and then heating according to the recommended cure cycle.

An instrumented drop weight impact test rig was used to impact the specimens with varying degrees of impact energy. The impactor consisted of a polished hemispherical tup (or striker) with a 12.7mm diameter. The tup was attached to an inertial-mass that accelerates, down a guided channel, due to gravity. Released by an electro-magnet the impactor can be dropped from any height up to 5m and has a combined mass of 1.46kg. The velocity of the impactor just prior to impact and just after rebound was recorded by a pair of light gates at the base of the guiding channel, allowing the kinetic energy to be calculated before and after impact, giving a measure of the energy absorbed by the specimen as damage. The specimens were supported in accordance with the British Standard for Impact Behavior of Rigid Plastics (British Standards, 2000). Two large clamped plates restrained the entire specimen apart from a circular unsupported area, of 120mm diameter, at its centre.

A Physical Acoustics Limited (PAL) Pizo (125-750kHz) sensor was mounted on the sample adjacent to the area of the impact. The sensor was connected to a PAL 0/2/4 pre amplifier with 0dB gain and an internal filter of 10kHz to 1200kHz. This gain setting was used to prevent saturation of the system due to the large impact signals. Data was acquired by a 2 channel PAL PCI-2 AE system. The system was configured for four levels of simultaneous data acquisition. Continuous waveform signals were obtained at a data rate of 2MHz. A threshold was set at 80dB and any signal over this level triggered the acquisition of a discrete waveform and the extraction of Hit Driven Data (HDD) waveform features (Peak Definition Time (PDT) 20μs, Hit Definition Time (HDT) 50μs and Hit Lock out Time (HLT) 200μs, (Bradshaw, 2003). Time Driven Data (TDD) was also recorded at a rate of 100Hz, meaning that during a 10ms period all energy recorded during that period will be summed.

Following the impact tests the samples were scanned in a PAL Ultrapac C-scan immersion system. A 5 MHz transducer was used in pulse receive mode to evaluate the samples by measuring the level of energy reflected from a glass plate below the sample. An evaluation level of -8dB was set to define the area of debonding.

Results and Discussion

The graphical results of the C-scan investigations can be seen in Fig. 1 (areas of debonding are lighter in colour). Details of the debonded area and a summary of all results can be seen in Table 1. Two sets of TDD data are missing from the data set (Samples 2 and 6) which where lost due to operator error.

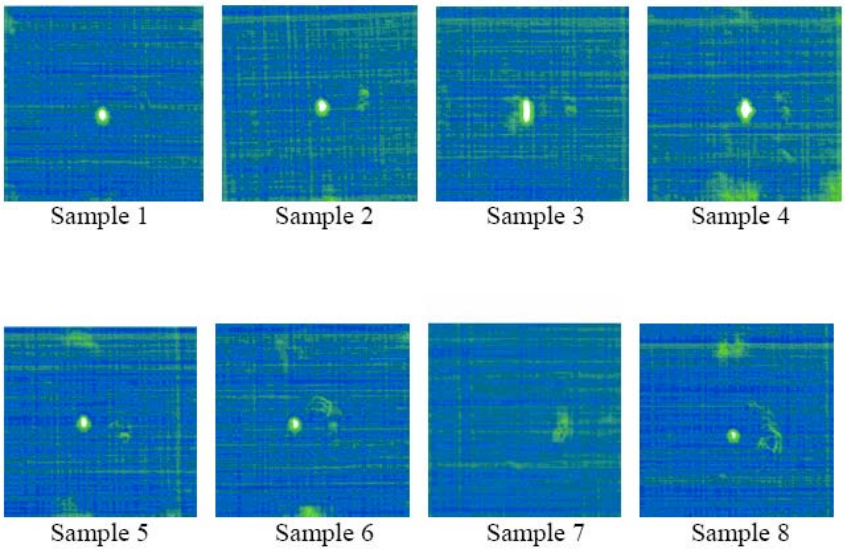

Fig. 1. C-scan images of plates after impact

Table 1. Summary of test results

Sample No.	Impact [J]	Debonded Area (C-scan) [mm^2]	Calculated Energy Absorbed [J]	Time-Driven Data [atto-J]	Hit-Driven Data [J]
1	8	165	3.8	1.82E+10	1.25E+10
2	8	180	3.4		2.56E+10
3	10	342	4.6	3.92E+10	3.92E+10
4	10	283	7.6	2.88E+10	2.87E+10
5	6	133	2.5	1.50E+10	1.50E+10
6	6	128	2.6		3.76E+08
7	5	0	1.5	7.39E+8	7.27E+08
8	5	110	2.5	9.66E+9	9.66E+09

Fig. 2 shows an example of the wavestream results recorded using the PAL PCI-2 acquisition board from the impact on plate 4. The figure clearly shows that there was no noise contamination or extraneous noises recorded during the investigation. The signal has been separated into three suggested regions as follows; region A is the contact of the impactor with the plate, region B occurs when the load is sufficient to initiate damage to the plate and region C is when the impactor leaves the plate. Based on velocity and distance between impact and the closest edge region B is not a reflection. The wavestreaming data shows how the initial processes A and B take 2500μs whist the entire process of impact and damage takes 5500μs. When compared with the TDD sampling speed it is evident that the entire impact could be split between two samples, however it would be unfortunate if the damage region were also split. The results of the wave streaming data contains information on frequency content and precise timings of the stages in the impact, however these are beyond the scope of this paper and will be the subject of a future publication.

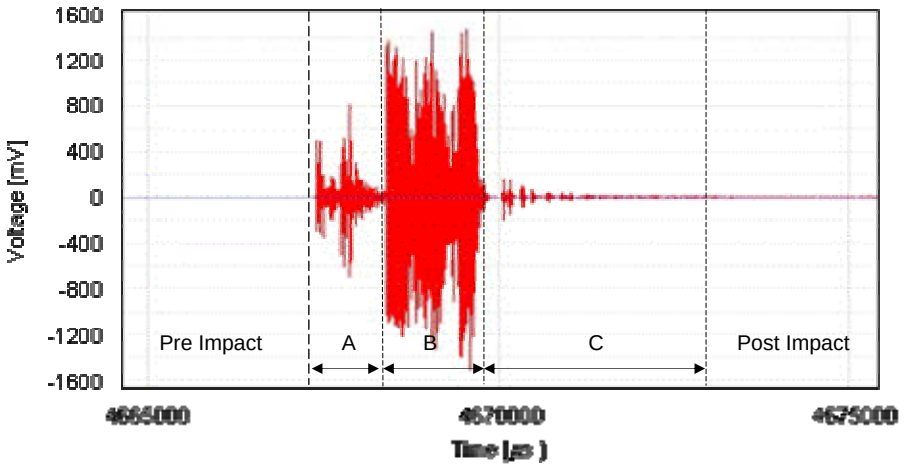

Fig. 2. Enlargement of wave stream data from sample 4

Fig. 3 shows a plot comparing the levels of debonded area (from the C-scan results) with impact energy level (from impactor mass and drop height) and the calculated (from impact speed and rebound speed) energy absorbed.

Examining the comparison of the impact energy with the debonded area shows that for a given level of impact a range of damage can occur, most notably a level of 5J impact caused no debondment in plate 7 and a debonded area of 110mm^2 in plate 8 and furthermore at an impact load of 10J the difference is 60mm^2. This is probably due to the quality of fabrication in the plates and

further shows how the monitoring of impact susceptible composite components is important, as large variations in damage can occur regardless of load.

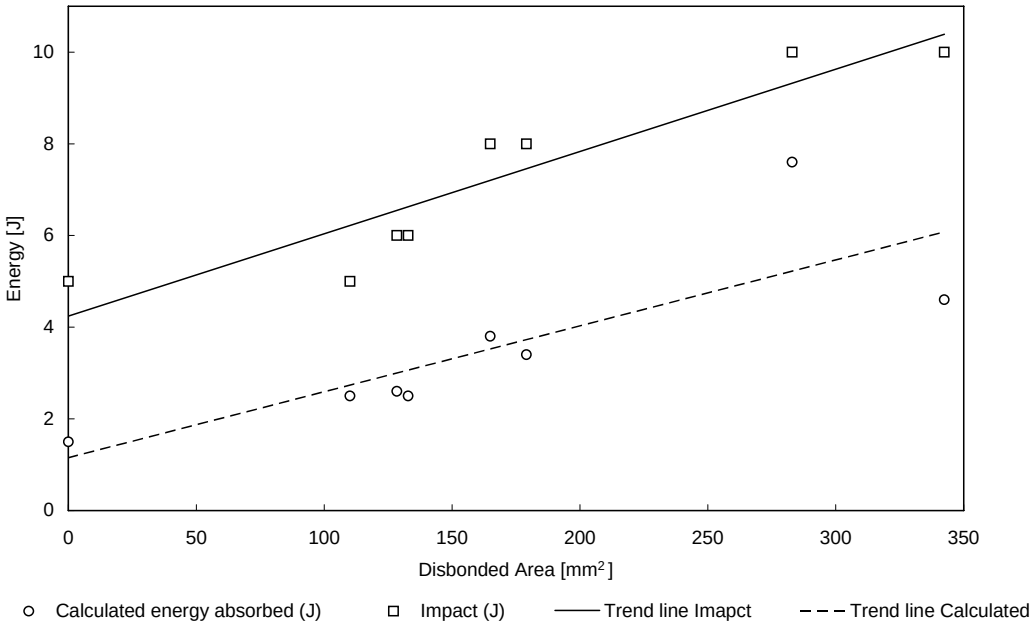

Fig. 3. Comparison of debonded area with calculated and impact energy

The calculated impact energy in Fig. 3 shows a good correlation with the debonded area as shown by the added trend line. However there is a large error in plate 4 (impact of 10J). The method used to calculate energy absorbed, based on the differences in kinetic energy is crude, assuming a purely vertical motion when the impactor rebounds and no losses in energy due to friction, heat and sound, which are plate dependent. In addition the light gates used for timing will be prone to larger errors at higher velocities. However this method of measuring damage due to impact is impossible in real situations where the velocity of an object prior and post impact could not be measured.

Fig. 4a and b show two plots of absolute energy against time for the HDD and TDD respectively for specimen 4. Absolute energy was selected as the chosen parameter as it can be traced to the S.I. units of Joules at the sensor face. The obvious differences in the shown plots is that the HDD only displays information from events above the 80dB threshold while the TDD, which is independent of threshold, displays the energy value every over a 10msec period. To allow an immediate and simple evaluation of the data the highest energy value (for TDD and HDD) is chosen and is assumed to be the energy for the impact event.

Fig. 5 shows the discrete waveform for the impacts on sample 4 for the HDD (shown in Fig. 4a). The discrete waveform matches the waveform shown in Fig. 2 demonstrating that by using a discrete waveform tool triggered by a threshold the appropriate data can be acquired. The major difference in the waveforms is the loss in the discrete waveform of the region defined as region C in the wavestream waveform (Fig. 2). Feature data for the hit presented in Fig. 5 showed the signal had a duration of 2450μsec, the signal then stayed below the threshold for the defined period of time (HDT 50μsec) and the hit ended and the discrete waveform stopped recoding. The hit duration matches the estimation of 2500μsec taken for regions A and B in Fig. 2.

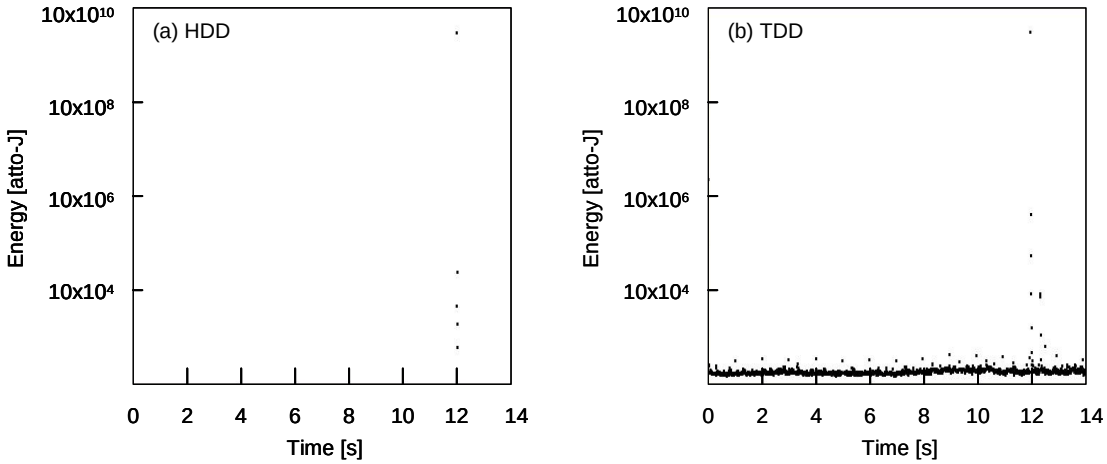

Fig 4. Recorded AE data from impact (8J) on sample 4, *(a) Hit driven data, (b) Time driven data*

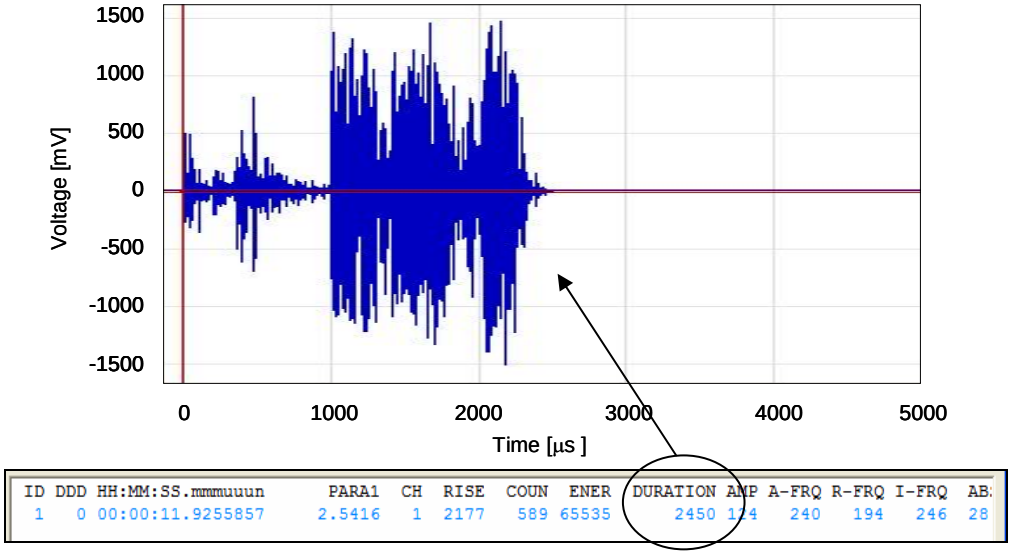

Fig. 5. Waveform from highest recorded energy hit on sample 4.

Fig. 6 compares the HDD and TDD absolute energy values with the measured damage areas. The HDD provides a better correlation than the impact energy or the absorbed energy but there are still deviations from the added trend line. The TDD measurement of absolute energy however shows a near perfect straight line correlation between the absolute energy received and the damage measured. The added trend line passes through (0,0) and is approaching 400J absolute energy for 400mm^2 of impact damage. This would provide a crude estimate of 1 atto-J for every 1mm^2 of damage. The difference between the TDD and HDD could be explained by the fact that the TDD is independent of threshold and in this case obtained more information than the HDD which is clinically cut off when the signal drops below the threshold for a set period of time. The HDD impacts are generally 2500µsec long while the HDD collects energy over 10000µsec. For this test the HDT may have been set too short and a longer period (500µs) may have provided results with a closer correlation. This will be investigated in future tests.

The work presented here has demonstrated that AE could be successfully used to not only detect low velocity impacts but give an estimation of the resulting damage. Further work needs to be completed to investigate if it is possible to locate the region of impact. The test rig used did not allow sufficient space for further sensors for a location array. More important, however is that the design of the sensors needs to be considered. The sensors used were of a small diameter and height but these would not be suitable in the application of plane wings or racing cars where sensors would need to be either a patch design or imbedded into the actual material.

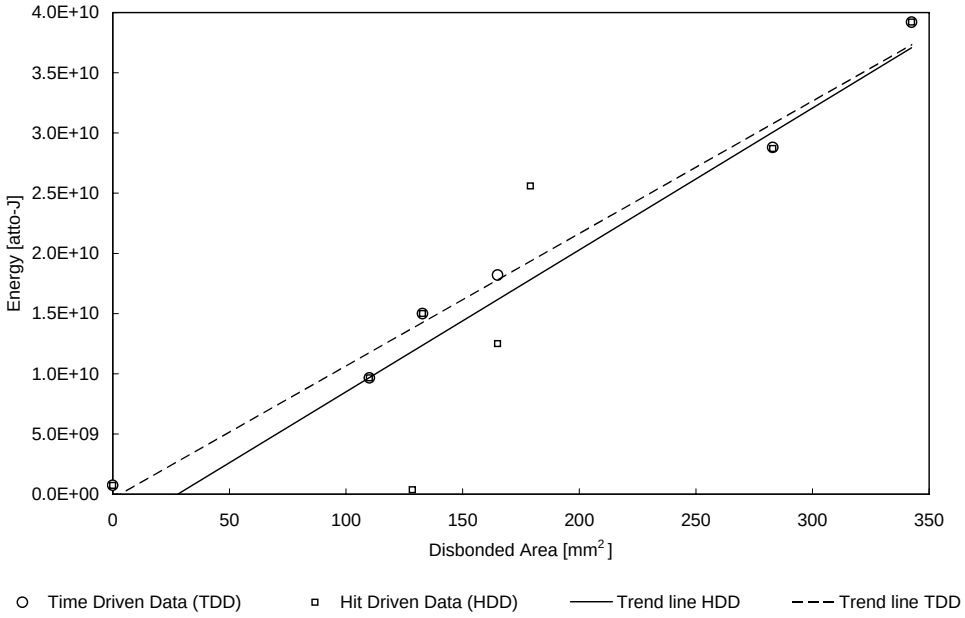

Fig 6. Comparison of debonded area with time and hit driven data

Conclusions

It has been demonstrated how different levels of AE can be acquired simultaneously allowing the same event to be evaluated in many a number of ways. The objective of these tests was to establish if AE could be used to evaluate the level of damage in a composite sample from an impact event. The mechanically calculated and measured values of impact energy and absorbed energy were shown to be limited in their capability to demonstrate the damage actually experienced by the material. It was shown that the detailed wavestream and discrete waveforms could provide information on the exact timings of the damage events during the impact itself. Correlation of this with load cell data on the impact head would provide detailed impact analysis tool.

The HDD was shown to have a good correlation with impact damage that could be improved with adjustment to the test set up. However the most accurate correlation was achieved by using the simplest data analysis method of TDD and looking at energy released over a fixed time constant. This is a technique that can easily be done in real time, provides a very small data packet and is very easy to analyse either manually or automatically. The completed work has demonstrated the possibility of using AE on composite impact critical specimens to monitor for impacts and the resulting damage levels.

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