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DETECTION OF MICROSCOPIC BEHAVIOR OF LOW VELOCITY IMPACT DAMAGED CFRP LAMINATE UNDER TENSILE LOADING
BY
ELASTIC WAVES

탄성파 응용기술에 의한 CFRP 복합재료의 저속충격 손상역의 미시적 거동 특성 탐지

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(Abstract)

Carbon/epoxy composite(CFRP) coupons previously damaged by low velocity impact were tested under static tensile loading and the microscopic progress of damage was characterized by ultrasonic C-scan, Scanning Acoustic Microscopy (SAM) and Acoustic Emission(AE) techniques which were based on the application of elastic waves. The degree of impact damage has been correated with the AE activity during monotonic or loading/unloading tensile testing as well as the result of ultrasonic test. The coupons were subjected to impact velocities ranged from 0.71 to 2.17 m/sec, which introduced the amount of damage rated as 0%, 10%, 30%, and 50% with reference to the total absorbed energy at fracture. Special attention was paid to determine optimal AE parameters to characterize the microscopic fracture process and to predict the residual strength of composite laminates. AE RMS voltage during the early stage of tensile loading was found an effective parameter to quantify the degree of impact damage. It was also found that the Felicity ratio is closely related to the stacking sequence and the residual strength of the CFRP laminates.

1. INTRODUCTION

Impact damage can be a serious problem in the structures made of brittle materials such as composite laminates. Polymer matrix composite laminates whose applications to aerospace structures are steadily increasing are likely to be damaged by low velocity impact of various moving objects such as tools, runway stones, ice balls, and even birds. For the damage assessment and residual strength determination, a variety of nondestructive evaluation(NDE) technique based on the application of elastic waves have been employed, either alone or in combination, such as ultrasonic C-scan, X-radiography, acousto-ultrasonics and acoustic emission.

A Scanning Acoustic Microscope(SAM) is very effective tool to characterize the internal damage microscopically of impact-damaged CFRP laminates. Moreover, acoustic emission has been successfully applied to detect and locate the damaged area of impact-damaged composites during the subsequent quasi-static or low-cycle fatigue loading[1-3]. They found that the severer the damage is, the more emission and the lower the stress level at which it initiates[1,2]. Although the impact damage is generally non-visual and was unable to be located during quasi-static loading, it could be easily detected and located under tension-tension cyclic loading even within a few cycle[1]. It was also found that long duration events could be used to differentiate between stable and unstable behavior and to predict residual strength when unstable behavior occured. The normalized cumulative event rate moment and the average event rates are also proposed to be a useful feature for the descremination[3]. AE event duration distributions during the initial load hold are, however, reported as independent of the degree of damage.

In this paper, we have tried to find one or more optimal NDE techniques for damage assesment and residual strength prediction of low velocity impact-damaged composites.

2.MATERIALS AND EXPERIMENTS

Specimens ere from fully cured composite panels made by autoclave molding with high strength carbon/epoxy prepreg(RS1222, Toho Rayon Co.) which has elongation of 1.16%. Type-A specimens have stacking sequence of $[\pm45/0/90]_2$ and type-B specimens of $[\pm45]_4$ so that their. strength are 803 MPa and 224 MPa, respectively. The configuration and dimension of specimen with the position marked at which the impact damage was introduced are shown in Fig.1. The degree of impact damage was adjusted by changing the impact velocity from 0.71 to 2.17 m/sec to be rated as 10%, 30%, and 50% with reference to the total absorved energy at fracture as 100%. The typical examples of load vs. time and energy vs. time curves during impact for type-A specimen were shown in Fig.2. Figure 2(a) showed the load, energy and time curves at fracture for the impact velocity v=1.13m/sec, on the other hand, Figure 2(b) indicated the experimetal results damaged by 50% with reference to Fig.2(a).

An electo-mechanical type Instron(Model 8162) was used under stroke control for monitonic loading and under load control for loading-unloading testing. The crosshead speed of 0.05mm/min was the same for all specimens under stroke control whereas the loading rates were 1.28kN/min and 0.27 kN/min for type-A and type-B, respectively. The unloading points were 40%,60%, 70% and 80% of the ultimate strength for type-A specimens and 30%,50%,70% and 90% of that for type-B specimens to obtain the Felicity Ratio(FR).

An AE sensor with wide band response(WD,PAC) and a strain gage were attached at each side to the closest position to damaged area. Detected signals were amplified by 60 dB with 125 kHz to 1 MHz bandpass filtering then fed into signal processors including a transit recorder as described elsewhere[4]. The intensity of AE activity was recorded by a true RMS voltmeter(HP3400A) together with load and strain on a chart recorder and on a computer. Threshold was set at 20 μV at the sensor. A microcoputer-based AE instrumentation(AET5500) was employed to collect the events and extract the AE parameters. A number of waveforms were also digitized and recorded using a stroage oscilloscope(LeCroy 9340).

3. RESULTS AND DISCUSSION

Ultrasonic C-scan and SAM observation results for Impact Area: The conventional ultrasonic C-scan technique with 5 MHz frequnency was applied to get some quantitative informations such as impact area of surface for both type-A and type-B specimens. The typical example of ultarasonic C-scan was shown in Fig. 3(a) for type-B specimen damaged by 50%. Figure 3(a) showed the internal impact damaged area for the same specimen observed by SAM operating at 50 MHz frequency. In Fig.3(b), the delamination between fiber and matrix and the breakage of fibers were clearly observed in this figure.

AE RMS Votage Data : AE intensity in RMS voltage during the monotonic loading was plotted together with load for damaged specimens of both type-A and type-B as shown in Fig.4. With the increasing degree of impact damage, the time for initiating AE activity was considerably shortened and the activity prior to the major ply failure was also increased. The periods are approximately up to 400 and 1800 sec for type-A and type-B specimens, respectively. The activity during this period can be considered as the friction generated emission[1]. In Fig.5, the first 400sec each of the Fig.4 is expanded together with corresponding AE events vs. time curves. It was found that the amount of friction generated emission or the emission during the initial stage of loading was proportionally increasing with the degree of impact damage.

AE Event Duration: Analysis with AE parameters such as distributions of energy or peak amplitude by events was also carried out. The results from the distributions itself, however ,were not very useful to differentiate between the degree of damage. When the peak amplitude was plotted against event duration, the distinction between AE signals from each state of damage became very significant as shown in Fig.6. It is found that the increase in signal energy with the degree of damage accounts not for higher peak amplitude but for longer event duration. Such a trend is more significant for type-A specimen than type-B specimen. This is due to the stacking sequence and higher strength type-A specimen is more vulnerable to impact damage.

Felicity Ratio: From the series of loading-unloading-reloading experiments, FR values were obtained for each degree of damage as shown in Fig.7. For both type-A and type-B specimens, undamaged specimens and specimen damaged by 10% showed almost same values of FR. This implies that AE may not be an effective tool for detecting small amount of the impact damage up to 10%. This was also the case when ultarsonic C-scan was employed to examine the damage area with this specimen. FR values for type-A specimen decreases wihth the increasing degree of damage faster than those for type-B specimen. This is again due to the stacking sequence and higher strength type-A specimen is more vulnerable to the progress or accumulation of damages. It was also tried to correate the residual strength with AE parameters or Felicity Ratio but there was no good coorrelation found from this study.

4. CONCLUSIONS

1. Acoustic emission technique in conjuction with ultrasonic C-Scan and SAM techniques provided very useful tool to monitor the progression of low velocity impact damge of CFRP.
2. The analysis of acoustic emission signals during the initial loading not more than 50% of the ultimate strength is effective for the assesment of impact damages in composite laminates.
3. Both AE rms voltage and event duration data appear to be very useful parameters to quantitatively evaluate the degree of damage.
4. Felicity Ratio can be one of the useful indicators for the damage assesment but the value was very sensitive to the stacking sequence.

5. REFERENCES

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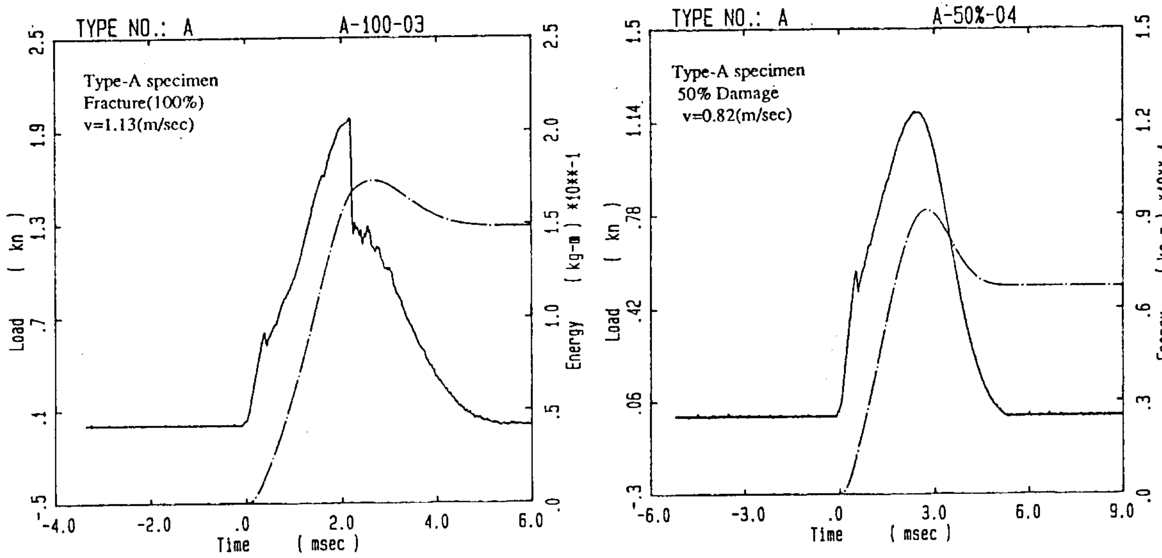


(a)

(b)

Fig.1. Typical example of load vs. time and energy vs. time curves for type-A specimen

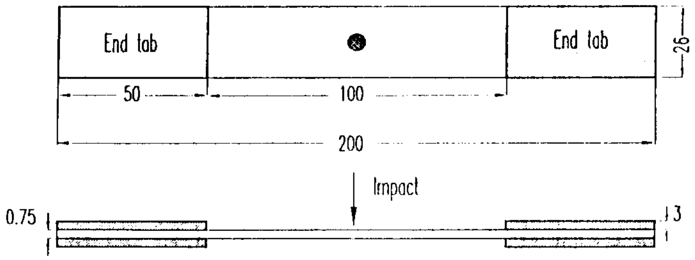
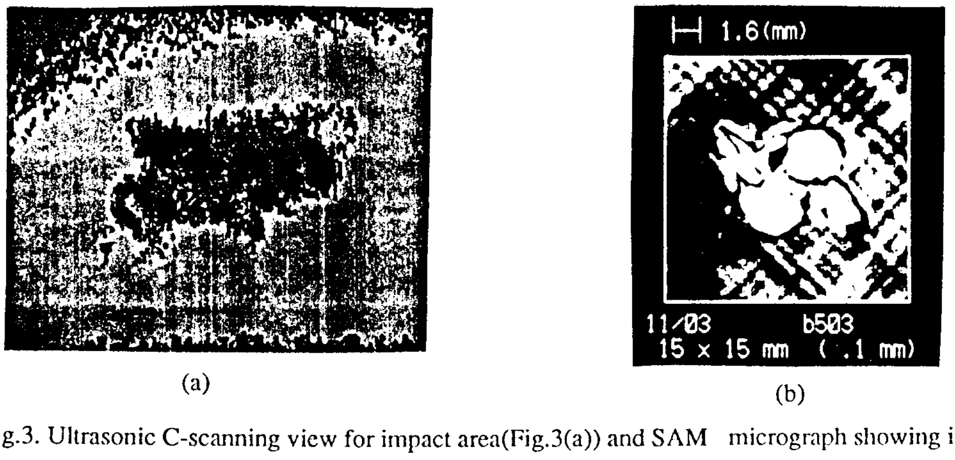


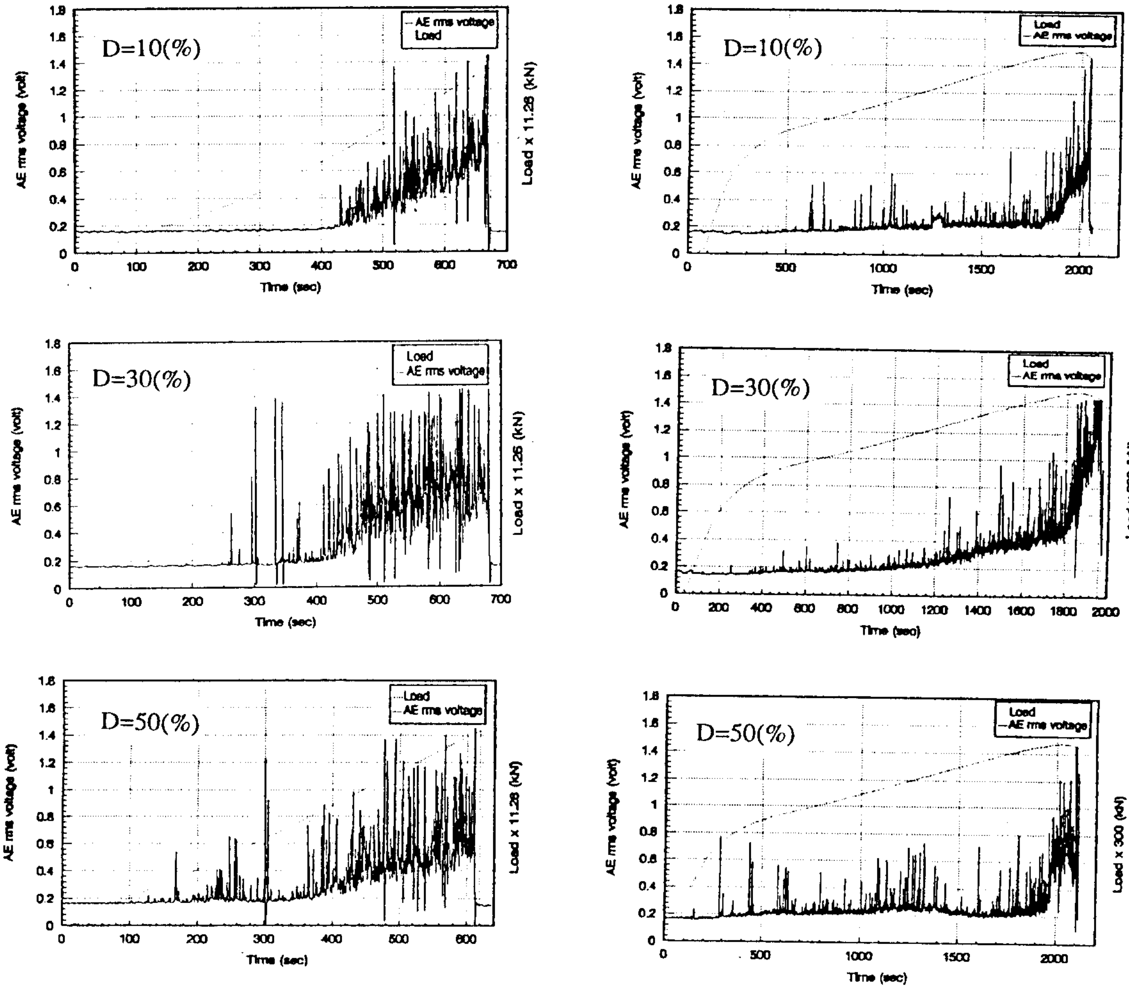
Fig.2. Configuration and dimension of composite specimen



(a)

(b)

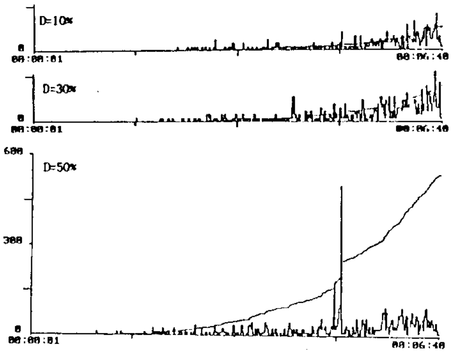
Fig.3. Ultrasonic C-scanning view for impact area(Fig.3(a)) and SAM micrograph showing internal damage(Fig.3(b)) for type-B specimen damaged by 50%.



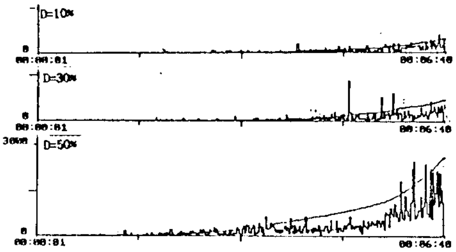
(a) specimen A

(b) specimen B

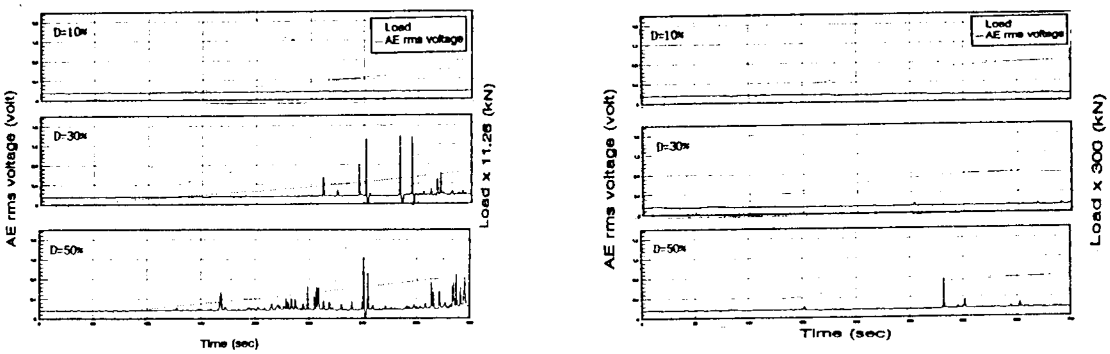
Fig.4. AE intensity and load versus time during monotonic loading



(a) specimen A



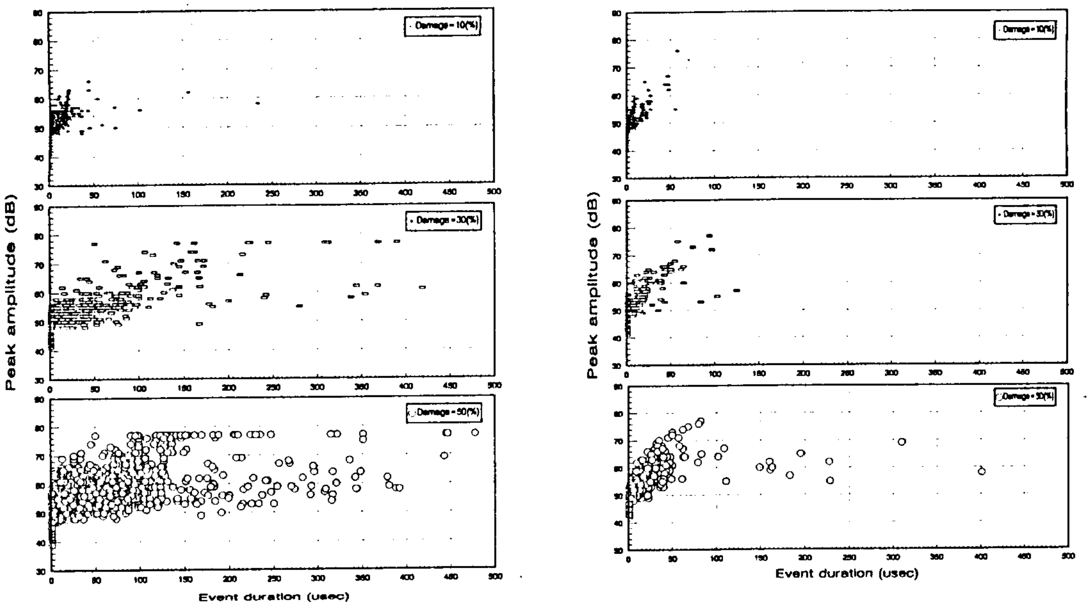
(b) specimen B



(a) specimen A

(b) specimen B

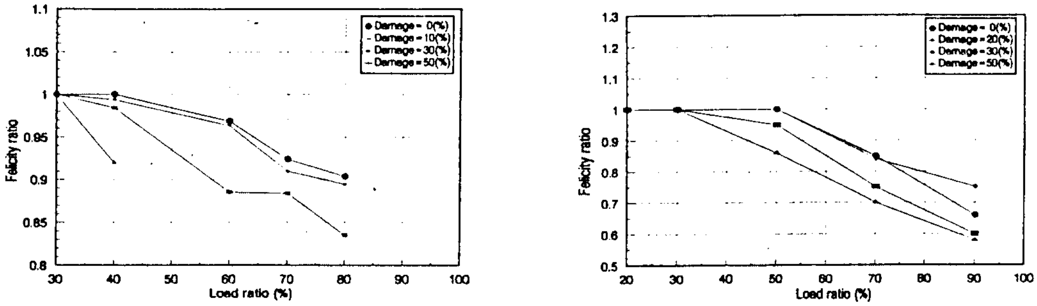
Fig.5. AE events, intensity and load versus time for the initial loading period



(a) specimen A

(b) specimen B

Fig.6. Cross-plot of peak amplitude against event duration for the entire test



(a) specimen A

(b) specimen B

Fig.7. Felicity Ratio as a function of the fraction of ultimate load