Prognostic and Health management of Damaged Area in Composites Under Multiple Impacts

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ABSTRACT

Real-time prognostics and health management research using electromechanical behavior for impact growth were limited and the analysis of damaged area by impacts were rare. In this paper, the structural health of the carbon-fiber-reinforced plastic was monitored using self-sensing data in real-time. Damage identifications were conducted by utilizing cross-sectional analysis and C-scan, and the analysis were correlated and compared with those of fracture analysis in real-time electromechanical behavior. Moreover, electromechanical behavior was predicted using particle filter in real-time based on historical electrical resistance change ratio data. This study has high applicability for industry fields in composites structures.

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1. INTRODUCTION

Carbon-fiber-reinforced-plastic (CFRP) has gained immense popularity in various industry fields (Muflikhun, 2019, Kupczyk 1988 and Bae, S.-Y, 1991). However, lots of accidents and fractures have been reported in recent years. As a consequence, lots of maintenance cost are required. To reduce those huge amount of maintenance costs, real-time structural health monitoring and prognostics should be studied. Among many non-destructive evaluation studies, self-sensing using electromechanical behavior analysis which has strength for real-time health monitoring system and no extra sensor attachment have been reported. But, health monitoring under multiple impacts are limited. Further, impacted damage analysis by impacts are rare.

Prognostics has attracted huge attention nowadays. It was conducted by two ways: data-driven and physics-based prediction. data-driven needs huge amounts of data set for reliable predictions. In physics-based prognostics, future health state can be predicted using small number of data sets and simple physical equation about property degradations. Based on these strengths, impact damage growth in glass fiber reinforced plastic was predicted using particle filter based on scanning-based non-destructive evaluation method (Banerjee, 2018). In addition, fatigue damage in adhesively bonded joints was prognosticated using particle filter based on ultrasound-based method (Palanisamy, 2022). Prognostics and health management (PHM) using self-sensing data is extremely rare.

This paper proposed real-time structural health monitoring (SHM) and PHM under repeated impacts conditions that is main fracture mechanisms in flights structures. Scanning-based health diagnosis methodologies were utilized to verify the analysis results of electromechanical behavior. And damaged area by multiple impacts was precited by prognostics tools.

2. EXPERIMENTAL

2.1. Sample preparation

CFRP samples, dimensions of 150 mm × 100 mm × 2.2 mm, were made by vacuum-assisted resin transfer molding with woven-shaped carbon fiber. Four electrodes were installed on the CFRPs using copper wire and silver paste for minimizing the contact electrical resistance.

2.2. Testing and prognostics algorithms

Multiple impacts testing was performed using CEAST 9350 drop-weight impact tester. 3J of multiple impacts were conducted. During the impact growth in composites, electrical resistance was obtained in real-time using four-probe measurement method by a digital multimeter from Keithley 2002, USA.

Ultrasonic C-scan and impacted cross sectional analysis were performed the failure mode damage identification and damage growth analysis by phased-array ultrasonic machines and optical microscope.

Particle filter which is most representative and powerful prediction tools in physics-based prognostics. It was utilized based on the linear shape of electromechanical behavior degradation equation and few self-sensing data. More in detail, after fiber breakage points, ten self-sensing data were utilized for electromechanical degradation prediction in advance. There are three steps for prediction: prediction, update and resampling. In prediction, the posterior distribution at previous step is utilized to estimate the prior distributions in the current step. In update procedure, parameters in model and degradation conditions are updated using likelihood function from estimated data at the current step. Lastly, in resampling step, all samples have same weight for efficient prognostics process. Electromechanical behavior was predicted with linear degradation functions in 0 to 0.000065 slope boundary conditions. Based on the prediction results, impact damaged area was predicted.

3. RESULTS

3.1. Electromechanical behavior analysis

Electromechanical behavior was shown in Figure. 1. Damaged area was calculated using C-scan images. During the multiple 3 J impacts, impact damaged area was increased, as the number of impacts increasing. Also, electrical resistance change ratio increased following the damaged area increases. At the puncture damage state, electrical resistance was not changed because the damage area was not increased further multiple impacts testing. This means that no further electromechanical behavior degradation not observed.

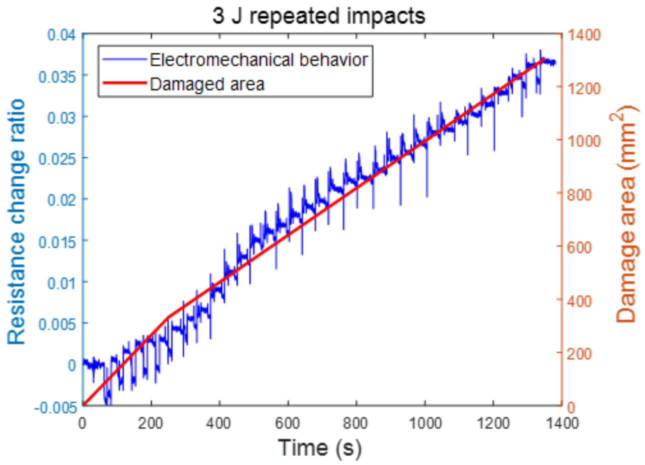

Figure 1. Electromechanical behavior and impact damaged area.

C-scan image result was shown in Figure. 2(a). Damaged area by multiple impact was indicated. However, different failure modes cannot be investigated by this analysis. There are no differences between fiber and matrix damages. Only the impact damage growth could be analyzed. However, different failure modes such as fiber breakage, delamination and matric cracking can be investigated by cross sectional analysis. Further, various fracture mechanisms such as puncture, indentation could be figured out using this scanning-based monitoring methodology.

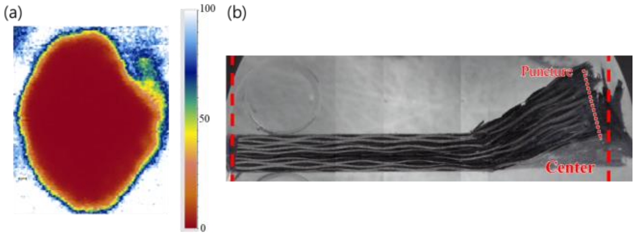

Figure 2. (a) C-scan image and (b) cross-sectional analysis of impact damaged samples.

For in-depth damage identification, result from cross-sectional analysis was correlated with the electromechanical behavior results. At the point of change in slope of electromechanical behavior showed the fiber breakage initiation point. It means that different failure modes can be monitored in real-time based on the self-sensing data.

3.2. Electromechanical behavior prediction

From the fiber breakage start points, few number of real-time self-sensing data were used for electromechanical behavior prediction using particle filter under linear shape of degradation behavior. Finally, impact damaged area was prognosticated based on the prediction result of electromechanical behavior. Red line indicates the actual measurement of damaged area. And blue long and short dash lines show the prediction of impact damaged area of median value and 95% prediction interval boundary lines, respectively. Impact damage growth was successfully predicted within 15 mm^2 RMSE error value using less than 10 historical self-sensing data. This indicates that electromechanical behavior also well predicted. In other words, impact damage propagation was well prognosticated in real-time.

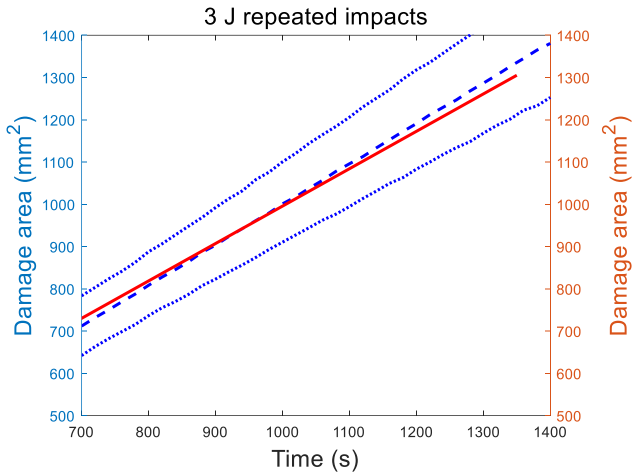

Figure 3. Damage area prediction using particle filter.

4. CONCLUSION

CFRPs were manufactured using the VARTM. Material behavior degradation can be monitored by real-time electromechanical behavior analysis. Cross-sectional analysis and C-scan were conducted to obtain the impact of the damaged area and in-depth damage identification. In electromechanical behavior analysis, the health state of composites could be figured out. For instance, the start point of damage and damage propagation could be investigated in real-time and that is verified with scanning based NDE methodologies. In means that damage accumulation, severity, and puncture can be analyzed using self-sensing data in real-time.

This study introduced an advanced real-time PHM system under repeated impacts structural health monitoring data. Since composites combined with more than two materials fiber and matrix, it is difficult to maintain and repair. As the expected effect, this can reduce the huge amount of maintenance cost by in-depth damage identification and prediction. The method can be applied to real-world composite structures that are exposed to mechanical strikes, such as flights, reducing unexpected accidents and extra maintenance costs that is came from mechanical impacts.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Ministry of Science and ICT, Korea (NRF-2017R1A5A1015311).

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