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NDE Detection and Characterization of Damage in Honeycomb Sandwich Composites

Kwang-Hee Im[1,a], Sun-Kyu Kim[2], Young-Tae Cho[3], Yong-Deuck Woo[1], Jong-An Jung[4] and David Kuei Hsu[5]

[1]*Department of Automotive Eng., Woosuk University 490, Hujung-ri, Samrae-up, Wanju-kun, Chonbuk, 565-701, Korea*
[2]*Division of Mech. System Eng., Chonbuk Natl. University, Duckjin-ku, Jeonbuk ,561-756, Korea*
[3]*Dept. of Manufacturing Design Eng., Jeonju University, Wansan-ku, Jeonju, Jeonbuk, 560-759, Korea*
[4]*Dept. of Mechanical and Automotive Engineering, Songwon University, 73 Sonarm-ro, Namgu, Gwangju 502-210, Korea*
[5]*Center for Non-destructive Evaluation, Iowa State University, Ames, Iowa 50011, USA*

Abstract. This study deals with a non-destructive evaluation technique for detecting defects in composite panels. In this non-destructive evaluation technique, various low-frequency techniques are applied such as a tapping technology. Another terahertz wave application will be utilized. In particular, the tapping technique is utilized in order to evaluate the characteristics of the honeycomb member based on the hysteresis effect analysis. Here, the area surrounded by the hysteresis loop in the force-displacement curve is related to the increased internal friction loss that is the cause of the energy absorption absorbed by the composite member after the load is applied. The loop area where the composite member was damaged was well agreed with the damage level. Artificial defects were manufactured on the surface of honeycomb sandwich composite panels. An NDE technique was proposed in order to detect defects by using terahertz waves and was discussed for tuning the practical use.

1 Introduction

Composite materials have the advantage of high specific strength and stiffness over compared to metals, but are brittle to impact damages. They could have their own unique damage and failure modes. In solid laminates, impacts can lead to delaminations at the ply interfaces[1]. In honeycomb structures, impact damage could make the structures fractured or crushed cores generated[2,3] and may also cause matrix cracking and delamination. The tap test imaging system can also be used to verify the internal substructures of composite parts. Tap test images are to be generated by both manual tapping and by using a mechanized scanner. The purshed system is used to produce images of both the impact duration of the taps and the deduced spring constant that shows the local stiffness of the structure [4,5,6]. These images determine quantitatively the degradation of stiffness due to flaws or damages and the enhancement of stiffness due to internal reinforcements, core splices and potted core. Structures used in the experiments included actual honeycomb sandwich panels and GFRP solid composites[7,8].

As an antoher tecnique, technology and instrumentation in terahertz radiation have provided a probing field on the electromagnetic spectrum because the terahertz radiation has a shorter wavelength, relatively higher resolution than microwaves, and lower attenuation [9,10]. Also the terahertz time domain spectroscopy (TDz-TDS) is leading noncontact accurate detection of flaws and impact damages in composites, in which the TDz-TDS is based on photoconductive switches, which rely on the production of few-cycle terahertz pulses using a femtosecond laser to excite a photoconductive antenna [2]. In this study, terahertz waves are explored as an NDE tool for detecting and characterizing flaws and damage in GFRP solid composites [11].

When GFRP solid laminates and honeycomb sandwich composite structures are subjected to impact damages, their stiffness would be influenced to a degree of severity in impact. In particular, the contact stiffness in the damage zone could decrease considerably. In addition, the resultant internal damage can produce a hysteresis loop in the load-displacement response of the impact site. This approach shows the stiffness reduction and the mechanical hysteresis caused by impact damage in composites and strives to develop nondestructive inspection methods based on these changes. Since qualitative manual tap test is perhaps the most widely practiced inspection for composites in service, particular attention is given to the development of tap tests as a quantitative nondestructive evaluation method based on the extraction of stiffness and mechanical hysteresis data from the force-time history of a tap test. Addtionally the use of T-rays as an NDE tool for detecting and characterizing flaws and impact damage in GFRP solid composites will be investigated compared with the results of tapping testing.

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[a] Corresponding author: khim@woosuk.ac.kr

2 Experimentation

2.1 Contact stiffness and tap test

In the inspection of composites for impact damage in GFRP solid laminates or disbond in sandwich panels, manual tap tests were widely used. An impact-damaged or disbonded area would make a dull or hollow sound produced ; whereas an undamaged region would make a crisp and solid sound produced. Such hearing-based tap tests are dependent on operators and will be easy is subjected to the interference by ambient noise. Instrumented tap test devices are still available for many years. We purchased the Computer Aided Tap Tester (CATT) from Iowa State University. These instrumented tap testers all made use of the contact time between the tapping mass and the surface to be inspected. The damage caused by an impact can reduce the stiffness of the part and lengthen the contact time considerably [3].

Figure 1. The components of the tapper system schematically.

The advantage of the mechanical tapper is that the tap spacing in the scan direction is highly constant compared to that of a hand scan, and that it is much less tedious.The use of the mesh template had very negligible effect on the duration during impacting.

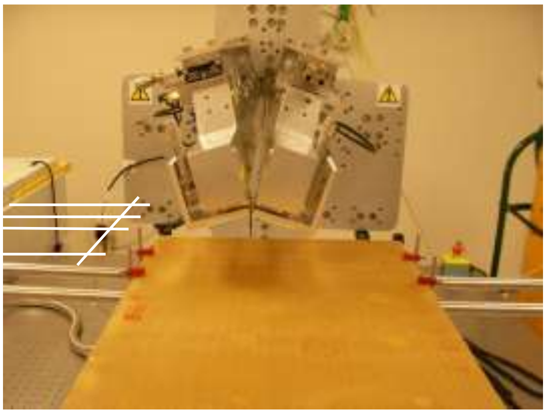


Figure 2. THz TDS system for imaging and material parameter measurement

2.2 T-ray scanner

Figure 2 shows a schematic of T-ray time-domain spectroscopy system (THz-TDS), the nondestructive test system. As shown in Fig. 2, a reflection mode was ste up for scanning defects on the honey-comb sandwich panels. The T-ray instrumentation systems used in this research were provided by TeraView Limited in England. The instrumentation is consisting of a time domain spectroscopy (TDS) pulsed system and a frequency domain continuous wave (CW) system.

The TDS system has a frequency range of 50GHz – 4 THz and a fast delay line up to 300ps. The beam is focused to focal lengths of 50 mm and 150 mm and the full width at half maximum (FWHM) beam widths are 0.8mm and 2.5mm respectively. The TDS system can be configured for through-transmission or reflection (small angle pitch-catch) measurements. The frequency range of the CW system is 50GHz – 1.5THz, with the best resolution being 100MHz. The focal lengths of the CW system are also 50mm and 150mm. Both the TDS and the CW systems are fully fiber optics connected[11].

2.3 Relationship between stiffness and contact time

The several recent extensions of the Hertzian contact theory have confirmed the impact time (i.e., contact time) between two impacting objects. For example, Greszczuk [4] analyzed the impact time of a spherical impactor dropped onto a flat plate and contacted on an expression for the impact time as a function of mass and radius of the impactor, the drop height, and the elastic properties of the target and the impactor. Such meanings were that the contact time of a tap is less sensitive to the velocity or the force with which the tap was made. Figure 3 shows the force-time history of taps made with the repetition tapping on the composite honeycomb panel with the differnet height. An accelerometer was utilized and its weight is 14.16g with different heights of 5mm to 8mm.

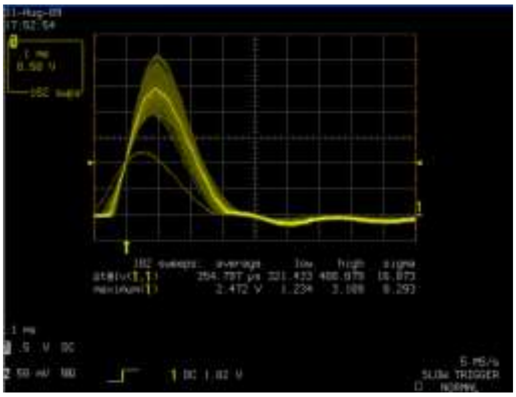


Figure 3. Force-time history of taps on a composite honeycomb panels with the same repetition tapping. [Horizontal axis 100µs/div, vertical axis 0.5V/div].

It was found that the contact time is approximately the same even if the different tapping force loaded on the panel. The curves were the voltage output of an accelerometer, which meant the tapping mass. It was shown that the GFRP composites and honeycomb sandwiche panels may be modeled on the basis of only the stiffness (spring constant) of the structure and the mass of the tapper [6].

Notice that the force-time history may be considered for one half of a sine wave cycle. So, the contact time τ is 1/2f and π/ω due to f=1/τ and τ=2 π/ω. A spring constant k is follows [5,6]:

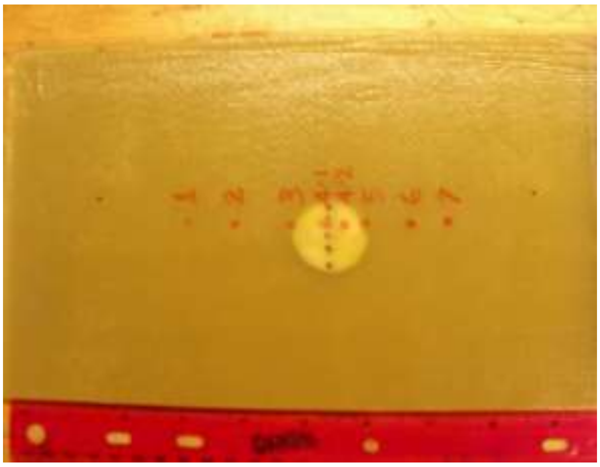
$$k = m\,(\pi/\tau)^2 \qquad (1)$$

In this manner, the spring constant k can be solved from the obtained tapper mass m and the measured contact time τ. Several tapping measurements have shown good agreement between the values of k deduced from tap test and measured in actual static load tests for damaged and undamaged honeycomb sandwich panels and GFRP composite laminates.

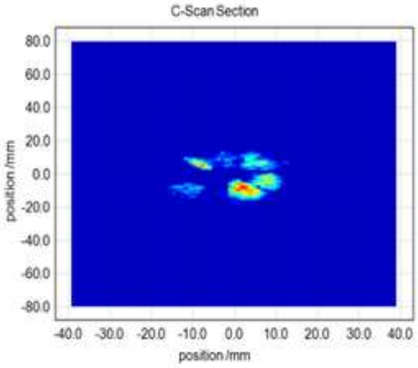
3 Results and discussion

3.1 Impact damages

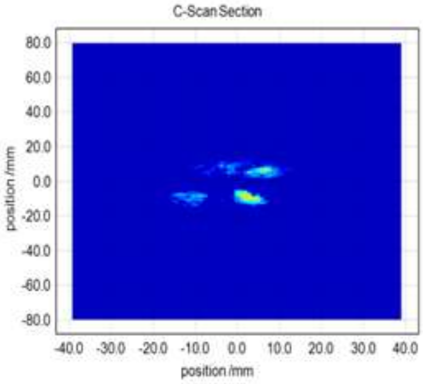
By using TDS T-ray waves, the several delaminations in GFRP solid composite laminates were imaged based on the reflection mode from on the power described above. The GFRP sample was a 24-ply woven glass epoxy solid laminate and the sample was impacted with a 51mm diameter tup and an impact energy is 16.6 Joules. The C-scan images were obtained from the impact point using reflection mode. Figure 4 (a) shows the photo with the size of impact point. Figure 4 (b) shows the T-ray scan image in order to produce the images of the impact-induced delaminations with the time gate range of 43-69ps. Figure 4(c) and (d) show an impacted images with the different time gate range of 47-69ps and 56-69ps respectively. These images clearly are showing the decreasing size of the delaminations toward the impact point.



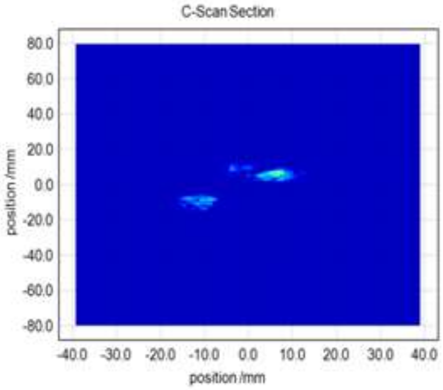
(a) Impacted GFRP solid sample



(b) 43-69ps



(c) 47-60ps



(d) 56-69ps

Figure 4. Time domain TDS waveform of GFRP composite laminate and impact delamination images using different time gate (43-69 ps, 47-69 ps and 56-69 ps in order)

The impact damage threshold had been investigated of GFRP solid laminates using the Instron impact tester Dynatup 8200 (such data are of interest to the work on solid laminates in Sandia) and the NDE of the damages so produced. In addition, we have also investigated the acoustic spectrum of the impact in a tap test. This was motivated by several factors. First, the tap test of a light-weight, flexible structure (e.g., honeycomb sandwich) will encounter limitations on a thick solid laminate, as the nature of the test transitions from a local test to a global test. It is therefore relevant to explore the acoustic spectrum.

We have founded that the effect of the tapping mass were investigated for detecting defects in GFRP solid laminates and found that the common wisdom of a "bigger hammer" will probe deeper did not seem to hold true. Figure 5 shows the tap test locations on a 12.7mm thick GFRP laminate (tapping through 14.3mm of material). With the consistent taps produced by the recently developed motorized tapper, we can now make use of the contact force as well as the contact time in a tap test.

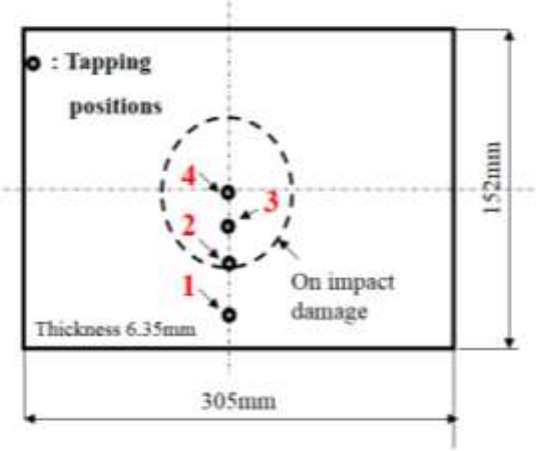


Figure 5. Contact time effect of tapper mass on impact damage

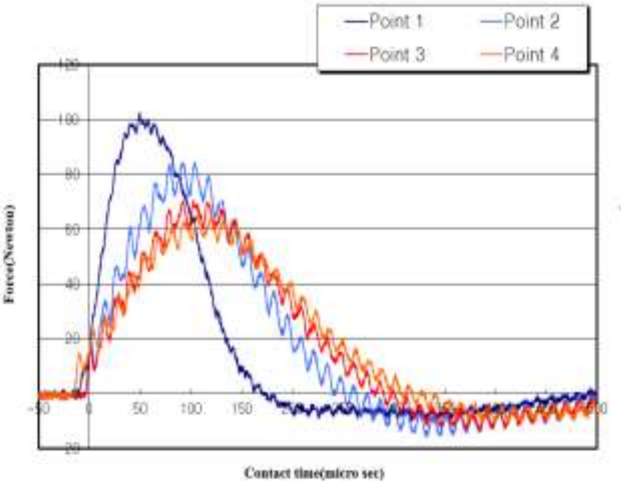


Figure 6. Force-time history of taps made by Robotapper. Point 1 – away from damage, point 2 – at edge of damage, point 3 and 4 – inside damage

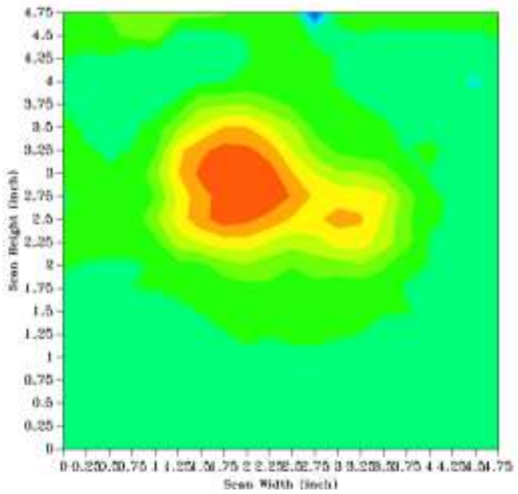
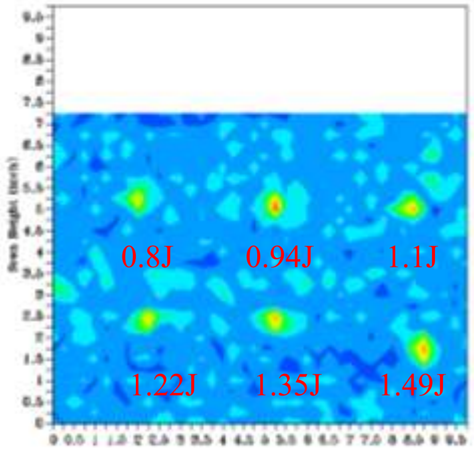
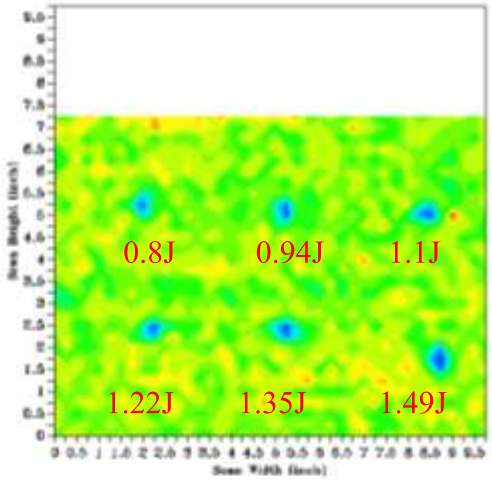


Figure 7. Those images were scanned on the impacted-opposite surface of GFRP laminates. Scan area are 190 x114 mm. The CATT was utilized to get data and it weight of an accelerometer is 14.16g.



(a) Contact time



(b) Stiffness

Figure 8. Scan image of impact damages on a glass composite honeycomb panel based on the tapping test.

Figure 6 shows the force-time history of taps made by the tapper. Point 1 is at a location away from an impact damage on a ~6.35mm GFRP laminate, point 2 is on the edge of the impact damage, and points 3 and 4 are within the impact damage. As expected, the peak force was lower in a less-stiff, damaged area and that the contact time "tau" is longer in the damaged area. With the tapper, it is now possible to acquire the entire tap response and use both the contact force and the contact time in the detection and quantification of flaws and damage. The specimen used for Figure 7 containing the pre-existing impact damage show the tapping image. Here,GFRP skin honeycomb sandwich panels were tapped by an instrumented tap test system (CATT: Computer Aided Tap Tester), which was developed by Iowa State University for evaluating the impact damages of GFRP solid laminates. The tapper scans were made for both sides of impact-damaged sample. Figure 7 shows the different impact energies of 0.8J, 0.94J, 1.1J, 1.22J, 1.35J and 1.49J. Figure 7 (a) and (b) show the tapped image based on the contact time and stiffness respectively. The two scan images seem to be similar to each other. However, the degree of image varied with the degree of severe impact damage of the honeycomb sandwich panels.

Here τ and k-based images of the samples could easily be obtained by this CATT software. It is found that stiffness of impacted areas is pretty lower than other area as expected. Also, a similar trend was observed for the contact time as Figure 7 as expected.

Therefore for enhancing good imaging and quantitative capabilities, this tap test is an attractive NDE testing tool for inspecting GFRP solid laminats and especaily sandwiche penels. It was recommended the amount of NDT information obtained per unit cost is believed to be among the highest of all the NDT techniques because of the simplicity. Also, the T-rays could be useful for various NDT applications. However, their applicability is currently limited by the high cost of instrumentation and difficulty of use. We are expecting the growing demand will cost down for the easy-to-use.

4 Conclusions

This paper showed several advances in doing the tap test a more quantitative technique for imaging, detecting and characterizing the defects and impact damage in composite structures. Even if there are various NDE methods available, the tap test is the simplest, less costly, and most widely experienced mode of inspection for composites, especially GFRP solid laminates and honeycomb sandwiches. For this reason, the capabilities of tap test could lead to a broader impact in the NDE of composite materials. Also the non-conducting composites with glass and fibers, the T-ray radiation can complement ultrasonic NDE, especially with its penetration degree and regardless of shadow effect. The applicability of T-ray spectroscopy for materials evaluation, contamination detection, and fluid ingression was studied. By the way, it was found that the T-ray waves were very sensitive to water and oil as well as impact damages.

5 Acknowledgment

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