Evaluation of Impact Damages in RTM Stitched Composites by Using Ultrasonic Multiple Imaging Techniques

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Abstract: Impact damages are important destroyed sources of RTM stitched composite structures in-service. With their applications in aerospace and aviation industries the attention to evaluation of impact damages were paid widely by specialists in these fields. The structural details and characteristics give the mechanism to evaluate nondestructively the impact damages. An ultrasonic multiple-scanning imaging approach based on special designed high resolution transducer and soft-electronic gate technique is developed to see the details of impact damages in RTM stitched composites. The experimental results show that echo pulse patterns give qualitative information about damages; C-scan imaging provides quantitative distribution of impact damaged area; B-scanning imaging offers possibility of seeing topologies of damages in impact zone and extending of damaged zone along depth of RTM stitched laminate. The surface dead-zone of the employed ultrasonic technique is close to 0.13mm.

Keywords: Ultrasonic evaluation, Impact damages, RTM stitched composites

1. Introduction

Resin transforming molding (RTM) stitched composites is used increasingly in aerospace and aviation industries because of their improvements in cost and laminar mechanical properties. Impact damages are the important destroyed sources of composite structures in-service. Design and manufacturing technology of composites need data as input for optimization. Industrial applications need to establish effective non-destructive evaluation and inspection (NDE&I) techniques for finding defects or damages in RTM stitched composites. Some articles reported their investigations on impacted damages in composites by ultrasonic evaluation methods [1-3]. One of the ultrasonic evaluation mechanisms is based on propagation of probe ultrasound in composites body. Impact damages will change materials uniformity, thus resulting in variation of ultrasonic wave propagation in it.

The complexity and speciality of RTM stitched composites in structure and technology need to investigate the effect of impact damages on mechanical properties and the mechanism of ultrasonic evaluation of impact damages and defects. A multiple imaging technique has been established to qualitatively and quantitatively evaluate impact damages in RTM stitched composites in this paper.

2. RTM stitched composite structure and ultrasonic evaluation method

Figure 1 gives the microstructure of a RTM stitched composite laminate in cross-section. The structural details, such as the characteristics of lay-up, stitching and weaving in laminate body, can be seen well in it. When probe ultrasonic wave impinges on RTM composites, their evident structural specificities will give a complex ultrasonic propagation and reflection: 1) in RTM composite laminate as a whole; 2) along different fiber directions; 3) at resin pocket; 4) at weaving bundle and 5) defect, as illustrated in figure 1. It is dependent on employed wavelength [4].

RTM stitched composite laminate is treated as uniform multi-layer acoustic media by ultrasound when its wavelength is much larger than their characteristic structural units. No ultrasonic reflection will result from structural details, as illustrated by □ in figure 1. However, in short wavelength limitation the interface between neighbor layers will give rise of reflection when ultrasonic wave pass through RTM laminate body [4].

When probe ultrasonic beam impinges on surface of stitched fiber bundles in RTM laminate, the ultrasound will propagate in a much fast speed compared the case of □ because of the very strong anisotropic properties of fibers [4], as illustrated by □.

A distinct reflection will take place at resin pocket because remarkably different acoustic properties of fibers and resin as well as weaving bundles in RTM stitched composite laminate, as illustrated by □ and □.

In generally, an absolutely reflection will occur when probe ultrasound impinges on a defect, for example, impact damage, as illustrated by □.

Therefore, ultrasound propagation and reflection in RTM stitched composites provide an effective mechanism for evaluation of impact damage.

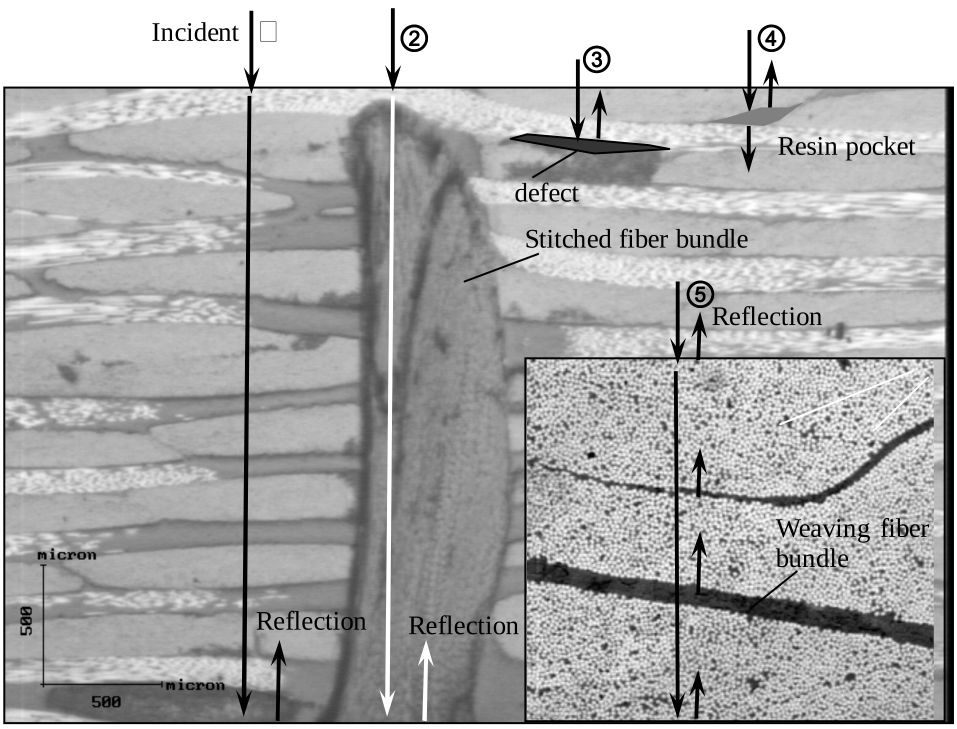


Figure1. Illustration of ultrasound propagation in RTM stitched composites

Figure 2 is the experimental setup of the ultrasonic scanning system, which is designed by Beijing Aeronautical Manufacturing Technology Research Institute (BAMTRI). A high resolution ultrasonic transducer is designed for evaluation of impact damage in RTM stitched composite materials. Its frequency is 5MHz. Focal spot is about Φ0.5 mm. Focal distance is about 55 mm. Focal waist is approximately 8 mm. The Resolution of the ultrasonic unit –including the transducer and FCC-B ultrasonic inspection instrument for composites, which are made by BAMTRI, China, can reach 0.13 mm –the thickness of a single ply in composite laminates. That means that impacted damage, even located in sub-surface of composites, can be discriminated by the ultrasonic unit.

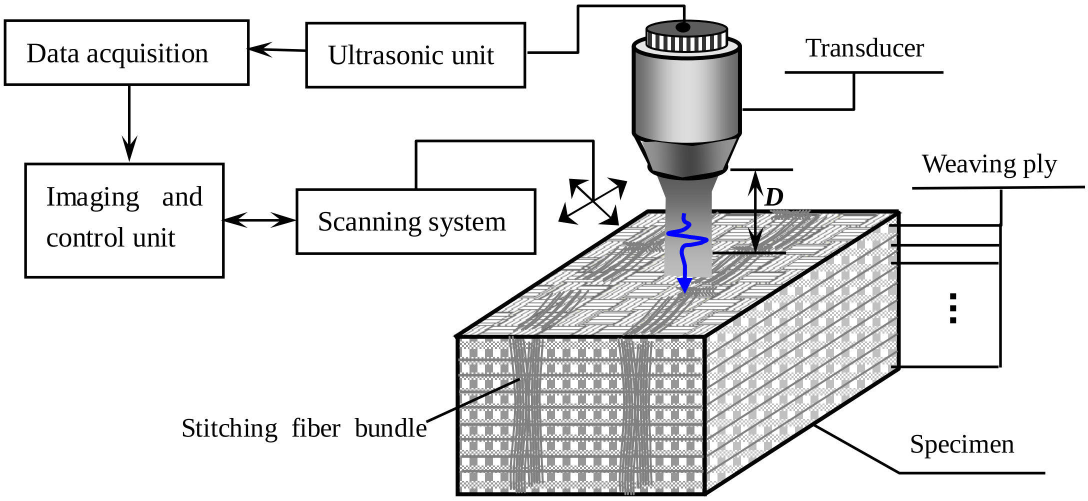
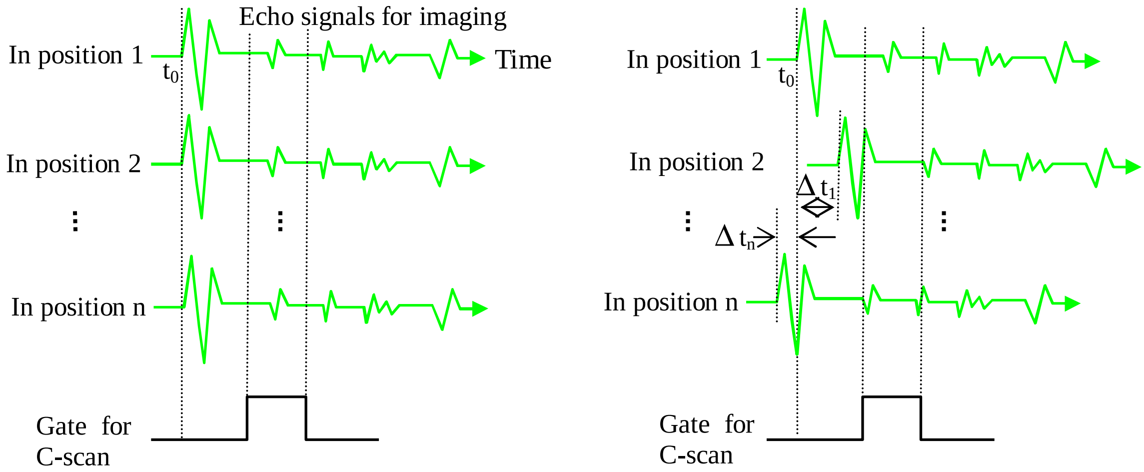


Figure 2. Experimental setup of ultrasonic scanning system

The signal acquisition with special software-electronic gates for this application is also designed by BAMTRI. Usually, commercial ultrasonic signal acquisition systems with pulse-echoes mode, whether all signals from transducer are recorded, or the gate-selected ultrasonic signals are sampled, are operated according to an assumption that the distance ***D*** between transducer and the surface of specimen to be tested is constant, shown as in figure 2. Then, it can assure to get a correct ultrasonic C-scan image, as shown in figure 3(a). All the signals are supposed to have same original position t_0 in time scale during scanning. But the real situation is that ***D*** may change in time-scale axis during scanning because of accidented surface of the specimen to be tested (see figure 4). Then the signal echoes maybe have a movement in time-scale axis, as shown in figure 3 (b), but the gate already was set before scanning, for example, according to the echo signal from transducer in position 1. When transducer is scanned to next position 2, a movement Δt_i (i=1, 2, n) of echo signal in time scale will occurs compared with the echo signal in the original position 1. It is much possible for the signal echoes to move out of the gate, or other echoes, for examples, echoes from surface or bottom of specimen, move into the selected-gate because of the change of ***D*** in different positions of specimen, shown as in figures 3(b). Therefore, a special soft-electronic gate technique is designed in the ultrasonic signal data acquisition system. The original position of the signal gate, used to switch A/D, is formed, based on the echo from surface of specimen to be tested in electronic circuit, shown as in figure 4. When a change of the distance ***D*** between transducer and surface of specimen takes place, the signal gate will vary with it in time-scale axis, i.e. tracing the signals from the positions of specimen with the same thickness.



(a) ***D*** without change (b) ***D*** with change

Figure 3. Conventional ultrasonic data acquisition

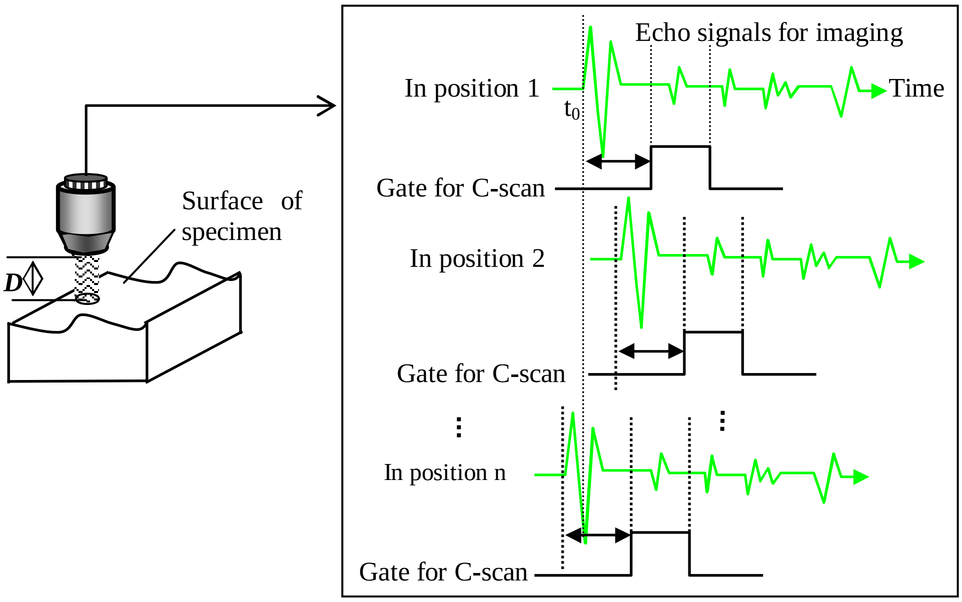


Figure 4. Soft-electronic gate for ultrasonic signal acquisition free of ***D*** change

3. Results and analysis

Figure 5 gives a series of ultrasonic echo signals (A-scans) and C-scan image of RTM stitched composite laminate specimen No. #2. Thickness of the specimen is 6 mm. Impact energy is 4.5J. Figure 5(a) is the echo signal from the zone without impact damage. The echo pulses ***F*** and ***B*** –resulting from ultrasound reflections at specimen surface and bottom, respectively, are seen clearly. The tiny echo pulses between ***F*** and ***B*** are resulted from ultrasonic reflections in the specimen body. Figure 5(b)-(d) are the echo signal patterns from different positions in the impact damaged zone. The damage may be caused nearby the surface of the specimen, for example, the echo pulse ***I*** in figure 5(b) is from ultrasonic reflection at the damage nearby surface of specimen. The distribution of damage has a topology in specimen depth because the echo pulse ***I*** and $\boldsymbol{I_1}$ ($\boldsymbol{I_2}$) in figure 5(b, c, d) from ultrasonic reflections at different positions of damaged zone have remarkable distinctness in time of flight (TOF). The echo pulses in figure 5(b, c, d) show a very interesting damage characteristics. For examples, no repeat reflection of ***I*** and echo pulse ***B*** are seen in figure 5(a). That means a serious porosity may be caused at this position. But in figure 5(c, d) the repeat reflection I_2 of I_1 is clearly. That means a delamination may be caused at these positions of the impact damaged zone. Some reflections resulted from the structural details in the RTM specimen body may be found in figure 5(a, b, c, d) although they are very weak.

The ultrasonic reflections in figure 5(a, b, c, d) provide very effective mechanism for C-scan imaging of impact damage. So, the damaged zone is visualized very well in figure 5(e), as the white area showed by the white arrowhead. The grey scales correspond to ultrasonic reflections in the damaged zone. In generally, one may get information about the degree of damage according to the C-scan image.

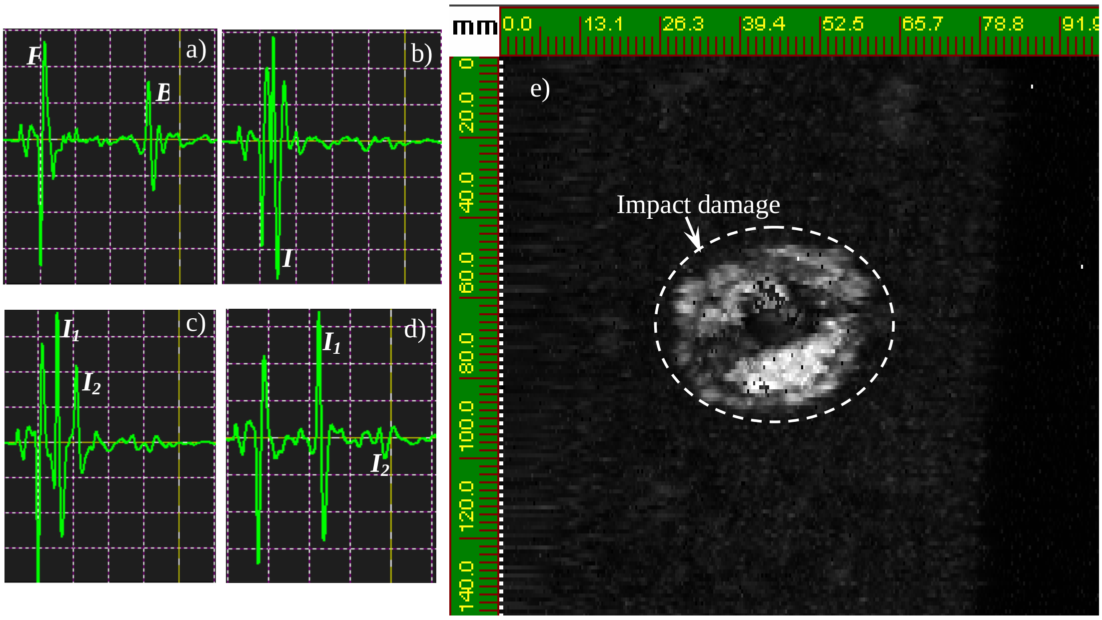


Figure 5. Echo signals and C-scan imaging of RTM stitched composites specimen No.#2. a) Echo signals from good zone, b) – d) Echo signals from impact damage zone, c) C-scan

A B-scan image of specimen No.#3 is presented in figure 6. Thickness of the RTM stitched composite laminate specimen is 6 mm. Figure 6 is one of a serials of the B-scans. The scanning line corresponding to the B-scan is passed through the central impact damaged zone. The surface and bottom of the specimen are seen clearly, as the white lines ***F*** and ***B*** marked by the arrowheads in figure 6. The topology of impact damages is visualized detailedly in figure 6. (1) The damages in specimen impact zone are seen clearly, as the light spots showed by A_1, A_2, A_3, A_4, A_5 and A_6. These damages locate in different depth of the specimen. The damaged characteristics is also supported by the echo pulse patterns in figure 5(b, c, d). (2) The B-scan image show particularity of the impact damages in RTM composites: They have a significant extending in RTM stitched composite laminate body, as the damages showed by A_1, A_2, A_3, A_4, A_5 and A_6 in figure 6. (3) The impact point on the specimen surface is also seen well, as the white concave showed by A_0. (4) The dark area showed by ***S*** in figure 6 is the ultrasonic shadow of the impact damaged zone. This is why there is dark spot in the damaged zone in figure 5(e).

The contrast distributions corresponding to the RTM stitched composite structural details can also be seen between ***F*** and ***B*** although they are very weak. This is agreed with the echo pulses in figure 5.

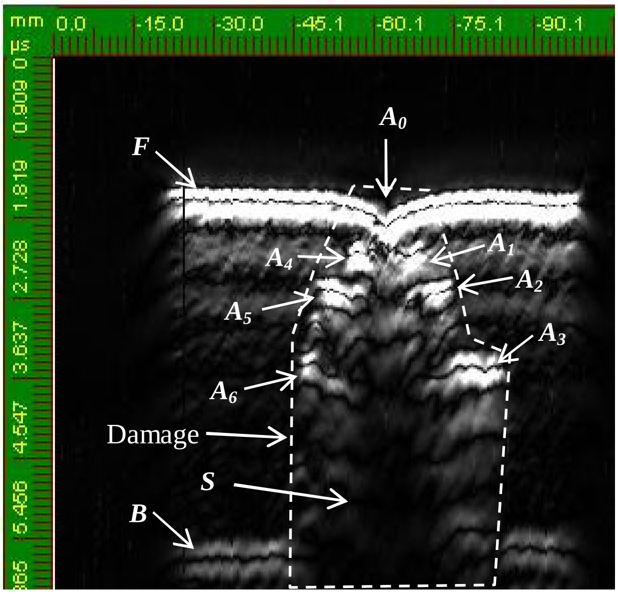


Figure 6. B-scan imaging of RTM stitched composites specimen No.#3

4. Conclusion

(1) The ultrasonic reflections in RTM stitched composite laminate body offer an effective mechanism to evaluate nondestructively the impact damages in it by using high resolution ultrasonic scanning system with soft-electronic gate technique.

(2) Ultrasonic multiple-imaging technique offers a powerful approach to see impact damages in details: (a) the qualitative information can be gotten by using echo pulse patterns resulting from damaged zone of RTM stitched composites; (b) ultrasonic C-scan imaging method gives the quantitative distribution of impact damaged area in RTM stitched composite laminate; (c) ultrasonic B-scanning imaging technique provides possibility of seeing topology of damages in the impact zone, and the extending of damaged zone along depth of RTM stitched laminate can be seen well in B-scan image.

References

[1] F. Aymerich, S.Meili, Ultrasonic evaluation of matrix damage in impacted composite laminates, Part B: engineering, Part B 31(2000): 1-6.

[2] B.T. Smith, J.S. Heyman, et al, Correlation of the deply technique with ultrasonic imaging of impact damage in graphite-epoxy composites, Materials Evaluation, 1989, 47(12): 1408-16.

[3] M.V. Hosur, C.R.L. Murthy, T.S. Ramamurthy, A. Shet, Estimation impact-induced damage in CFRP laminates through ultrasonic imaging, NDT&E International 1998,31(5): 359-74.

[4] Liu Songping, Application of Acoustic Microscopy for Studying Elastic Properties And Microstructure of Carbon Fiber-Reinforced Composite Materials, Ph. D. in Physics and Mathematics dissertation in acoustics, M. V. Lomonosov Moscow State University, 2004.