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Characterizing Barely Visible Impact Damage in Carbon Fiber Reinforced Plastic Using a Raster-Rotational Transmit-Receive Eddy Current Probe

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ABSTRACT
This research presents characterization of barely visible impact damage (BVID) in carbon fiber reinforced plastic using a raster-rotational transmit-receive eddy current probe. The probe is used in a raster-rotational pattern to image the defect over an area at different rotational angles to account the anisotropic nature of carbon fiber. Visual, thresholding, and statistical analysis techniques are employed to classify a BVID area. Various postprocessing methods are applied to compensate for the noise and gradient during the scanning process.

Keywords: eddy current testing (ECT), barely visible impact damage (BVID), materials characterization, carbon fiber reinforced plastics (CFRPs), nondestructive testing (NDT), polymer composites

BACKGROUND
Eddy current testing (ECT) is a well-established nondestructive testing (NDT) method for conductive non-ferromagnetic and ferromagnetic materials. It can be used to find smalls cracks, determine coating thickness, determine between pure materials and alloy composite, and hardness of a piece, etc [1]. However, ECT for composite materials, specifically carbon fiber reinforced plastics (CFRPs), are not as established due to the complexity in fiber layup and its anisotropic conductive nature. ECT, however, possesses distinctive advantages over computed tomography (CT) and ultrasonic testing (UT). Advantages include: 1) almost instantaneous data collection which allows for high-speed testing [2], 2) no liquid medium required for sound waves to propagate, 3) it does not produce radiation, and 4) compact test setup.
ECT operates on Faraday's law, Equation 1, which states time-varying magnetic flux induces a current in a conducting material.

$$\boldsymbol{emf = -\frac{d\Phi_B}{dt}} \qquad \textbf{(Eq. 1)}$$

where
emf = electromotive force
Φ_B = magnetic flux

In a Transmit-Receive (TR) eddy current probe, Figure 1, the alternating current is put through the transmit probe which generates a magnetic field that concentrates at the center of this coil and progressively weakens further away. When the probe comes into proximity of an electrically conductive material, the primary magnetic field penetrates the material and generates circular eddy currents. This induced current then generates a secondary magnetic field opposing the primary magnetic field. The secondary magnetic field will induce a current in the receive probe, which is captured to determine the impedance of the test piece [1].

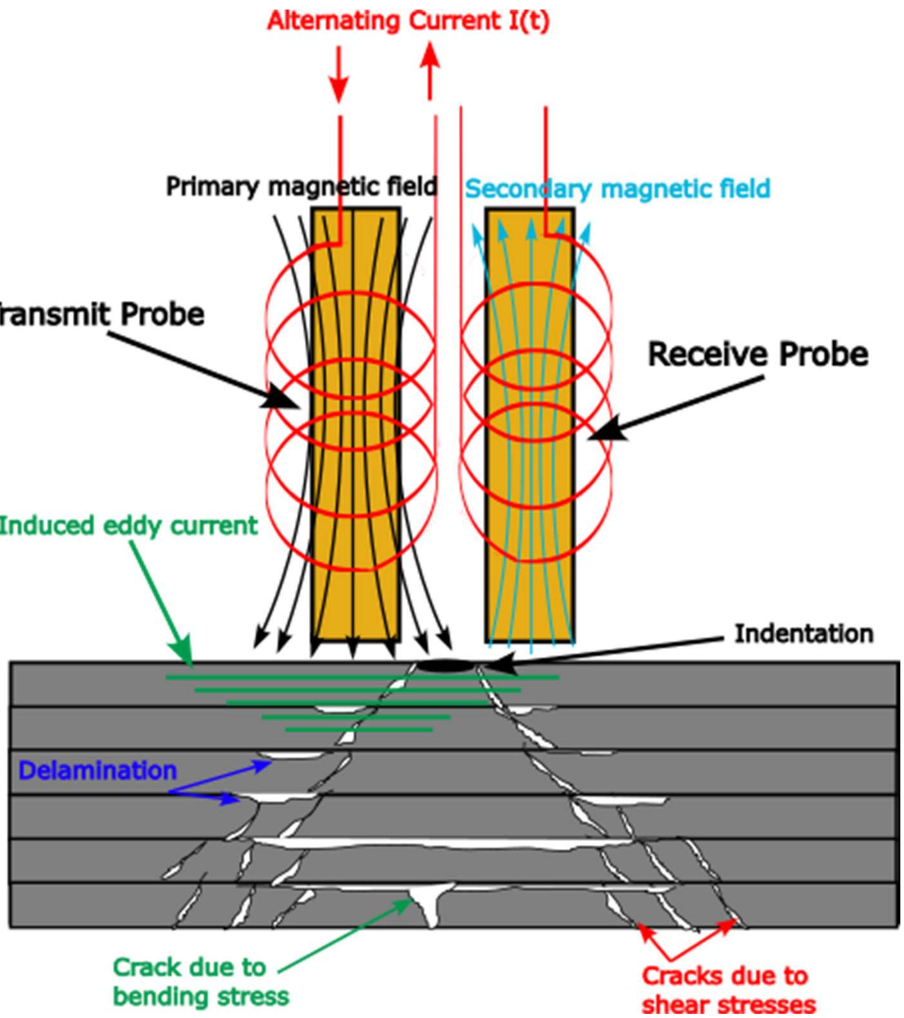

Figure 1. Principle of Transmit-Receive Eddy Current Probe [1][3][4].

EXPERIMENT

Due to its anisotropic nature, a raster rotational ECT scan was chosen to image the barely visible impact damage (BVID) area while also accounting for changes in conductivity at different layers due to layup orientation. Ten BVID parts were scanned using the TR eddy current machine [5] in a raster pattern of a 40mm-by-40mm area and rotated every 45 degrees. This was repeated 4 times. This is done on the BVID area and non-BVID area. Upon collecting scan data from the eddy current testing machine, the data is downscaled into a resolution of 0.5mm to reduce computation time, while still ensuring scan accuracy during post processing. For post processing, a Fast Fourier Transform filter is first applied to remove a repeating horizonal pattern left by the scanner, then a two dimensional detrend algorithm is used to remove any potential gradients from an uneven scan surface. Finally, a MATLAB adaptive filter is used to remove artifacts caused by surrounding noise.

Three tests are used to determine if a part has internal damage: a distribution test, threshold test, and visual inspection test. The distribution test is chosen to look for anomalies in the range of measured reactance, since the internal damage could lead to increased or reduced material conductivity, which can affect the secondary magnetic field. The threshold test with the Generalized Extreme Studentized Deviate (GESD) outlier method [6] is used since it assumes a normal distribution, which most of the non-damaged scans are, so any deviation detected could indicate damaged area. The visual test was used because the eddy current scans from certain angles yield similar outputs to UT scans of the same part [7].

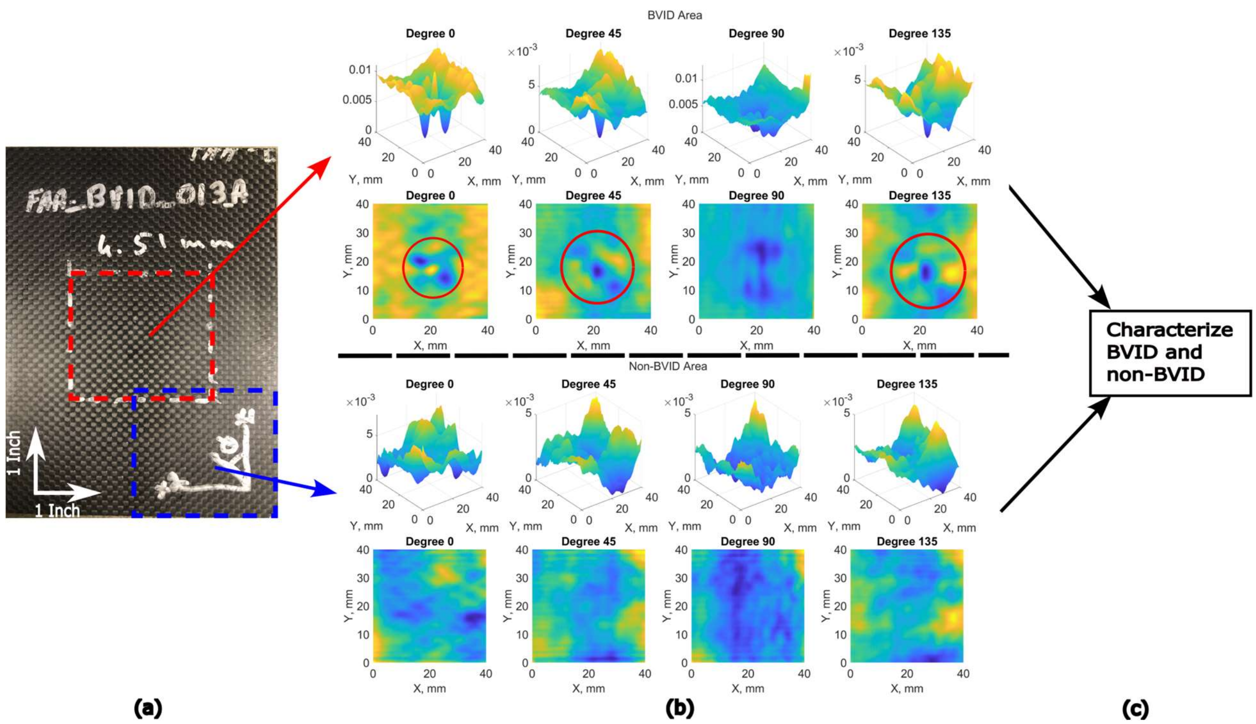

Figure 2. (a) A 40mmx40mm area of BVID region (red) and non-BVID region (blue) were scanned for comparison. (b) Postprocessing is done to remove artifacts and gradients for better representation of each scan; red circles represent the area considered to be damaged when using visual test. (c) Determine using visual, thresholding, and statistical analysis to determine if a part has barely visual impact damage.

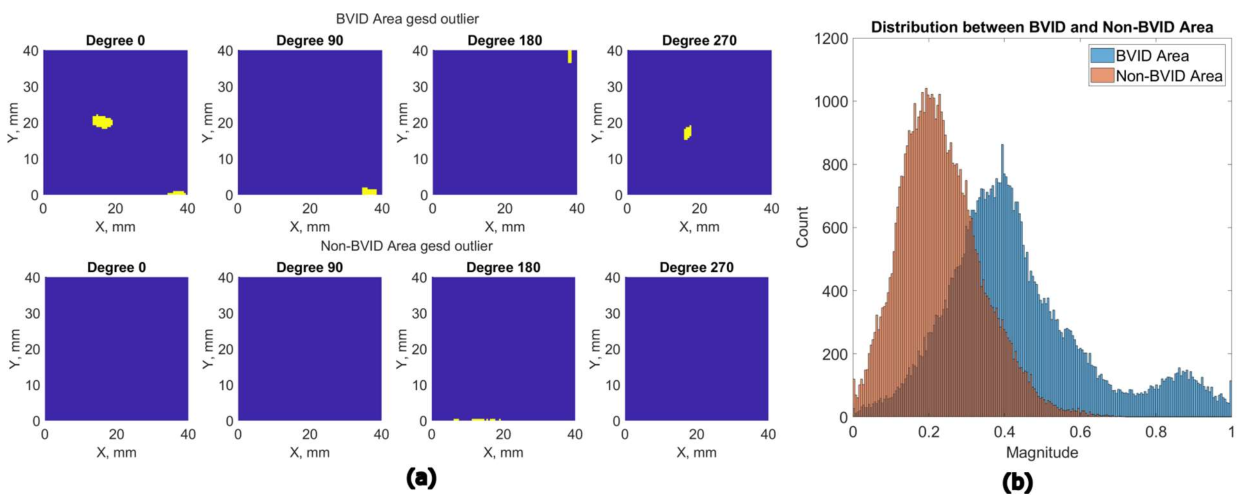

Figure 3. (a) GESD outlier test for BVID and non-BVID areas of the FAA_BVID_013A part in Figure 2. (b) Distribution comparison of BVID and non-BVID area for part FAA_BVID_013A.

INITIAL RESULTS AND CONCLUSION

Figures 2 and 3 show the three tests applied to an example part. Figure 4 shows a summary of results over a sample of ten BVID parts. For this data, the BVID areas always score higher in the visual test, and also higher in the threshold test most of the time, with one exception. In all but one case, the distribution of the BVID areas also have a larger range or variance when compared to the non-BVID area of the test piece. From Figure 1, BVID spreads out like a cone from the initial impact area causing three different types of defects in a composite material: delamination at different layers, cracks due to shear stresses leading from the impact, and cracks due to bending stress at the bottom layer of a composite if an impact is strong enough [4]. Due to the lateral path of the induced eddy current, delamination would not have contributed to the change in impedance measured by the TR probe. The change in impedance is suspected to be produced by shear cracks, because it tends to occur at 45° to the impacted surface, which can lead to interference with the induced eddy current path [4].

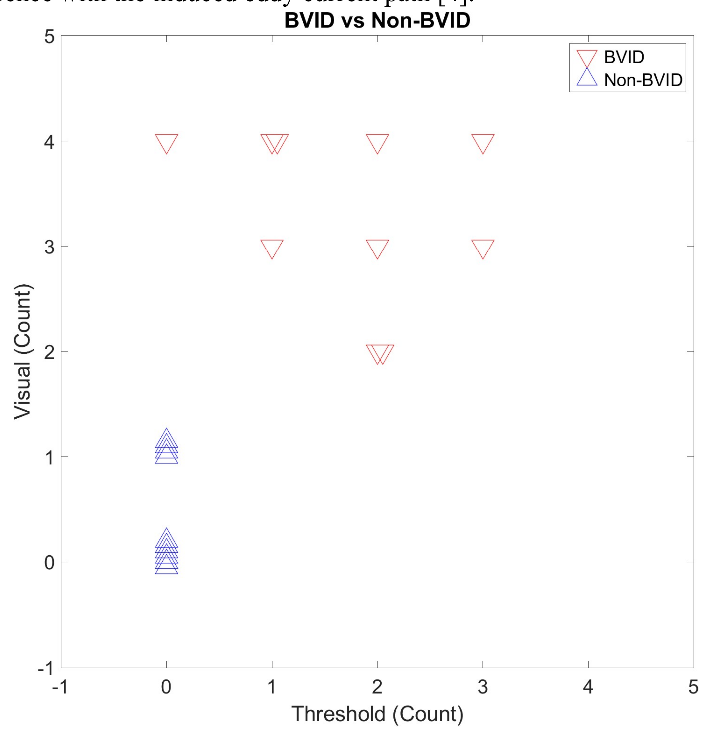

Figure 4. The results from performing visual and threshold tests on ten test pieces.

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REFERENCES

(1) J. García-Martín, J. Gómez-Gil, and E. Vázquez-Sánchez, "Non-Destructive Techniques Based on Eddy Current Testing," *Sensors*, vol. 11, no. 3, Art. no. 3, Mar. 2011
(2) Placko, D.; Dufour, I. Eddy current sensors for nondestructive inspection of graphite composite materials. In Proceedings of the IEEE Conference of the Industry Applications Society (IAS'92), Houston, TX, USA, October 1992; pp. 1676-1682.
(3) Z. Li and Z. Meng, "A Review of the Radio Frequency Non-destructive Testing for Carbon-fibre Composites," Measurement Science Review, vol. 16, no. 2, pp. 68–76, Apr. 2016.
(4) A. Wronkowicz-Katunin, A. Katunin, and K. Dragan, "Reconstruction of Barely Visible Impact Damage in Composite Structures Based on Non-Destructive Evaluation Results," Sensors, vol. 19, no. 21, Art. no. 21, Jan. 2019.
(5) M. Newton, T. Chowdhury, I. Gravagne, D. Jack, "Non-Destructive Evaluation of In-Plane Waviness in Carbon Fiber Laminates Using Eddy Current Testing," MDIP Appl. Sci. 2023 vol. 13, no. 10, May 2023
(6) "Find outliers in data - MATLAB isoutlier." Accessed: Feb. 28, 2024. [Online]. Available: https://www.mathworks.com/help/matlab/ref/isoutlier.html
(7) W. Yin, P. J. Withers, U. Sharma, and A. J. Peyton, "Noncontact Characterization of Carbon-Fiber-Reinforced Plastics Using Multifrequency Eddy Current Sensors," IEEE Transactions on Instrumentation and Measurement, vol. 58, no. 3, pp. 738–743, Mar. 2009.