DEVELOPMENT OF NONDESTRUCTIVE INSPECTION METHODS FOR COMPOSITE REPAIR

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ABSTRACT. This paper describes the development and implementation of two complementary nondestructive inspection methods for repairs made on aircraft composite honeycomb structures: computer aided tap testing (CATT) and air-coupled ultrasonic testing (AC-UT). The CATT, being a semi-automated and quantitative technique, is exploited to map out the interior conditions of a repaired part. The same repair is also imaged with air-coupled ultrasound and both compared with the results from destructive sectioning.

INTRODUCTION

This paper describes an effort aimed at developing nondestructive inspection methods for evaluating the condition and quality of repairs made on composites, especially honeycomb sandwich structures used on aircraft. The current goal is to establish the relationship between the internal features and conditions (the "anatomy") of a composite repair and the features in the images of the repair formed by nondestructive methods. The techniques chosen for inspecting composite repairs are the Computer Aided Tap Test (CATT) and air-coupled ultrasonic testing (AC-UT). The former is an old, time-proven method recently made quantitative and image-capable with the help of electronics and laptop computer [1,2]. The latter is a new, maturing technique that has distinct advantages and a potential for becoming a practical tool for inspecting composite repairs [3,4]. Using the two methods, several repairs on composite aircraft parts were imaged and evaluated. To verify the aforementioned relationship, one of the repaired panel was sectioned to reveal the internal construction and defects. Both the CATT image and the AC-UT image correlated well with the core splice, scarfed ply region and delamination in the repair.

The composite repair panel used in the nondestructive imaging and subsequent destructive sectioning was a 14"x14" honeycomb sandwich with woven carbon epoxy facesheets and 5/8" thick Nomex core. Figure 1 shows a photo of the test panel, after one saw cut was made to expose the interior for correlation with the nondestructive imaging results. The thickness of the top and bottom facesheets were measured to be 0.040" and 0.030", respectively. The cell size of the honeycomb core was 3/16". The repair consisted of a 4-inch diameter core replacement at the center, and a scarfed repair on the top facesheet that was concentric with the core replacement and extended out to a diameter of about 9 inches. The lower facesheet in this "one-sided" repair was reinforced with 0.040" of extra plies between the replaced core and the lower facesheet. An oval-shaped "plug" was bonded on the exterior side of the lower facesheet at the center of the repair. This test panel was fabricated by a major airline for composite repair training and NDT exercise purposes; it was apparently built to contain a delamination defect.
COMPUTER AIDED TAP TEST (CATT) FOR COMPOSITE REPAIR

The CATT is an instrumented tap test system developed for the quantitative evaluation and imaging of composite structures [1,2]. The system consists of three components: the magnetic cart for mechanized tapping, the electronic circuitry for acquiring and processing the accelerometer signal, and the software for displaying, analyzing, and storing the test results in a laptop PC. The mass that taps on the surface of a part is an accelerometer fitted with a hemispherical steel tip. Using the repulsive force between strong permanent magnets embedded in a wheel and a magnet in the accelerometer frame, the magnetic cart drives the accelerometer up and down as the cart is moved across the surface by hand [5]. The voltage output of the accelerometer is conditioned by the electronic circuit in the accelerometer-computer interface, where the "contact time" is measured and converted into digital data. The contact time is the duration when the accelerometer tip is in contact with the surface. For most composite parts found on aircraft, the contact time typically ranges from 200 to 1000 microseconds for an accelerometer mass of the order of 20 grams. Damages and defects lower the local stiffness of the part and hence lengthen the contact time. The scan data, in the form of contact time versus position, are displayed on the computer screen while scanning. Damaged regions appear as areas of anomalously high contact time as compared to the surrounding. Based on a simple spring model, the local stiffness can be deduced from the contact time and the accelerometer mass. It had been demonstrated previously that the stiffness deduced from tap test agreed well with the stiffness measured directly in static load tests for a variety of composites [6].
The CATT scan image of the composite test panel, shown in Fig. 2, revealed that the 4" diameter central region over the replaced core is less stiff than the original structure (i.e., it gave a longer contact time in tap test). A narrow circle of shorter contact time (higher stiffness) was seen at the boundary of the replaced core. A circular band, approximately 6" in average diameter, of much longer contact time (i.e., much lower stiffness) appeared just outside the narrow circle of high stiffness. These features were later correlated to features on the air-coupled UT scan image, and then both sets of features were correlated to the internal conditions of the repair after the destructive sectioning. It should be noted that the dark square boundary was due to edge effect and should be ignored.

AIR-COUPLED ULTRASONIC TESTING (AC-UT) FOR COMPOSITE REPAIR

Ultrasonic inspection has been one of the primary modes of NDI in aircraft maintenance. For composite honeycomb structures, especially the repaired regions on such components, the high attenuation often hinders the application of megahertz range ultrasound. On a practical level, water-coupled ultrasonic scanning is cumbersome in an airline maintenance hangar, even with closed cycle systems. For these reasons, air-coupled ultrasound is particularly attractive because it can operate without any liquid couplant. The frequency range is typically between 50 kHz and 500 kHz, although some systems extend the frequency into the low megahertz range.

Because of the extremely large impedance mismatch between air and composite, ultrasonic transducers for air-coupled operation are specially designed and manufactured. Several different manufacturing technologies have been advanced in the last decade or so [3]. In this work, a commercial air-coupled UT system with piezoceramic transducers at 50, 120, and 400 kHz is used [7]. For each frequency, one transducer is used as a transmitter and a second transducer, with a built-in low noise pre-amplifier, serves as the
receiver. The system is adapted to an existing motorized ultrasonic scanner [8] to image composite parts in the laboratory.

COMPARISON OF NDT RESULTS AND DESTRUCTIVE SECTIONING

After scanning with the computer aided tap tester and the air-coupled ultrasonic system, the repair panel slated for destructive sectioning and correlation with NDT results was sectioned with a diamond saw, polished and examined under optical microscope. Figure 4 shows the saw cut surface and the "anatomy" of the repair. The 4" diameter replacement core, together with extra plies and a cloth layer underneath, were held to the rest of the honeycomb by the core splice, in the form of a circular ring of potting. The top skin over the re-cored region was rebuilt in a scarfed fashion and extends outward to a diameter of about 9 inches. The most significant finding was the discovery of a physical delamination just outside the circle of core splice. On the cut surface the delamination appeared to be about 1" wide and the separation was between the honeycomb core, with the adhesive fillet and the lowest ply of the facesheet attached to it, and the rest of the facesheet. Furthermore, the delamination on the left seemed to be more severe than the one on the right (see Figure 4.) More microscopic examinations are still underway, but the lower surface of the replacement core did not appear to be well bonded to the lower facesheet of the panel.

Once the repaired panel was sectioned, the CATT image and the air-coupled UT image acquired before were enlarged to true size and physically matched to the sectioned surface. These direct comparisons are shown in Figure 5 for the CATT scan and in Figure 6 for the air-coupled transmission C-scan. In Figure 5 it can be seen that the delamination matched very well with the circular band of long contact time (low stiffness) on the CATT image, and that the core splice corresponded well with the narrow circle of short contact time (high stiffness.) The degree of stiffness reduction on the left and on the right was also consistent with the severity of the two exposed delaminations. Finally, the lower stiffness of the re-cored region could be due to the presence of the cloth layer under the replacement core.
A comparison of the sectioned panel with the air-coupled UT image (see Figure 6) showed that the core splice corresponded well with the position of the discontinuous circle of high transmission (through the potting), and that the delamination matched well with the broad circular band of lowest transmission. The transmitted amplitude through the replacement core was considerably less than that through the unrepaired region, possibly due to the attenuation of the cloth layer under the new core. The gradual increase of the transmitted amplitude in the outward direction matched well with the extent of the scarfed repair of the top facesheet. In contrast, this gradual change outside the re-cored region was not seen by the CATT scan. Overall, the features in both the CATT scan image and the air-coupled transmission scan image corresponded quite well with the internal conditions of the repair.
FIGURE 6. Comparison between air-coupled UT image and interior of repair.

CONCLUSIONS

It was demonstrated that both the computer aided tap test and the air-coupled ultrasonic scan were able to image the internal features and conditions of a composite repair, including the re-cored area, the core splice potting, the scarfed skin repair and the delamination in the repaired skin. The interpretation of the features in the tap test image was based on the variation of the contact time (or local stiffness), whereas the features in the air-coupled transmission ultrasonic image were interpreted based on the amplitude of the transmission. Both the CATT image and the AC-UT imaged were found to agree well with the internal features of the repair after sectioning. Because of the wide variety of composite structures and the repairs made on them, an on-going effort is to develop appropriate test parameters for both CATT and AC-UT. In terms of the system hardware, the CATT is fieldable and continues to be applied in the inspection and imaging of various composite repairs. The air-coupled through transmission scans have so far been made with a laboratory scanning system, but efforts are underway to make the AC-UT system fieldable.

ACKNOWLEDGMENT

This work is supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order No. IA047. The technical monitor is Cu Nguyen.

REFERENCES


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8. Ultrasonic scanning system provided by SONIX, Inc., Springfield, VA.