STUDY OF COMMONLY ENCOUNTERED DEFECTS IN FRP COMPOSITES THROUGH AIR-COUPLED ULTRASONIC C-SCANNING WITH DIFFERENT FREQUENCIES AND WAVEFORMS

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ABSTRACT

Air-coupled ultrasonic C-scanning is one of the fast emerging techniques in the field of non-destructive evaluation, recent advances in transducer and related instrumentation technology being the major driving forces for the same. The air-as-couplant approach is especially useful for highly damping / lossy materials like foams and certain polymer composites wherein the conventional C-scan methods are either not recommended or not convenient for use. Compared to the conventional ultrasonic scanning methods, the major advantage of air-scanning lies in the elimination of external couplant media (liquids, gels, pastes etc.) from the measurement process.

In view of the fact that very few literature and database exist on air-coupled ultrasonic testing (ACUT) of fiber reinforced polymeric (FRP) composites attempts have been made to generate a preliminary database of the transmission and frequency responses of three commonly encountered defects viz. delamination, debonding and resin rich areas in such FRP composites using through transmission mode ACUT techniques. Glass FRP test panels were fabricated by intentionally incorporating the above defects of different dimensions within them and studies were conducted for sensitivity determination of this newly emerging non-destructive evaluation (NDE) technique. Ultrasound of three different frequencies viz. 120 kHz, 225 kHz and 400 kHz were used for the above study using compression wave forms. The same exercises were also repeated for guided and shear wave modes to study the responsiveness of these defects to the different ultrasonic wave modes.

It was found out that compression waves could identify delamination and resin rich regions at 120 kHz, 225 kHz, 400 kHz frequencies. Debonding could be identified only at 120 kHz frequency by using shear waves, whereas when guided waves were used only defects in the direction of propagation of the plate wave could be identified. The guided waves also could identify many of the inherent inhomogenities present in the laminates.

The database thus generated can be used to interpret ACUT results of similar composite structures in terms of the possible presence of internal defects, their nature and size.

Keywords: Air-Coupled Ultrasonic Testing, Defect Database, FRP Composites

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1. INTRODUCTION

Ultrasonic testing (UT) is one of the most effective methods of nondestructive inspection of materials and structures. Contact mode UT methods typically use liquids (mostly water or oil), pastes or gels as couplants and are widely used for scanning various aerospace structures, mostly by automated squirter systems. In the recent past however, air coupled ultrasonic C-scanning is also fast emerging as a viable alternative in the field of non-destructive evaluation (NDE). The latest advances in transducer and related instrumentation technologies to minimize the signal losses at the solid-air interfaces have been the major driving forces for the same. The air-as-couplant approach is especially useful for highly damping / lossy materials like foams and certain polymer composites wherein the conventional C-scan methods become difficult to apply. The lower frequencies employed in this new method ensures improved transmission characteristics of the ultrasound through materials, which is especially beneficial for foams and composites. Compared to the conventional ultrasonic scanning methods, the major advantage of air-scanning lies in the elimination of external couplant media from the measurement process. The use of such coupling media not only reduces the defect detectability in certain materials due to surface ingestion (especially for porous structures like foams), but also may prove to be detrimental to the properties of some materials which are sensitive / reactive to liquids /
other couplants. The Air-coupled Ultrasonic Testing (AC-UT) is also more versatile in terms of scanning structures with complex geometries. As a result, the Non-Contact Ultrasound (NCU) mode is becoming increasingly desirable for NDE of plastics, rubbers, foams and similar materials [1-4].

The major challenge for using AC-UT had always been minimizing the acoustic impedance mismatch between most solid materials and air. The deciding factor for successful application of AC-UT for NDE of materials and structures is the penetrating power of the ultrasonic waves through the material in question. The difference in orders of magnitude between the acoustic impedance of air (420 Rayl) and that of typical structural materials (51 MRayl for steel and 4.8 MRayl for CFRP) is the fundamental cause for the highly inefficient transmission of air-coupled ultrasound [5-7].

There are three modes of ultrasonic waves which are used in air coupled ultrasonic testing. These are

1. Through Transmission Compression wave: In a compression wave the oscillations of the particles occur in the longitudinal direction, i.e. the direction of propagation

2. Through Transmission Shear wave: In a transverse/shear wave the particles do not oscillate in the direction of propagation but at right angles to it. The excitations can be visualized as a motion in which the particles on the left interface of the body are moved sinusoidally up and down by a periodical shear force.

3. Through Transmission Guided wave: In a guided plate wave the oscillatory motion of the particles is elliptic and their wavelength is considerably smaller than the thickness of the plate. Hence these waves are called as guided plate waves. Figures 1-3 show three through transmission modes of waves.

The present paper attempted to generate a limited database of the transmission and frequency responses of three commonly encountered defects viz. delamination, debonding and resin rich areas in Fiber Reinforced Polymer (FRP) composites through Air Coupled Ultrasonic techniques. Three different waves viz. compressional, shear and guided waves were introduced in the material using the Air coupled transducers and the transmission and transmission and frequency responses of the defects were noted.

2. EXPERIMENTAL

2.1 Material Details

Three GFRP laminates of sizes 200 X 200 mm and thickness 5.5 mm were prepared. These are given below:

Laminate 1: Varying widths of Teflon placed in the center of the four different locations

Laminate 2: Rectangular pockets of varying width are cut out from 4 layers at the center

Laminate 3: Varying widths of aluminum strips placed in the center at four different locations

The diagrammatic representation of the defects is shown in figure 4.
2.2 Air-Coupled C-Scan

2.2.1 Instrumentation

M/s QMI Inc., USA make air-coupled ultrasonic test equipment was used in the present study. Planar / focused narrow-band piezoelectric air-coupled ultrasonic transducer probes with center frequencies of 120, 225 and 400 kHz were used for the measurements. These transducers were driven by their matching electronics provided by the SONDA 007CX pulser and receiver system. The AC-UT system used a toneburst-excitation on the transmitting transducer and had a built-in low noise preamplifier in the receiver transducer. Due to the high power of the tonebursts, the super low-noise and high gain amplifiers, this system was very well suited to traditional ultrasonic methods (as with water squirtsers and roller probes) to test the parts that have exceptionally high losses. Scanning was accomplished in through transmission mode with separate transmitting and receiving transducers on opposite sides of the sample.

2.2.2 Measurement Parameters

2.2.2.1 Parameters for laminate with Teflon inserts

1. Gain and Attenuation settings (in dB) for the laminate at frequencies 120, 225 and 400 kHz using compressional waves are (68&40), (60&40) and (58&20) respectively

2. Gain and Attenuation settings (in dB) for the laminate at frequencies 120, 225 and 400 kHz using shear waves are (59&40), (61&40) and (56&20) respectively

3. Gain and Attenuation settings (in dB) for the laminate at frequencies 120, 225 and 400 kHz using guided waves are (51&40), (62&40) and (55&20) respectively

2.2.2.2 Parameters for laminate with resin rich regions

1. Gain and Attenuation settings for the laminate at frequencies 120, 225 and 400 kHz using compressional waves are (68&40), (63&40) and (59&20) respectively

2. Gain and Attenuation settings for the laminate at frequencies 120, 225 and 400 kHz using shear waves are (58&40), (65&40) and (75&20) respectively

3. Gain and Attenuation settings for the laminate at frequencies 120, 225 and 400 kHz using guided waves are (56&40), (60&40) and (55&20) respectively

2.2.2.3 Parameters for laminate with aluminium inserts

1. Gain and Attenuation settings for the laminate at frequencies 120, 225 and 400 kHz using compressional waves are (68&40), (60&40) and (56&20) respectively

2. Gain and Attenuation settings for the laminate at frequencies 120, 225 and 400 kHz using shear waves are (56&40), (60&40) and (57&20) respectively

3. Gain and Attenuation settings for the laminate at frequencies 120, 225 and 400 kHz using guided waves are (56&40), (57&40) and (75&40) respectively

3. RESULTS AND DISCUSSIONS

The laminates were fabricated and C-Scanning was employed to the same using three different wave modes. Based on the observations from the C-scan images, detail analyses were done and conclusions were drawn. The subsequent sections briefly describe the observations pertaining to these studies.

3.1 C scan by using compression waves

Table 1 illustrates the C scan images of the laminates using compression waves. In the C scans of the laminates using compessional waves it was observed that delamination regions of all four sizes were identified at three frequencies viz 120, 225 and 400 kHz. At 120 kHz higher transmission percentage was observed due to Poisson’s bright spot phenomenon as the Teflon tape used to induce delamination was still present inside the laminate. At 225 and 400 kHz lower transmission was observed due to the high acoustic impedance mismatch between GFRP and teflon.

The resin rich pockets of all four sizes were identified at 120 kHz frequency whereas 225 kHz frequency three of the resin rich pockets was identified. None of the resin rich pockets were identified with 400 kHz frequency probe. At 120 kHz resin rich pockets gave a higher transmission percentage whereas at 225 kHz a lower transmission percentage through the resin rich pockets was observed. This indicates the frequency dependence of resin rich regions i.e. at different frequencies their transmission characteristics differ.

The debonding caused due to the presence of aluminium inserts was not identified using compressional waves at all three frequencies.

3.2 C scan by using shear waves

Table 2 illustrates the C scan images of the laminates using shear waves. In the C scans of the laminates using shear waves it was noted that although delamination was observed at all three frequencies the transmission percentage through the delaminated areas of the laminate was shown to be a little higher than surrounding areas at 120 kHz and a little lower than surrounding areas at 225 and 400 kHz frequencies. The resin rich pockets were identified by the 120 kHz frequency probe with a slightly higher transmission percentage than the surrounding areas these pockets were not identified by the 225 and 400 kHz frequency probes. The debonding caused due to the aluminum inserts were identified by the 120 kHz frequency probe with slightly higher transmission percentage than the surrounding areas. Only two of the aluminum inserts were identified which were of thickness 10 and 15 mm. These inserts were not identified by the 225 and 400 kHz frequency probes.

3.3 C scan by using guided waves

Table 3 illustrates the C scan images of the laminates using guided waves. In the C scans of the laminates using guided waves it was observed that only the defects which were in the direction of propagation of wave i.e. defects placed parallel to the probe movement were identified. The thickness
Table 1: C scan images of laminates using compression waves at 120, 225 and 400 kHz

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<th>Laminate</th>
<th>Frequency (kHz)</th>
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<td><img src="image7" alt="Image" /></td>
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Table 2: C-scan images of laminates using shear waves at 120, 225 and 400 kHz

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<th>Laminate</th>
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Table 3: C-scan images of laminates using guided waves at 120, 225 and 400 kHz

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No Image could be captured
variations were identified using guided waves as well as the inherent inhomogeneities present in the laminates due to the fabrication process. The aluminum inserts were not identified by all three frequency probes. The resin rich regions and delamination regions were identified by the 120 and 225 kHz probes which were parallel to the movement of the plate wave.

4. CONCLUSION

The research culminated into the following accomplishment:

- Generation of a limited database of the transmission and frequency responses of three commonly encountered defects viz delamination, debond and resin rich areas in FRP composites through ACUT technique.
- When laminates with defects such as delamination, debonding and resin rich regions were scanned using ACUT it was found out that compressional waves could identify delamination and resin rich regions at 120, 225, 400 kHz frequencies.
- Debonding could be identified only at 120 kHz frequency by using shear waves whereas when guided waves were used only defects in the direction of propagation of the plate wave could be identified.
- The guided waves also could identify many of the inherent inhomogeneities present in the laminates.
- It was also seen that for some laminates the defects gave a higher transmission percentage and this was attributed to poisson’s bright spot phenomenon.

REFERENCES