ESTIMATION OF POROSITY AND MOISTURE CONTENT IN POLYMER COMPOSITES USING THERMO-ACOUSTIC WAVES

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Experimental investigations were carried out for non-destructive evaluation (NDE) of porosity and moisture content in polymer composite materials. In this study, porosity of varied levels were induced in the carbon fiber reinforced epoxy polymer (CFRP) composite laminates by varying the fabrication parameters such as applied vacuum, autoclave pressure and curing temperature. Further, the composite laminates with varied porosity levels were subjected to different humidity and temperature conditions to study the hygro-thermal effects. Degradation of the composite materials due to varied porosity contents and then further due to moisture absorption were investigated through series of experimental tests in the laboratory using ultrasonic imaging and acoustic wave velocity and attenuation measurements.

Acoustic wave propagation was stimulated by mechanical point source as well as by giving high power LASER shots using a Q-switched Nd-Yag pulse laser system. Waves thus generated from the center region of the laminates were picked up by highly sensitive PZT sensors placed at four corners. Changes in wave characteristics as they propagate across the laminates of different porosity and moisture content were studied. NDE parameters such as ultrasonic attenuation coefficients, changes in acoustic wave propagation characteristics etc., were studied with regard to different extents of porosity content and different degree of hygro-thermal degradation.

The different sets of experimental investigations have yielded encouraging results. Acoustic wave propagation studies using lead pencil breakage as well as non - contact LASER source show that the wave attenuation characteristics can be correlated to variation in the porosity and moisture content in the composite laminates.

Key words: Porosity, Moisture, Composites, Acoustic Waves

1. Introduction

As porosity cannot be completely eliminated in a polymer composite material, percentage porosity is specified above which the material is classified as defective and this critical porosity percentage is material and application specific. Voids and Porosity form in composite laminates primarily because of air bubbles and volatile substances liberated during curing. In addition, void formation is due to the chemical composition, method of mixing the binder and preparation of the pre-preg, mechanical treatment, configuration and thickness of the composite laminate, method of creating the molding pressure, moisture content, etc. In many cases, insufficient pressure during curing is the most important factor that affects formation of porosity in a composite laminate.

Many techniques have been investigated for estimation of porosity in fiber-reinforced composites [1-4]. The most commonly accepted method is the ultrasonic one for which the porosity percentage is linearly correlated to the attenuation of ultrasonic waves [1, 4, 5]. As a non-contact method, ultrasonic waves can be generated by using pulse [6-8] and continuous laser [9], and the corresponding responses can be measured by using laser interferometry [10, 11].

Porosity above a critical level affects static and fatigue strength of composite parts and a greater susceptibility to water absorption and environmental effects. Though different non-destructive evaluation techniques are used extensively in industries to detect major type of defects in composite parts viz. delamination, debond, air gaps etc., such a tool is still not available suitably for detection, quantification or evaluation of porosity in polymer composite materials.

Hence, it is essential and of prime importance that a novel tool be developed to detect and quantify the porosity content and moisture content in a polymer composite material as also to study the effects of these parameters on the properties of the composite structures in the form of degradation in terms of reduction in static and fatigue strength.

2. Experimental Details

Four laminates with varied porosity content were subjected to ultrasonic imaging as well as acoustic wave propagation studies. Acoustic wave propagation was stimulated by mechanical point source, breaking of standard pencil lead as well as by giving shots of high power LASER shots. Waves thus generated from the center region of the laminates were picked up by highly sensitive PZT sensors placed at four corners. Changes in wave characteristics as represented by signal amplitude and energy content as they propagate across the laminates of different porosity content were studied.

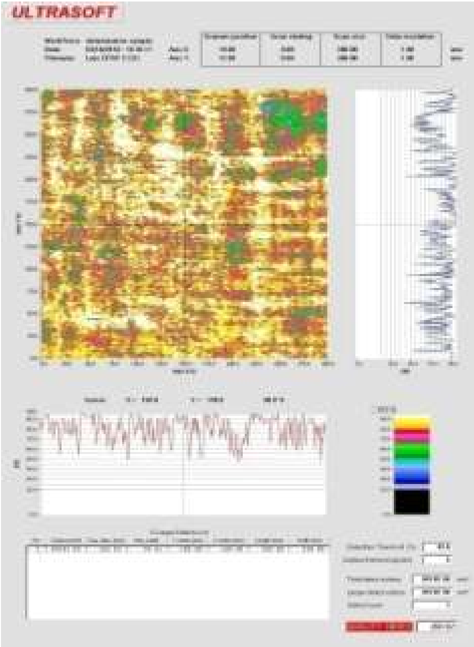
2.1 Ultrasonic Imaging

Ultrasonic C - scan images were obtained with identical test parameters for all the four CFRP laminates with different porosity content to make sure that there were no gross defects induced during the fabrication process. Figure 1, presents this particular set of images and it can be observed that a clear trend in terms of loss of intensity with increase in porosity is followed.

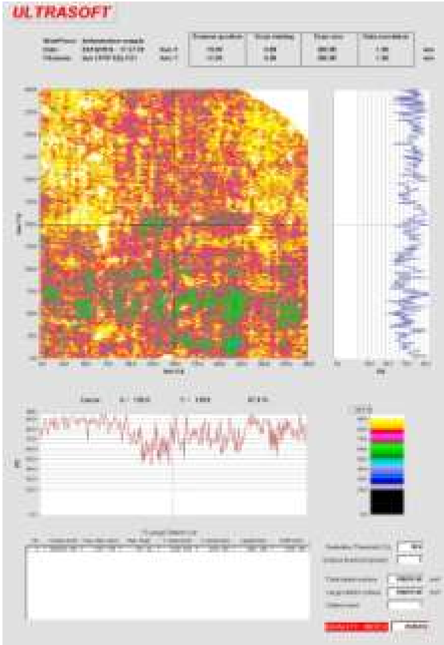
2.2 Acoustic Wave Propagation

Acoustic waves were made to propagate through these CFRP laminates. Four PZT - AE sensors were used at the corners of the plate to receive the acoustic waves generated by stimulating the source using a standard lead pencil breaks at the center region of the laminates. Again, optimized and constant set of test parameters in terms of inter-sensor distance, preamplifier gain, identical sensors with sensitivity, constant energy input to generate acoustic waves etc., were followed.

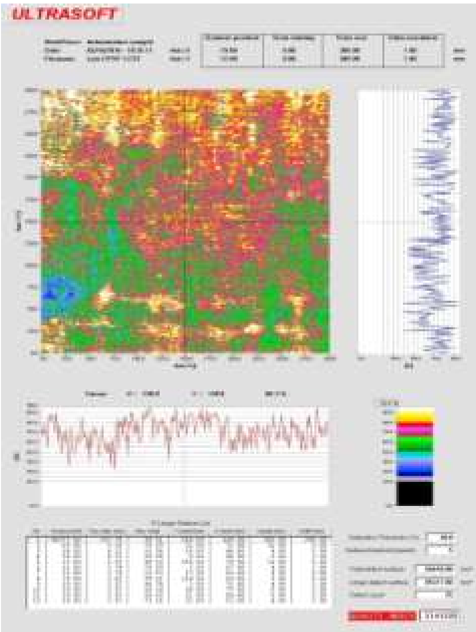
Received signals were analysed for the four laminates and the sample results are as presented in Figures 2.



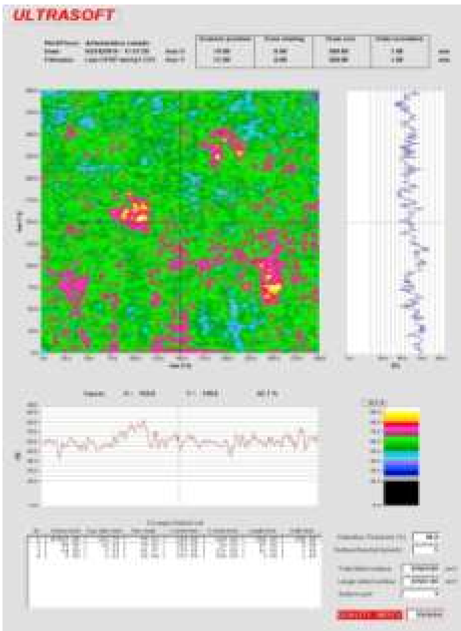
a) Average Intensity 88 dB



b) Average Intensity of 83 dB



c) Average Intensity of 78 dB



d) Average Intensity of 65 dB

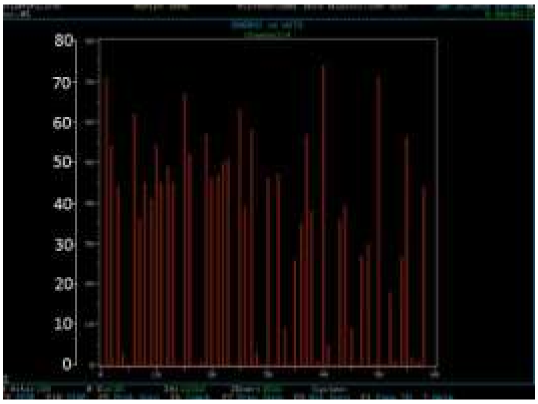
Figure 1. Ultrasonic C-scan images of CFRP laminates with different porosity content

[% Porosity of: - a) 1.8801 b) 2.6202 c) 7.7035 & d) 8.8307]

Porosity content in four CFRP laminates were determined by standard acid digestion tests. It can be observed that AE waves generated and propagated through the laminates follow a pattern in terms loss of intensity as represented by energy units shown in Figures 2.

2.3 Thermo-elastic wave generation using High Power LASER

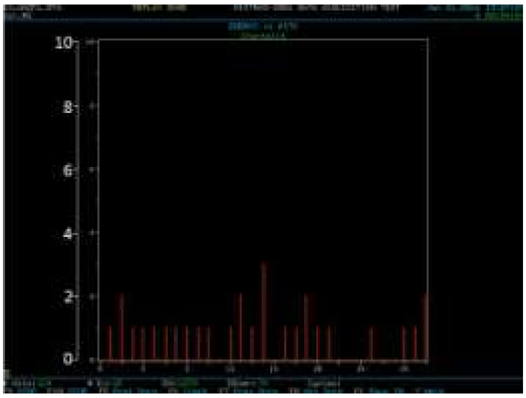
Experiments were carried out using non- contact, high power LASER for thermal - elastic wave's generation in the composite laminates (Figure 3) and the observations made from this experiments are as presented in Figures 4. Similar trend in terms of loss of intensity with porosity content was observed though the absolute value of Acoustic Signal amplitude and energy content from LASER source generated signals were measured to be much lower compared to mechanical sources using lead pencil breakage.



a) Average Energy of 45 units

b) Average Energy of 28 units

c) Average Energy of 21 units

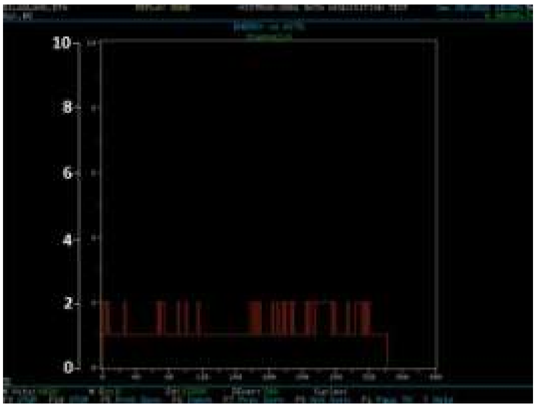


d) Average Energy of 05 units

Figure 2. Acoustic Signal Energy for CFRP Laminates with different porosity content

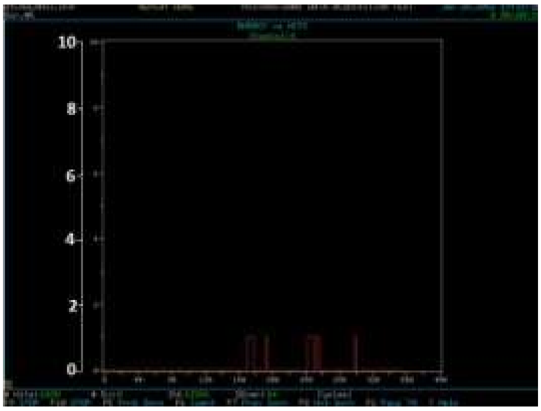
[% Porosity of: - a) 1.8801 b) 2.6202 c) 7.7035 & d) 8.8307]

Figure 3. Experimental set up for Acoustic Wave propagation using LASER source



a) Average Energy of 02 units

b) Average Energy of 01 units



c) Average Energy of 0.5 units

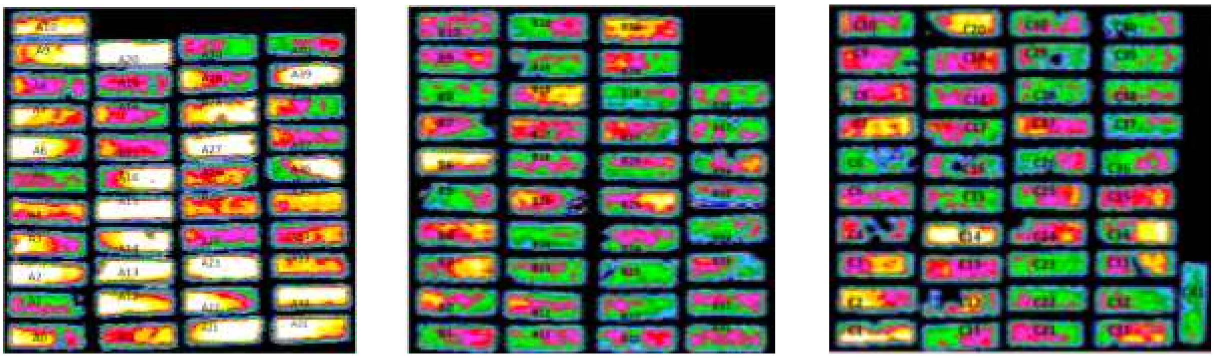
d) Average Energy of 0.1 units

Figure 4. Acoustic Signal Energy for CFRP Laminates with different porosity content - from LASER source experiments). [% Porosity of: - a) 1.8801 b) 2.6202 c) 7.7035 & d) 8.8307]

Thus, the different sets of experimental investigations have yielded encouraging results as presented in above sections. C-scan images clearly brings out the difference between laminates with varied porosity in the form of reduction in average intensity of color images obtained. Acoustic wave propagation studies using lead pencil breakage as well as non - contact LASER source show that the wave attenuation characteristics can be correlated to variation in the porosity content in the CFRP laminates.

Experimental investigations were continued on smaller standard Inter laminar shear strength (ILSS) coupons cut out from set of laminates after putting through varied degree of hygro thermal conditioning to study the effect of moisture absorption on NDE measurements and loss of mechanical properties.

Figure 5, shows these three sets of scanned images of CFRP, ILSS samples. A sub set of each group of samples were directly subjected to standard ASTM tests to determine their ILSS property. Another subset of the group of samples was put in the Hygro-thermal conditioning (HTC) chamber to undergo ageing under higher temperature and humidity conditions (75^{o} C & 75% humidity) and then were subjected to standard ILSS tests.



A B C

Figure 5. C-scan images of Specimens cut out from different zones of CFRP laminate with varied porosity

While the behavior of the samples followed a similar pattern in terms of load displacement variation, the actual ILSS values were different and reduction in the ILSS was observed for the samples subjected to hygro-thermal ageing.

Table 1 - Ultrasonic signal attenuation and ILSS for set of unaged and hygro-thermally aged CFRP samples

Unaged specimens			Aged Specimens					% drop in ILSS (Mpa)
specimen	db/mm	ILSS (Mpa)	specimen	db/mm			ILSS (Mpa)	
				Before HTC	After HTC	% increase		
A1	1.58	62.48	B1	1.56	1.81	13.60	56.54	9.5
A2	1.59	58.56	B2	1.58	1.79	11.91	51.14	12.7
A3	1.63	58.74	B3	1.68	1.84	9.00	46.93	20.1
A4	1.69	59.86	B4	1.68	1.68	0.02	54.24	9.4
A5	1.77	57.23	B5	1.71	1.59	-6.95	55.93	2.3
A6	1.82	53.49	B6	1.71	1.81	5.52	53.23	0.5

Table 1. presents the results of the experimental investigations carried out on CFRP samples with varied porosity.

While it can be observed that the ultrasonic attenuation increases with moisture absorption by the CFRP samples, the mechanical property degradation due to ageing is represented by the drop in the ILSS values as shown in Figure 6.

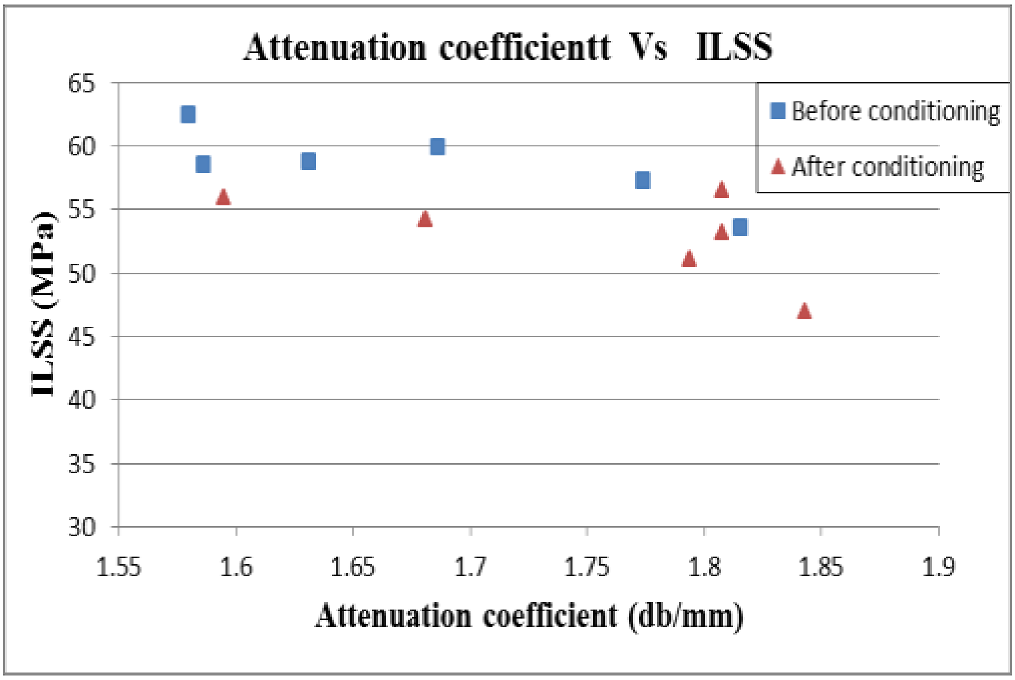


Figure 6. Plot showing the correlation between ultrasonic attenuation, ILSS with hygrothermal ageing

3. Summary of conclusions

Experimental investigations were carried out to study the effect of varied porosity and moisture absorption on CFRP composite materials using NDE approach. A novel thermo-elastic wave generation was induced in the laminates and the wave propagation characteristics were studied to correlate porosity content and moisture absorption to NDE parameter as well as mechanical property degradation. The outcome of these experimental are encouraging. Acoustic wave propagation characteristics show a definite correlation with porosity content as well as moisture content.

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