EXPERIMENTAL VALIDATION OF ULTRASONIC NONDESTRUCTIVE EVALUATION OF RESIDUAL SERVICE LIFE OF FIBREGLASS REINFORCED PLASTIC STRUCTURES

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ABSTRACT

Defects in Fiberglass Reinforced Plastic structures differ from the traditional structural materials, because internal damages in the FRP are not visible to inspectors until the catastrophic failure occurs. Therefore, it is critical to find not only the internal defects but also the residual service life of the composite structures in service without physically damaging the structures. Most of the existing non-destructive ultrasonic testing technologies are only able to detect the defects in the composite structures. They are unable to predict the residual service life of the defected or aging composite structures based on the ultrasonic testing results. This paper validated experimentally a unique and innovative ultrasonic nondestructive technology to inspect FRP structures and determine their residual service life without damaging the structures. The proposed technology determines physical properties of FRP using the nondestructive ultrasonic proprietary testing technology.

1. INTRODUCTION

Fiberglass Reinforced Plastic (FRP) structures have been used in commercial and industrial applications since the 1930's and has received increasing popularity due to its ability to provide weight savings as well as the ability to combine existing parts into simpler molded shapes. As a result of this increased demand, there has become a need to study this material in detail and determine characteristics of the material during operation to provide insight into its residual service life. The current standard is to conduct destructive tests such as the ASTM D790 and visual inspections on samples which are cut from the material itself. This is not the ideal scenario as this requires the equipment to be non-operational, many defects of the material are not visible to the naked eye, internal damages are often overlooked and it may not be valid to assume that this section accurately represents the entire structure. Over the recent years, non-destructive testing has provided an alternative which is able to overcome these limitations. More specifically, this paper explores a unique and innovative ultrasonic non-destructive technology has been able to not only detect defects within the structure but also provide an estimate of the modulus of the material itself. If the materials theoretical value is known, the residual life of the equipment can be estimated by a linear projection from the theoretical value through the current value to the end of life which is approximately 20% – 40% of the theoretical value.

1.1 Basic Concept of Ultrasonic Testing for Composite Materials

The application of ultrasound for material testing was first patented in 1940. The basic idea here is that a pressure pulse is applied to a material and defects/inhomogeneities are detected when the path of the pulse is obstructed. It must be noted that defects parallel to the path of the pulse generally cannot be detected. These defects appear as an attenuation of the transmitted signal and properties of the material are then inferred. In the case of composite materials such as FRP's, the layers that comprise the material often block the path of the pulse and are identified as defects and inhomogeneities themselves which pose a challenge when analyzing the data. For a more detailed discussion please refer to [1].

2. EXPERIMENTATION

The two experiments were conducted in parallel to determine the effectiveness of this technology. In the first, ultrasonic readings were taken from the sample and then a 3 point destructive test as per ASTM D790 was performed. In the second, the sample was initially preloaded and then ultrasonic readings were taken followed by the ASTM D790 destructive test.

2.1 Experimental Set-up

Ultrasonic readings of the samples were taken using the EPOCH 4 system (Figure 1) and then uploaded to UTComp's server where their proprietary software analyzed the data. MTS system was used to conduct ASTM D790 destructive tests as well as preload the materials (Figure 2).

Figure 1. EPOCH 4 System

Figure 2. MTS Loading System

2.2 Experimental Procedure

Samples were separated into two parts each labeled A and B respectively. The following procedure was applied to both samples with the second experiment having an additional step of preloading before any ultrasonic measurements are captured. The preload was applied until the deflection of the specimen reached 3 % of the span.

1. Each of these parts was then further separated into 5 specimens with a width of 33 +/- 1 mm and a length which is equivalent to 16 times the thickness of the sample (as per ASTM D790 specification).
2. A 25 mm by 40 mm section was cut from the sample which was used for ignition loss testing to determine the theoretical modulus of the sample.
3. Ultrasonic readings are taken at 32 mm intervals across the entire length of the specimen
4. ASTM D790 destructive tests were performed on each specimen

3. RESULTS

The ultrasonic readings were analyzed by UTComp's proprietary software and compared with the results obtained from the ASTM D790 destructive tests. The raw data from the ASTM D790 test gives the load-deflection curve of the sample as well as the samples after fracture is shown in figures 3 and 4. The modulus from the destructive tests is then calculated as follows [2]:

$$E_B = \frac{L^3 m}{4bd^3} \qquad [1]$$

where E_B is the modulus of elasticity, L, m, b and d are the length of the span, slope of the tangent to the initial straight-line portion of the load deflection curve, width of the beam and depth of the beam respectively.

Figure 3a. Sample #7 after fracture

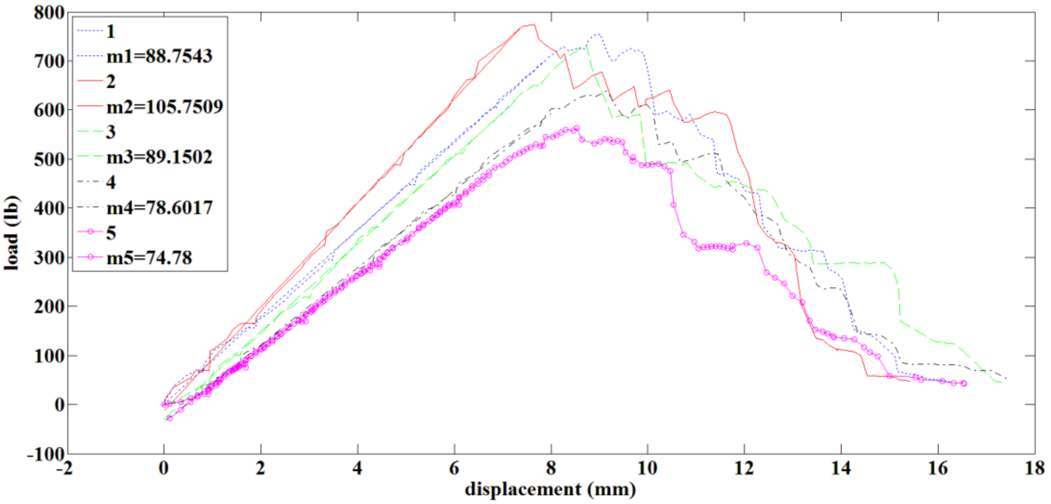


Figure 3b. Load deflection curve of sample #7

Figure 4a. Sample #28 after fracture

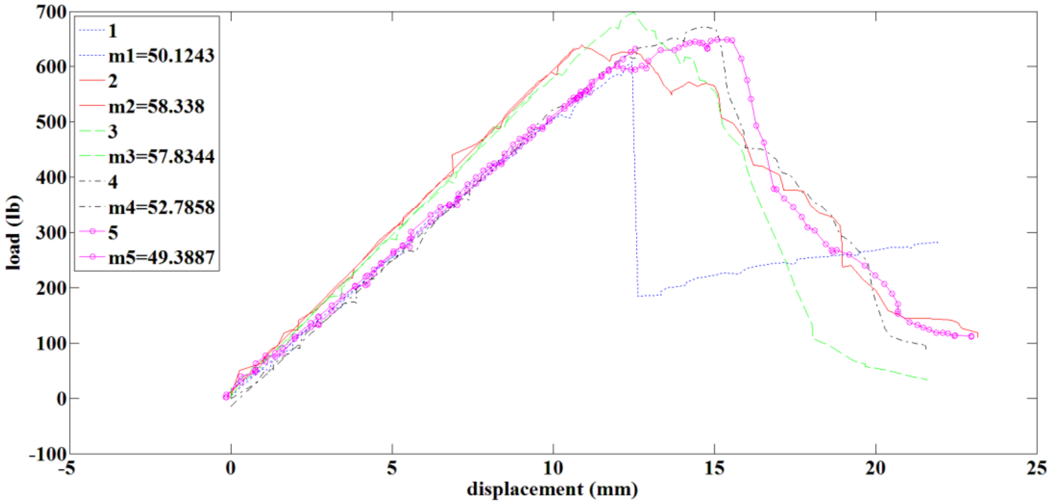


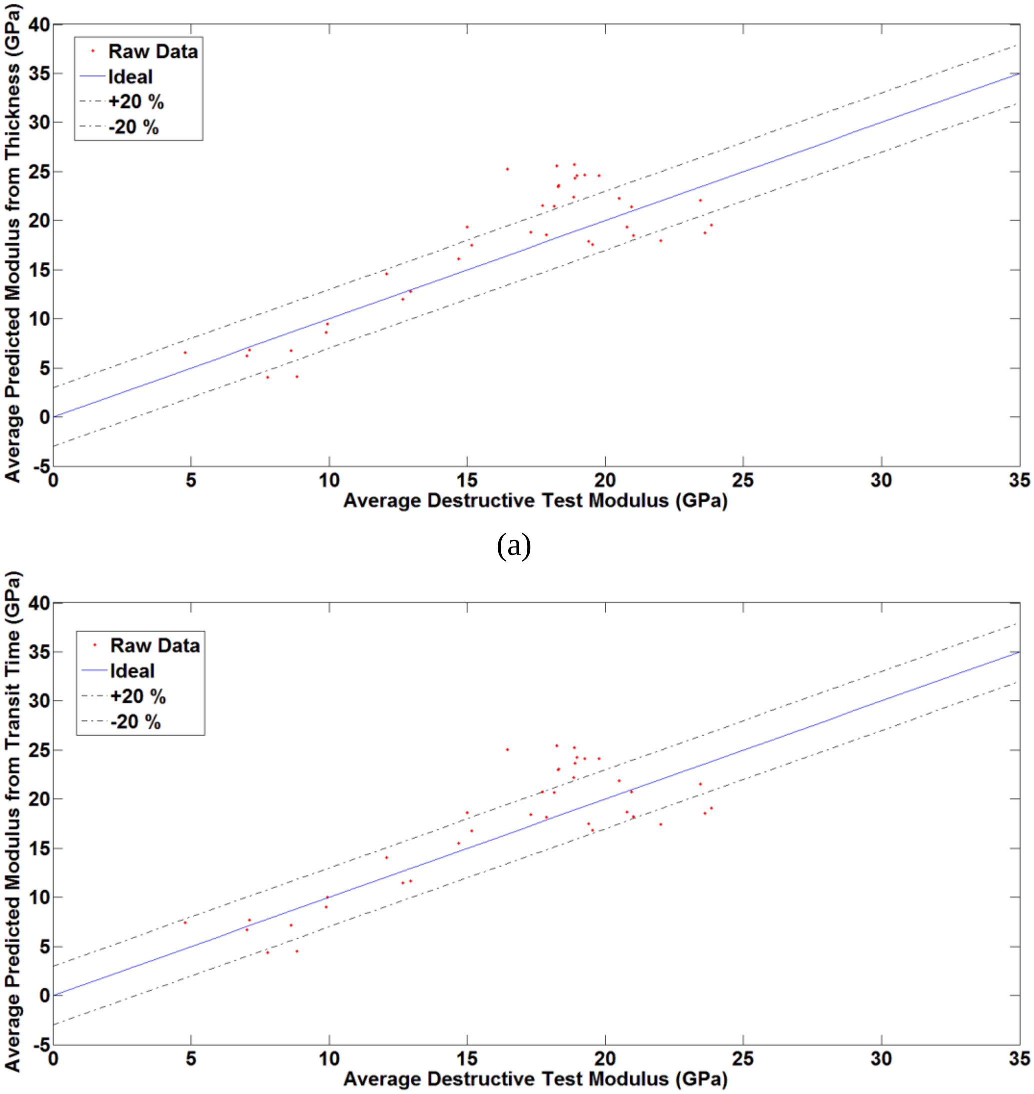
Figure 4b. Load-deflection curve of sample #28

3.1 Comparison Between Destructive and Non-Destructive Tests

Table 1 outlines the average dimension of each sample. The results are shown in Fig. 5. It can be seen that the results of nondestructive tests and predictions are in good agreement. Majority of the errors is within +/- 20 % as seen from Figure 5. There are two results generated by UTComp's software, the first being Predicted Modulus for Transit Time, which calculates the modulus without knowledge or measurement of the samples thickness and the second being Predicted Modulus for Thickness which takes into account the measured thickness of the material.

Table 1. Comparison between destructive and non-destructive tests

Samples	Width (m)	Thickness (m)	Span (m)	Fibre Type
N11A	0.0303	0.006	0.0978	Long Fibres
N11B	0.0303	0.006	0.0978	Long Fibres
TH149161A	0.0302	0.0063	0.0978	Long Fibres
TH149161B	0.0302	0.0063	0.0978	Long Fibres
TW105031A	0.0303	0.0126	0.163	Long Fibres
TW105031B	0.0295	0.0113	0.163	Long Fibres
TW121352A	0.0298	0.0063	0.0978	Long Fibres
TW121352B	0.0298	0.0063	0.0978	Long Fibres
TW149163A	0.0303	0.0067	0.0978	Long Fibres
TW149163B	0.0303	0.0067	0.0978	Long Fibres
YU15A	0.0356	0.0268	0.4018	Long Fibres
YU15B	0.0355	0.0263	0.4018	Long Fibres
YU16A	0.0352	0.0261	0.4018	Long Fibres
YU16B	0.0352	0.0276	0.4018	Long Fibres
YU17A	0.0356	0.0278	0.4018	Long Fibres
YU17B	0.0347	0.0253	0.4018	Long Fibres
YU18A	0.0355	0.0268	0.4018	Long Fibres
YU18B	0.0352	0.026	0.4018	Long Fibres
YU19A	0.0356	0.0282	0.4018	Long Fibres
YU19B	0.0363	0.0258	0.4018	Long Fibres
YU20B	0.0359	0.027	0.4018	Long Fibres
YU22A	0.0386	0.008	0.0978	Long Fibres
YU22B	0.0389	0.0083	0.0978	Long Fibres
YU23A	0.039	0.005	0.0978	Long Fibres
YU23B	0.0378	0.0053	0.0978	Long Fibres
YU24A	0.0383	0.0082	0.0978	Long Fibres
YU24B	0.0389	0.0082	0.0978	Long Fibres
YU26A	0.0378	0.0042	0.0978	Long Fibres
YU26B	0.0385	0.0043	0.0978	Long Fibres
YU27A	0.038	0.0035	0.0978	Long Fibres
YU27B	0.0388	0.0037	0.0978	Long Fibres
YU28A	0.0375	0.0056	0.0978	Long Fibres
YU28B	0.0377	0.0051	0.0978	Long Fibres
YU29A	0.0381	0.006	0.0978	Long Fibres
YU29B	0.0379	0.006	0.0978	Long Fibres
YU30A	0.038	0.0054	0.0978	Long Fibres
YU30B	0.0378	0.0056	0.0978	Long Fibres
YUS5A	0.0365	0.0092	0.163	Long Fibres
YUS5B	0.0362	0.0095	0.163	Long Fibres
YUS3A	0.037	0.0105	0.163	Chopped Fibres
YUS4A	0.0383	0.0131	0.163	Long Fibres
YUS7A	0.0363	0.0105	0.163	Chopped Fibres
YUS7B	0.0361	0.0101	0.163	Chopped Fibres
YUS1A	0.0351	0.0087	0.0978	Chopped Fibres
YUS1B	0.0354	0.0089	0.0978	Chopped Fibres
YUS2A	0.0357	0.0088	0.155	Chopped Fibres
YUS2B	0.0357	0.0089	0.155	Chopped Fibres



(a)

(b)

Figure 5.

Figure 5 Comparison between average destructive test modulus and predicted modulus from (a) thickness and (b) transit time.

3.2 Estimate of the Residual Service Life

The residual service life of the sample can be estimated if the theoretical modulus is known along with the time which the equipment has been in operation. By plotting the modulus versus time, the residual service life can be interpolated by a linear function. The following is an example calculation for sample #38. The theoretical modulus for this specimen was obtained using standard ignition test loss. This value is assumed to be the initial modulus at time zero. In practice, data sheets may be available to give more accurate information about the equipment itself. It is also assumed that the specimen was in service for 5 years.

The modulus of sample #38 was estimated to be 4.1 GPa and the theoretical modulus obtained from the ignition loss test is 5.53 GPa. By expressing both values as a percent of the initial value, the change in modulus results in a decrease of approximately 5.2%/year. Therefore in another 15 years the modulus will become 20% of its initial value which can be considered end of life.

4. CONCLUSIONS

The results from the nondestructive tests are in good correlation with the prediction by the nondestructive test. Thus, the ultrasonic nondestructive test is a good indication of the modulus of material and the residual service life can then be inferred with knowledge of the design/theoretical modulus of the material. Also, it is interesting to note that the thickness of the material need not be known to obtain accurate results. The thickness is inferred from the pulse transit time, which is another advantage of this approach. In practice, this is advantage for the ultrasonic nondestructive test method as the inspector can inspect the pressure vessels from outside without the need to shut down the plant to get the thickness information by drilling.

5. REFERENCES

1. Clarkson, Geoffrey E. “Baseline Values for Non-Destructive Structural Evaluation of Glass Reinforced Composites.” *The Composites and Advanced Materials Expo*. Orlando, Florida, October 13-16, 2014.
2. ASTM Standard D790-03, 2003, “Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials” ASTM International, West Conshohocken, PA, DOI: 10.1520/D0790-03, www.astm.org.