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DEVELOPMENT OF A NOL RING TEST TO STUDY GLASS/EPOXY SPECIMENS DEGRADATION AND ITS IMPLEMENTATION ON PERTINENT PRESSURE VESSELS

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ABSTRACT

The use of filament winding techniques for the fabrication of plastics composite structures has grown at a fast pace in recent decades. But the test methods and evaluation techniques have lagged behind the field of applications. Methods have been developed for the evaluation of filament wound composite structures making use of NOL (Naval Ordnance Laboratory) ring test specimens. These methods have all been found of value in making materials comparisons in research and development work and have also served as materials quality control techniques. The internal pressure can be applied to the ring shaped specimens similarly to the burst tests of actual pressure vessels. It is important that the fracture behavior inside of the FRP layers could be observed directly while it is impossible to observe the fracture behavior under the surface of actual pressure vessels. A method of ring fabrication and testing techniques for determination of ring tensile strength have been standardized and are presented herein. Also, in order to demonstrate the advantages of ring burst test, the fracture analysis of Glass/Epoxy NOL Rings under defect free as well as adverse conditions was carried out using AE measurement. Consequently, the effect of degradation in strength of Glass/Epoxy NOL Rings was understood by using Acoustic Emission (AE) technique. Moreover, a mathematical approach is used to predict the failure load of Glass/Epoxy NOL Rings at lower level itself with a reasonable error margin. These ring tests have been oriented towards more realistic lines than tensile test on flat specimens. Due to simplicity and low cost of this testing technique, a number of NOL ring tests can be repeated easily comparing with burst tests of actual pressure vessels.

Key words: Glass/Epoxy NOL Rings, Burst pressure, Acoustic emission, Pressure vessels and Mathematical approach.

1. Introduction to NOL Ring Test

The composite specimen's potential damages (internal or external) are identified using AE data. The tensile test per se is commonly used to identify the mechanical properties of composite specimens. In this case, dog bone specimens were cut from composite pipe wall parallel to its axis. Consequently, this test does not appear well adapted to reveal damages due to cracks, parallel to the pipe axis as observed for brittle failures. Other tests like hydrostatic pressure tests needed too long time and its design and manufacture are more expensive. Thus, the development of the test method called "NOL Ring" has been oriented towards a more realistic test than tensile test but easier to carry out and cheaper than common pressure tests. In this paper, in order to get adequate number of test results to confirm the AE studies were done on adequate nos. of NOL rings. Their failure results are investigated clearly and validated with composite pressure vessel.

2. Composite Pressure Vessel vs NOL Ring Testing

The Naval Ordnance Laboratory (NOL) ring test is followed from ASTM standard D 2290-04, adapted for characterizing the degradation evaluation of polyethylene pipes [1]. In case of pressure vessels, the fibre can be wound along the hoop direction to get maximum strength. The maximum stress along the hoop direction in pressure vessels will be equal to the strength of the fibre along longitudinal direction. Ring specimens cut from the pipes are also subjected to hoop (circumferential) stress. The load can be applied to the

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ring shaped specimens similarly to the burst tests of actual pressure vessels. Both the tests were carried out using a computer-controlled hydraulic testing machine in air under constant rod speed. In order to obtain the information on micro fracture process such as fibre breakage and interlaminar friction, AE measurement was also carried out using sensors attached on the specimen. The AE signals as well as axial load were measured by AE system, simultaneously. Since the tests were carried out under constant rod speed, it was observed that the inner plies remained after the failure of outer plies. The effect of fibre waviness on the strength of filament wound FRP was understood by using NOL ring test. To demonstrate the advantages of NOL ring test, the fracture investigation of filament wound FRP, with the various degrees of fibre waviness, was carried out using AE measurement. It was frequently reported that the strength of the filament wound FRP components are lower than expected value, which is caused by the influence of inhomogeneous microstructures such as fibre waviness on the fracture process. It was also reported that the formation of waviness is caused by thermal shrinkage during curing and the compressive deformation of inner layer by the binding of outer layer (bandage effect) during filament winding. The tension in fibre is controlled during filament wound to obtain various degrees of fibre waviness. It was strongly suggested that strain in inner plies are lower than that in outermost ply at the failure. Consequently, it can be concluded that the failure load of filament wound FRP composite is successfully enhanced by controlling the tension in fibre during winding. Due to the simplicity and low cost of the testing technique, a number of NOL ring tests can be repeated easily comparing with burst tests of actual pressure vessels. Sanchez M (2008) did show that NOL Ring test subjects the test specimen to a hoop stress, which, between the restricted areas, is quite similar to the stress induced by internal pressure [2]. These reasons show that the NOL ring test is more relevant for identifying pressure vessel damages than the standard tensile test. Further, severe and unexpected pressure vessel degradation can be revealed. Also with NOL ring test, the two main characteristics that were relevant for assessing the degradation of the pressure vessel are:

The surface aspect of the specimen’s inner wall after the test (viewed without magnification) and

The elongation at break.

Yu Yunhua (2009) showed that the pressure vessels are designed by the properties of engineering materials and its behavior under tensile, compressive, shear and other static or dynamic loading conditions in both normal and adverse test environment [3]. Pre-qualification for a composite system require that testing be performed on specimens. Flat specimen is tested under uniform thickness whereas in ring test the stresses are more in outside surface than inside. Therefore, the ring test was developed to evaluate tensile properties of unwoven, glass-reinforced, filament wound, plastic specimens. These results are closer to the actual loading in a circular casing. For these reasons, the researchers Fujishima, O. (1994), Horide, A (1996 &1999) recommended that whenever the material properties for any pre-qualification of a composite system is required, for the design purposes and assessment, the same can be obtained from a ring test [4-8].

3. Test Specimen

The band of continuous epoxy resin impregnated Glass rovings are hoop wound around a rotating mandrel using a filament winding machine to maintain uniformity of resin content around the circumference. Then, it is cured at a temperature of 100ºC for 4hrs in an oven after that, it is cooled at room temperature. Thereafter, the specimens are removed safely from the mandrel by hydraulic extractor to make NOL rings.

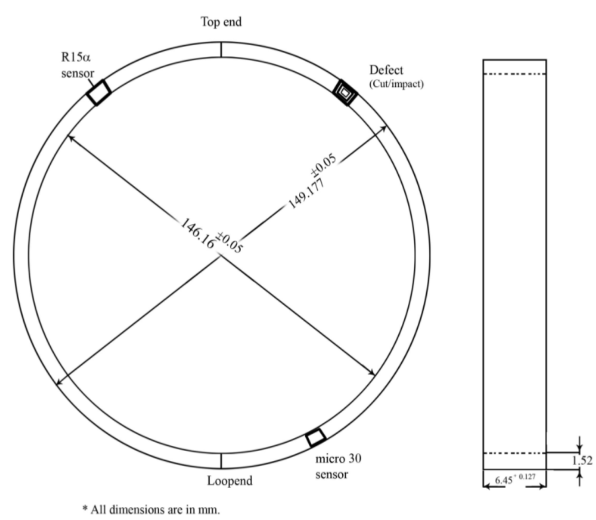


Fig.1 Ring Test Specimen

The obtained NOL ring test specimen is shown in Fig.1. The used winding machine is numerically controlled for laying exact number of layers of reinforcement. The number of layers is kept as 16 for each of the test specimens. In each group of specimens, a few are identified as impact specimens for the test purposes. Artificial damages are cut at 60º at the top end and 240º at the loop end with respect to the horizontal axis. Fig. 2 depicts the preparation of NOL specimens.

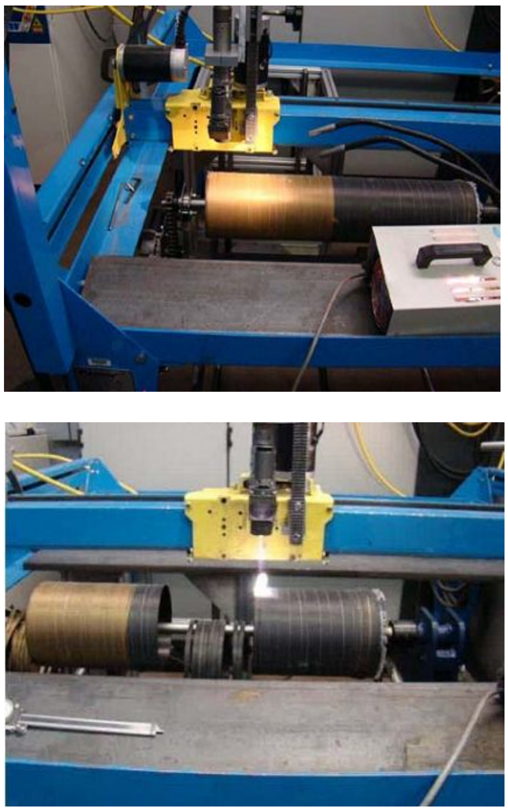


Fig.2 NOL Ring Preparation

4. NOL Ring Test Setup

The apparent hoop tensile strength or NOL-Ring tensile strength of various reinforced plastic composite is determined by split disk method. A universal testing machine INSTRON 5985 is used for loading at constant rate of specimen extension. The machine can load the specimens upto 250KN. A suitable fixture is used for gripping and holding the specimen in the test machine. Fig. 3 Shows the setup for the NOL ring testing.

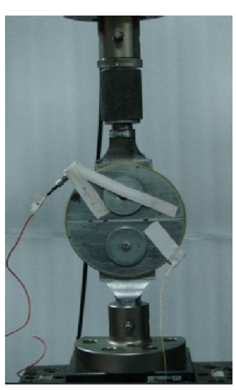


Fig. 3 Test Setup for the NOL Ring

Two AE sensors (R15α & Micro 30) are mounted on the NOL ring. As to one of the AE sensors, say, R15α is mounted at 120º at the top end and the other AE sensor, say; micro 30 is mounted at 300º at the loop end with respect to horizontal axis. In order to secure the AE sensors in position, vacuum grease and self-adhesive rayon cloth tape are used. The sensitiveness of the AE sensors need be frequently verified. Hsu-Nielsen Pencil lead break technique is followed to check the sensitiveness of each of the AE sensors. This was done at the start of every test.

Table 1: Details of Glass NOL Rings

NOL Specimen	Type of Defect, if any	Dimensions of defect (bxd) in mm	Avg. Internal dia in mm	Avg. External dia in mm	Avg. Ring Thickness in mm	Avg.Failure Load(KN)
Type-1 Glass/Epoxy (10 nos)	No defects	-	146.34	149.12	1.64	19.88
Type-2 Glass/Epoxy (6 nos)	cut	1.09 x 0.9	146.5	149.15	1.82	17.50
Type-3 Glass/Epoxy (5 nos)	cut	1.09 x 1.0	146.99	149.0	1.64	16.43

From the Table: 1 one could identify that the artificial damages (cut/impact) might definitely affect the failure load. The deformation and fracture process in NOL rings are observed by high magnification video system. The deformation of the NOL rings is similar to pressure vessels. The failure of NOL rings are tension as well as split. Fibre splits that occur during the NOL ring failure is almost similar to the pressure vessel failures. Even though the pressure vessel is pressurized at constant rate, the developed stress is maximum in hoop direction. Stresses are more in the outer layers than inner layer as in the NOL rings.

5. Evolving an Empirical Relation Using NOL Ring Test Results

The load cycle for the Glass/Epoxy NOL ring is shown in Fig.4.In this studies and analysis, the major derived AE parameters chosen were count, duration, amplitude and Felicity ratio(F.R). The load at which significant emissions start during first repeat cycle is considered as ‘P1’. The maximum load reached during the previous cycle is,say, ‘P2’.The Felicity Ratio F.R. is, therefore, P1/P2. The other parameters are chosen just before the load “hold” that follows during the first repeat cycle. The empirical relation is nothing but a relation connecting the dominant AE parameters with expected failure load and applied load at which the prediction is attempted. This relation is developed in the first NOL ring test itself. After that, the same is getting refined after every remaining NOL ring test. The solution of each NOL is found out by MATLAB software. The unknown constants are arrived at by substituting all the major AE parameters into the empirical relations. In any NOL ring, the tentative failure load is arrived at by substituting the other NOL's constants. The authors also observed that the damaged NOL's are used to fail earlier than the defect free NOL rings.

All these steps are repeated for all the NOL rings. In this studies, the output of this NOL ring results are compared with the remaining glass/epoxy NOL rings to know the variation in the percentage error of prediction. There are three different damage modes for the NOL integrated tensile rings, namely complete rupture, incomplete rupture and interlayer peel off. Some of them are shown in Fig.5.

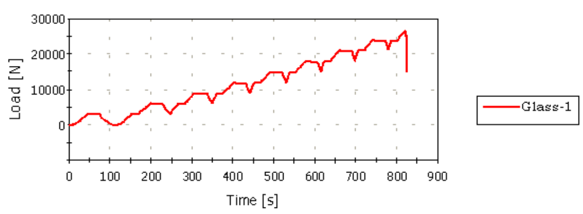


Fig. 4 Load cycle for Glass/Epoxy NOL ring

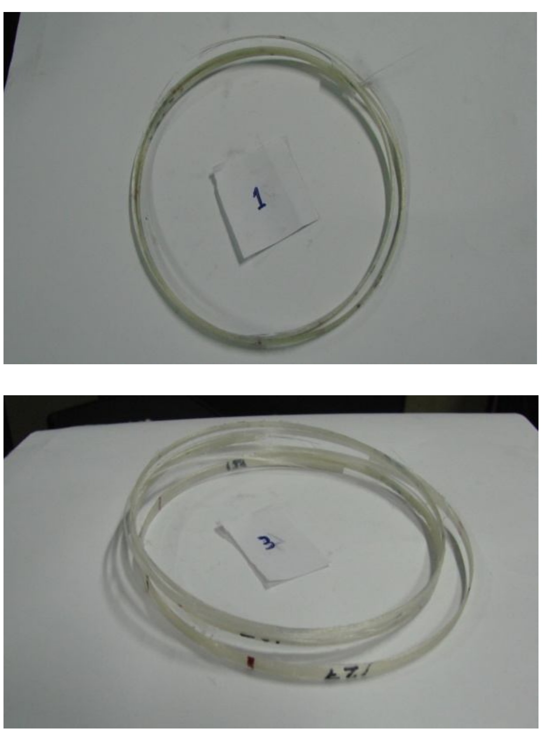


Fig. 5 Failure Modes of Various NOL Rings

Table 2: Prediction using Type-1 Glass NOL Ring Constants

Type-2			Type-3		
Actual Burst load in 17.50 KN			Actual Burst load in 16.43 KN		
Applied load level in KN	Predicted Burst load in KN	ERROR in %	Applied load level in KN	Predicted Burst load in KN	ERROR in %
3	25.272	44.411	3	26.088	58.783
6	25.952	48.298	6	20.111	22.404
9	22.089	26.227	9	20.084	22.240
12	21.384	22.194	12	19.968	21.534
15	17.999	2.854	15	19.151	16.561

In order to verify the failure load prediction, the type-1 NOL constants are substituted into eqns. pertaining to the load cycles of type -2 & type 3. The obtained tentative failure load and its error percentage are as shown in Table 2.

The final empirical constants pertaining to NOL - 2 are substituted into the equations pertaining to the load cycles of NOL- 1 & 3. The obtained tentative failure load and its error percentage are as shown in Table 3.

Table 3: Prediction using Type- 2 Glass NOL Ring Constants

Type -1			Type -3		
Actual Burst load in 19.88 KN			Actual Burst load in 16.43 KN		
Applied load level in KN	Predicted Burst load in KN	ERROR in %	Applied load level in KN	Predicted Burst load in KN	ERROR in %
3	17.063	-14.170	3	18.269	11.193
6	17.015	-14.411	6	17.483	6.409
9	17.973	-9.592	9	18.165	10.560
12	16.430	-17.356	12	17.804	8.363
15	17.385	-12.550	15	17.450	6.208

From the Tables 2 & 3 one could observe (based on failure prediction) that the error margin is minimum in the third load cycle (range 9KN to12 KN). That means, prediction is possible in the range, 50 to 75 % of failure load. In some of the cases failure load is predicted reasonably well even at 50% of failure load.

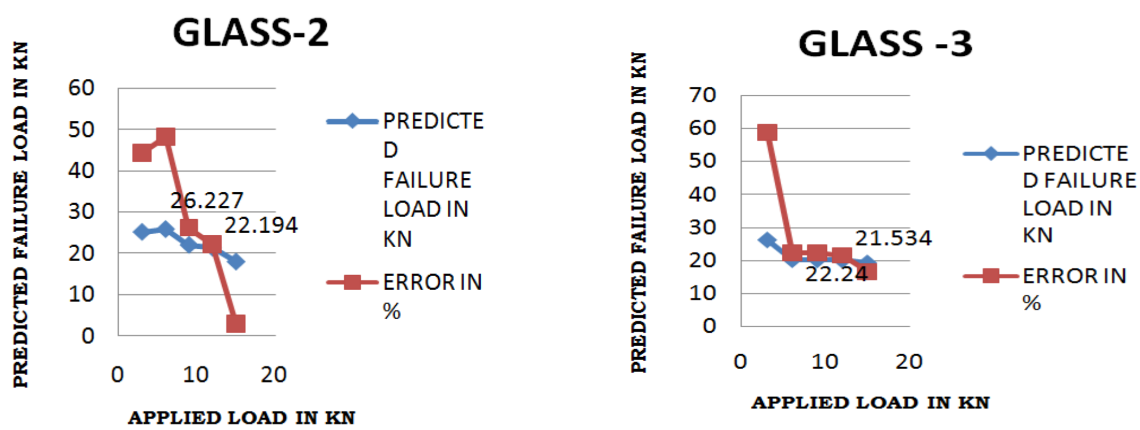


Fig. 6 Prediction using Type-1Glass NOL Ring Constants

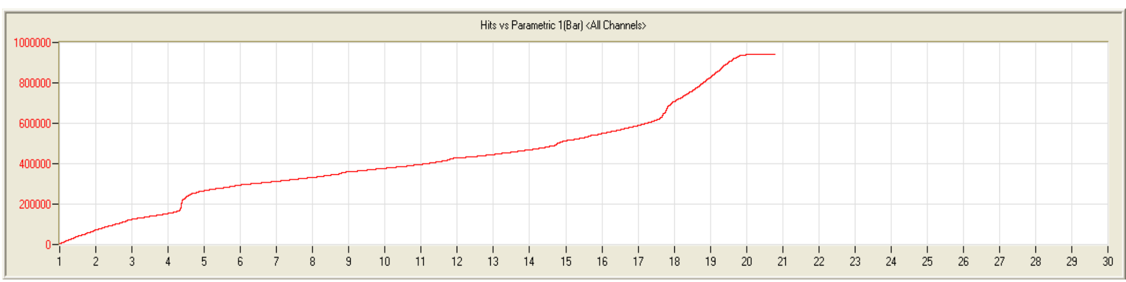


Fig. 7 (a) Hit rate Vs Load (in N) for Glass NOL -1

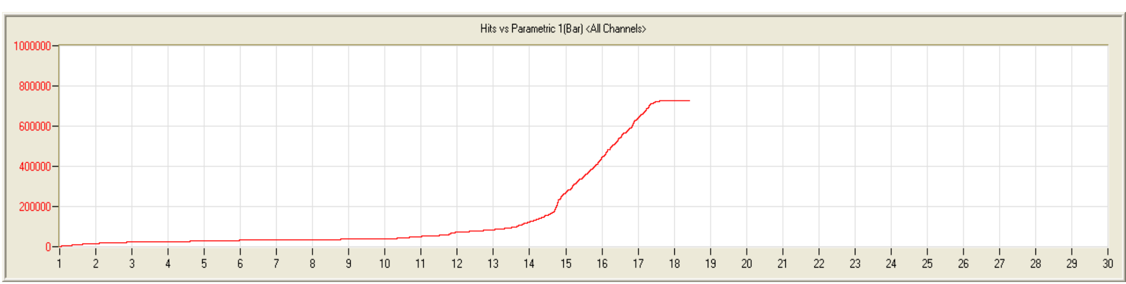


Fig. 7(b) Hit rate Vs Load (in N) for Glass NOL -2

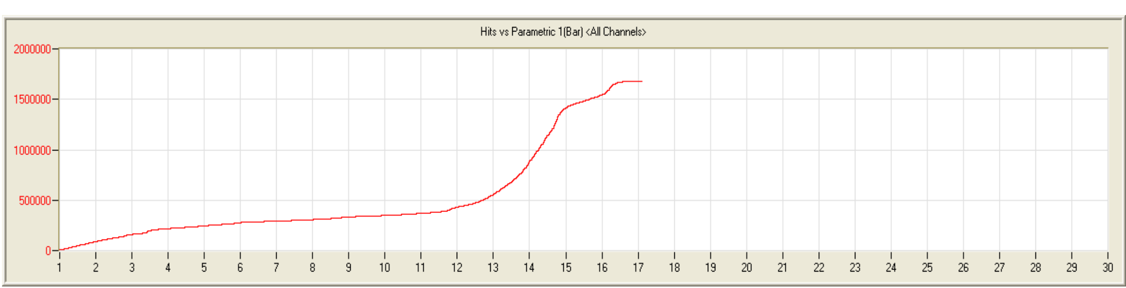
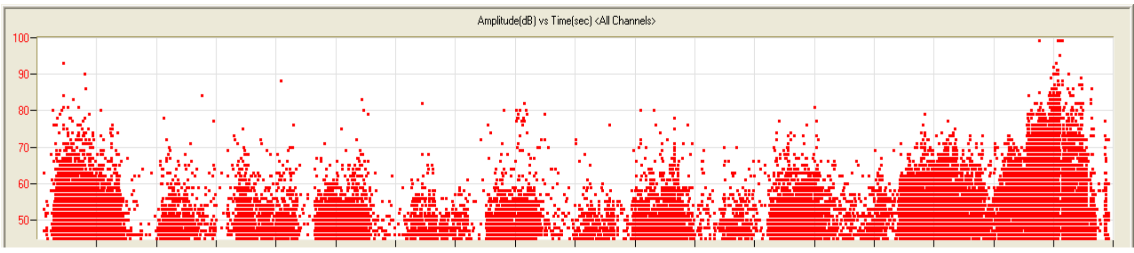
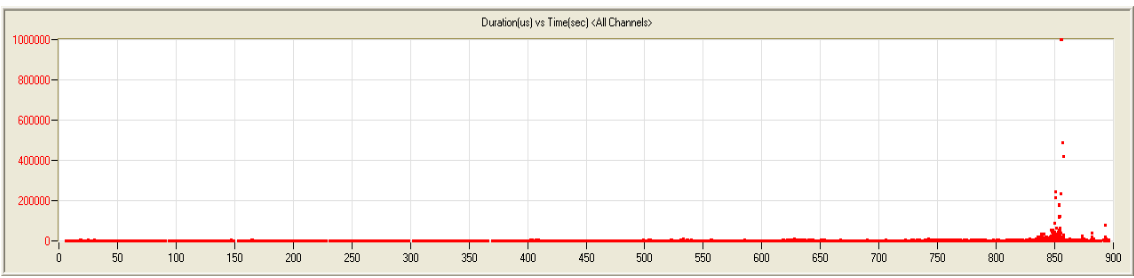


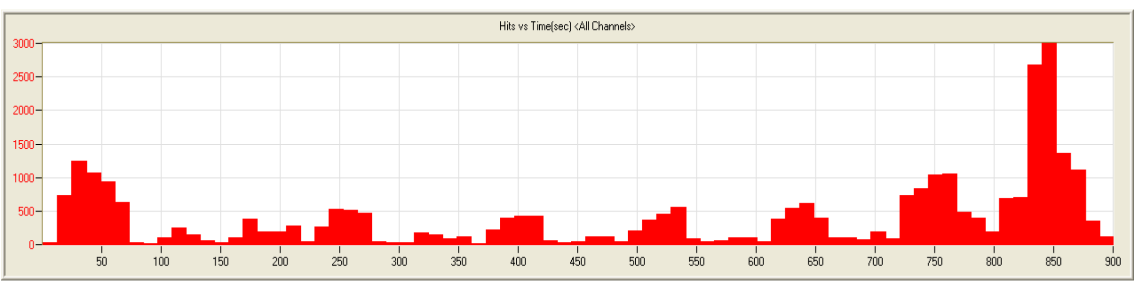
Fig. 7 (c) Hit rate Vs Load (in N) for Glass NOL -3
Fig. 7 Comparative studies between Glass specimens



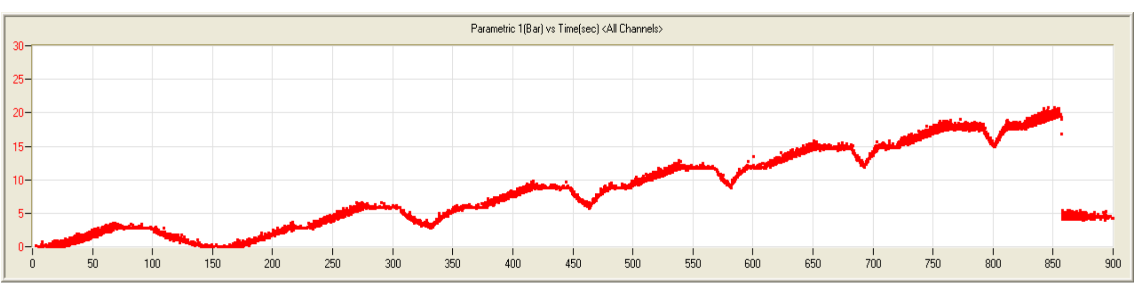
Amplitude(dB) Vs Time (sec)



Duration (μs) Vs Time (sec)



Pressure (bar) Vs Time (sec)



Hits Vs Time (sec)

Fig. 8 AE for Glass Specimen (defect free)

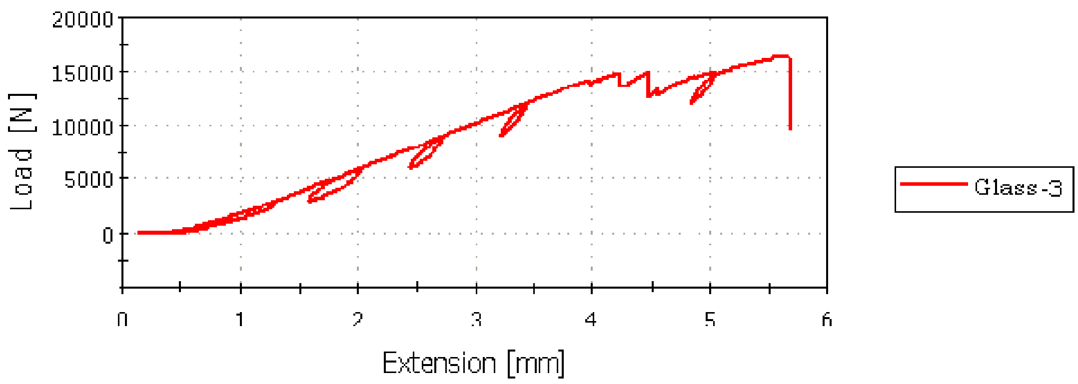


Fig. 9 Load Vs Extension graph for Glass/Epoxy NOL-3

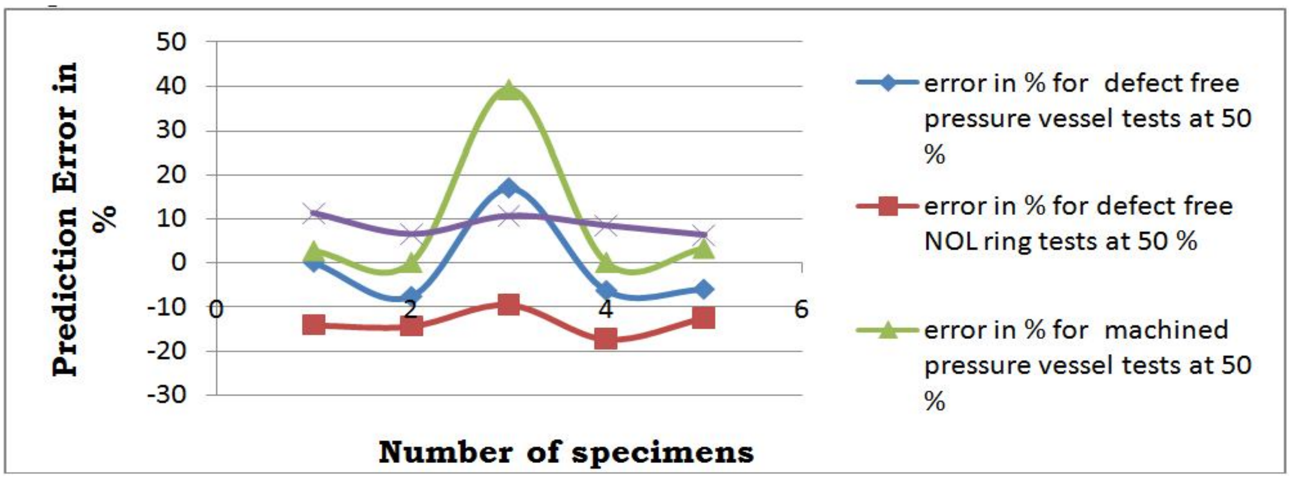


Fig. 10 Prediction Error Percentage Comparison of Pressure vessels Vs NOL Rings at 50 % failure load

The Fig. 6. and fig. 7 shows that the specimen exhibiting low failure load has the definite variation in the slope which can be identified using AE analysis. The graph depicting Hit rate Vs Load shows the significance of AE. Fig. 8 illustrate how AE data is seen for defect free specimens.

The extension of the NOL ring can be determined using the graph drawn between load and extension. Fig.9 depicts the Load Vs Extension graph for Glass/Epoxy NOL-3.

From the graph, it can be verified that the maximum extension 5.675 mm occurred at the load of 16,432.45N. Also, from the results one could see that the maximum damaged specimen has more extension than the less damaged/undamaged specimens. The emissions are more for glass specimens at lower load itself which indicate the weakness of the material. Fig.10 illustrates the prediction error percentage comparison of pressure vessels and NOL rings at 50 % failure load.

The error graph is drawn at 50% of failure load. From the graph one can identify that the error is more for defective specimens and the same is less for defect free specimens. Using the Mathematical approach, one can predict the failure for both pressure vessels and pertinent composite specimens at reasonably acceptable error margin.

6. Summary

From this experimental work it is clearly verified that the prediction of failure load is possible in the case of Glass/Epoxy NOL ring specimens with a lucid empirical relation. Using the empirical constants of the defect-free specimens, prediction possibility with an error margin varying from +22.24% to +26.227% is obtained at 50% failure load for this class of NOL ring specimens. The constants of impact damaged specimens are not recommended for prediction purposes because it demonstrates the worst case of prediction – error margin at 50% failure load. These types NOL ring might have failed earlier than other specimens due to high extension at lower load itself. The correlation of the remaining specimens are reasonably better with an acceptable error margin i.e.,-9.592 to +10.560% at 50% failure load. Moreover, for verifying the prediction results, the failure load is also applied for lower load cycle at 25% failure load where, the error margin varies from -14.411 to 6.409%. From these results one could clearly infer that the failure load prediction of NOL ring specimens is less accurate at lower loads and it is quite reasonable at 50 % failure load. The "empirical approach" will therefore be very useful for real time AE evaluation.

The major AE parameters/derived parameters like ring down counts, event duration, peak amplitude and felicity-ratio exhibited during first repeat cycle could substantially facilitate accurate prediction of failure. When the constants obtained are substituted in different NOL ring specimen, the failure load values will not be same but there is some variation. If the NOL ring is good one, ie, if the fibres are of good quality, the windings are proper, the curing is adequate then use of this empirical approach gives very close prediction of failure load.

Inputs for the design of vessels are Burst Pressure, diameter of the vessel and unidirectional strength of the composites which is normally found by testing "NOL rings" processed with similar winding condition as adopted for pressure vessel winding. From the test one can verify the assumed burst pressure of the pressure vessel and the corresponding developed stress. The AE parameters obtained from the pressure vessel tests is comparable with that of NOL ring tests to govern the empirical equations.

Acknowledgments

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References

1. *ASTM D 2290-04 "Standard Test Method for Apparent Hoop Tensile Strength of Plastic or Reinforced Plastic Pipe by Split Disk Method".*

2. *Sanchez M, Louis S, Bruzek C E, Rozental-Evesque M, Rabaud B and Glucina K (2008), "Development of a 'NOL ring' test to study polyethylene pipe degradation", Proc. of PPXIV conference, Oct. 22 – 24, Budapest, Hungary.*

3. *Yu Yunhua, zeng Wei, li Moyu, sui Gang,yang Xiaoping, guo Xiaodong (2009), "Relationship between the moisture absorption and properties of carbon fibre filament-wound NOL rings", Journal of Acta Materiea Composite Sinica, Vol. 26, 72-78.*

4. *Fujishima O, Wakayama S and Kawahara M (1994): "AE Characterization of the Fracture Behavior during Ring Burst Test of FW-FRP Pressure Vessel", Progress in Acoustic Emission VII, Kishi, T., Ed., The Japan Society for Nondestructive Inspection, Tokyo, 463-468.*

5. *Horide A, Wakayama S and Kawahara M (1996), "Acoustic Emission Characteristic during ring Burst Test of FW-FRP Multi-ply Composite", Non destructive Characterization of Materials VIII, Green, R.T., Jr., Ed., Plenum Press, New York, 641-646.*

6. *Horide A, Wakayama S and Kawahara M (1999), "Evaluation of Strength in FW-FRP Composites using Ring Burst Test (Effects of Winding Tension on Fracture Behavior and Strength)", Transactions of the Japan Society of Mechanical Engineers (A), Vol. 65, 631.*

7. *Michael D Lambert, Eric A Clark, Thomas H Fronk (2008), "Mechanical properties of hybrid polymer fiber-reinforced laminates in cryogenic conditions", Utah State University, Logan UT.*

8. *Rozental-Evesque M, Rabaud B, Sanchez M, Louis S and Bruzek C-E (2008), "The NOL Ring test an improved tool for characterising the mechanical degradation of non-failed polyethylene pipe house connections", Suez-Environnement Cirsee, France.*

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