



Life Strength Prediction of GFRP Pressure Vessels Using Acoustic Emission Technique

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ABSTRACT

Acoustic Emission (AE) has the unique potential for the real time integrity evaluation of pressurized systems. The technique has found greater importance in its application towards fibre reinforced plastic (FRP) pressure vessels in aerospace use. There is no method till date spelt out in open literature for burst pressure prediction of composite pressure vessels. This paper brings out a methodology for the burst pressure prediction of Glass Fibre Reinforced Plastic (GFRP) pressure vessels using a lucid empirical relation. Acoustic Emission monitoring was carried out during hydrostatic loading of five identical GFRP pressure vessels, about 6- litre capacity. An empirical relation was generated on the basis of the governing AE parameters viz., count rate, duration rate, amplitude rate and felicity ratio exhibited when the h/w was subjected to cyclic proof pressure cum burst test. AE data is acquired up to 50% of the theoretical burst pressure, and then the vessels were pressurized upto failure. The authors have framed an empirical relation to predict the burst performance, solving the typical equations with MAT LAB program for the four identical GFRP vessels. An attempt is made on the fifth hardware to predict its burst pressure. This innovative methodology illustrates the behaviour of GFRP pressure vessels in terms of AE parameters and its derivatives. This can possibly predict in real time the burst pressure of similar hardware if extended to other material systems. The failure is significant even at 50 to 60% of Maximum Expected Operating Pressure (MEOP) with an acceptable error margin.

Keywords: Acoustic Emission, GFRP pressure vessels, Burst pressure, empirical relation, AE parameters, MEOP, prediction.

1 Introduction

Acoustic Emission Technique (AET) is widely used for both materials research and structural integrity monitoring applications because of its unique potential for detection and location of dynamic defects under operating stresses. In the past three to four decades, AE has been mostly applied for testing pressure bottles undergoing proof/acceptance tests. In aerospace application, FRP pressurised systems are made with low margins with their attendant light weight construction. With the rapid advances taking place in the composites area, there has



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been a strong need for an NDT technique which can indicate the degradation that takes place during the course of the proof or acceptance testing of pressurized systems. In codentally there are cases reported in the literature that composite hardware that have successfully undergone proof pressure tests did fail during their actual use. In this respect, AE technique has assumed a unique role. More than evaluating the structural Integrity of pressurized systems it has the capability to predict the burst pressure within certain limits. It is well known that GFRP pressure bottles undergo degradation during acceptance/proof pressure test in view of resin crazing, fiber fracture, fiber pullout, etc. Such degradations can be indicated through major AE parameters and their derivatives. A lucid methodology is being developed in this paper to estimate the residual strength of GFRP pressure bottles.

2 GFRP Test Hardware and Instrumentation

AE studies have been performed on five Nos. of similar Glass epoxy pressure bottles about 6-litre capacity. The schematic view of the hardware is shown in the figure below. E- Glass fibres impregnated with epoxy resin are wound over an inner liner made of polypropylene. The bottles are built up of hoop layers and polar layers alternately placed in groups. The dome openings are equal and are closed with flat plates for the pressure test purposes. The average thickness of the composite wall is 5 mm.

The layout of AE sensors required for AE monitoring are shown in Fig .1. A PAC-Disp 4 AE work station is used to monitor Acoustic Emission in conjunction with AE sensors R-15 model (150 KHz, resonant type) and matching pre-amplifiers with 40 dB amplification and integral with high pass analog filter, range 20 KHz -400 KHz. The sensitiveness of each of the sensors is verified using Hsu-Nielsen pencil-break technique. The strain gauges that are bonded on the test hardware are also shown in Fig .1. The AE sensors are mounted as per standard procedure [ASTM, 1986], connecting co-axial cables with AE system. The deformation of the bottle as the test progresses is measured using single- element 350 Ω strain gauges (ranges 0-18000 μ .

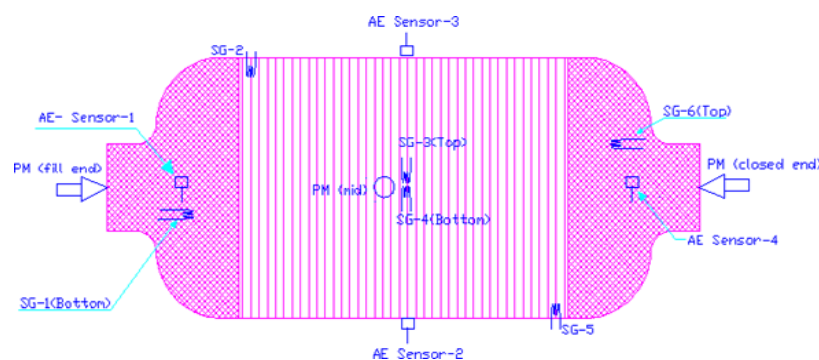


Figure 1: SG/AE instrumentation on GFRP pressure bottles



3 Hydrostatic Pressure Test

The pressure cycle is carried out upto 50% of their theoretical burst pressure in a cyclic mode. The pressure cycle is brought down to zero after every cycle. In this paper AE signature is studied during the first repeat cycles. The pressurisation rate maintained at 20 bar/min throughout the test three linear potentiometers are also mounted to find out the axial and diametrical dilation of the hardware. In the first test during pressurization the hardware failed due to adaptor failure. In order to avoid this nature of failure, the remaining four hardware were gently machined at the cylindrical portion by 1 mm depth. Two sets of pressure schemes are used to pressurise the bottles. Initially the first hardware is pressurized in cyclic steps upto 200 bar and the remaining hardware were pressurised upto 150 bar only. An air assisted hydraulic pump is used to pressurise upto 150 bars and for the higher pressurisation mechanical pump is used. The incremental pressure rise was 25 bar in all cases. The first time “holds” at various incremental pressures were for a minimum period of 1 min until the event rate declines. The maximum “hold” shall be for a period of 3 mins. In this paper, the AE emissions were studied only for repeat cycles. For every cycle, the AE parameters just before pressure hold is taken into consideration for developing the empirical relation predicting the burst pressure. In all cases, AE parameters were studied for a maximum pressure of 125 bar except for the first hardware. In the first hardware, cycling was done upto 175 bar.

4 AE Parameters and Empirical Relation

In this studies and analysis, the major derived AE parameters chosen were count rate, duration rate, amplitude rate and Felicity ratio (F.R). The pressure at which significant emissions start during first repeat cycle is considered as „ P_1 “. The maximum pressure reached during the previous cycle is, say, „ P_2 “. The Felicity Ratio F.R. is, therefore, P_1/P_2 . The other parameters are chosen just before the pressure “hold” that follows during the first repeat cycle. The empirical relation is nothing but a relation connecting the dominant AE parameters with expected burst pressure and internal pressure at which the prediction is attempted. This relation is developed in the first hardware itself. After that, the same is getting refined after every remaining hardware test. The solution of each hardware is found out by MAT LAB software. The unknown constants are arrived at by substituting all the major AE parameters into the empirical relations. In any hardware, the tentative burst pressure is arrived at by substituting the other hardware’s constants. In the first bottle, initially the emissions were very low. Therefore, the equation is formed from 75 bar pressure cycle onwards. The authors also observed that the machined hardware used to fail/ burst earlier than the first hardware failure pressure.

5 Results and Discussion

In the case of one of the h/w, say, GFRP-02, for the first repeat cycle at 75 bar, the values of



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derived AE parameters and pressure at which prediction was attempted are substituted into their equations corresponding to 75, 100, 125, 150 & 175 bars respectively. The solution initially gave low burst values comparing with the actual burst pressures of 299.5 bar. In the pressure range 100 / 125 bar, it gave reasonable percentage of error, say, 2.67. The felicity ratio is estimated using corresponding data sets as described earlier. The chosen values were also verified with the sixth equation at 200 bar. In this case, it indicated the value of burst pressure with an error margin of -1.42 %. Using these equations one could find out the constants effectively with the help of MAT LAB software. This software displays the output for any {mxn} matrix, where $m=n$. Similarly, for the other hardware the AE parameters are acquired from 25 bar pressure onwards at an incremental pressure rise of 25 bar. The mathematical procedure is same for all the hardware. If we compare the performance of all the hardware it could be seen that the failure of GFRP hardware is preceded by high count rate, large number of long duration events, high amplitude rate and a very low felicity ratio. The authors observed from the mathematical analysis that the predicted burst error margin is high at lower pressure and it is reasonable in the range 75 bar to 100 bar. For each of the pressure bottles the dominant AE parameters preceding failure could be detected at around 75% of MEOP. From the acquired data, a set of multiple parameters can be developed with a small error margin. The initial emissions are more for all the bottles except for the first bottle. The prediction attempted in the GFRP-03 pressure bottle gave the percentage error from -6.11% to 3.22% at 75 / 100 bar pressure cycles. Its constants gave a prediction of -15.37 to 21.9% at 50 / 125 bar pressure cycles. The constants of GFRP-01 and GFRP-05 pressure bottles exhibited reasonably low error margins at -0.64 to 2.67% and -11.4 to 6.43% respectively at 50 / 100 bar cycle range. GFRP-04 pressure bottle failed at very low pressure (125 bar) compared to all the remaining hardware. Substituting the GFRP-02 hardware constants gave a prediction for this hardware with an error margin of 16.9% at 75 bar cycle. This methodology can be extended for other material systems like Kevlar- epoxy, Carbon-epoxy etc.

6 Concluding Remarks

The authors have clearly verified that the prediction of burst pressure is possible in the case of GFRP pressure bottles with a lucid empirical relation. The correlation of all the five hardware is reasonably better with an acceptable error margins at -0.64% to 2.18% and for the worst case the percentage of error prediction is -19.2% to 16.9% at around 75% of MEOP. The major AE parameters like count rate, duration rate, amplitude rate and felicity ratio exhibited during first repeat cycle could substantially facilitate accurate prediction of failure. This innovative approach can be extended to any other material system to predict the burst strength and can send out warning signals well ahead of failure.