QUANTITATIVE ASSESSMENT OF BASE DEFECTS IN COMPRESSED GAS CYLINDER BY FRACTURE MECHANICS

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Assessment was carried out on a geometrically complex base in a compressed gas cylinder. The surface appearence of the base area, attributable to the process of forging, made this study necessary for the prediction of the following: a) calculation of applied stresses using the finite element method ; b) appraisal of the stability of defects either in terms of crack propagation in fatigue or in structural collapse.The results have demostrated the validity of the design, producing the required reliability of service for a cylindrical pressurized container.

INTRODUCTION

The analytical methods currently used to estimate conditions of structural stability may be used for prediction or control of service fracture in industrial components such as compressed gas cylinders (G.C.) . The procedure can be divided into two stages:

a) determination of nominal stress in the critical zone. Determination of the state of tension is generally carried out either by experimental techniques or by analytical methods such as finite element techniques.

b) the use of fracture mechanics concept to evaluate the probable conditions for crack initiation, propagation under cyclic load and the instability condition. With regard to G.C. under pressure, predictive formulations exist to evaluate the stability of through thickness and surface defects in the wall. The theory of leak before break has clearly established the fracture criteria. With regard to the other areas: valves, welds and bases, the fracture mechanics has not yet estabilished a generalized approach as it has for the wall, but allows the use of a different approach specific to the case under examination.

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The purpose of the work reported here, is to perform a quantitative assessment of base defects in compressed G.C. using finite element techniques and a fracture mechanics approach.

EXPERIMENTAL PROCEDURE

Geometry of Components

The profile of the lining is to specification PRS 37 for high pressure gas cylinders and working pressure P=200 bar, produced by ILVA - Dalmine. The nominal dimensions of the profile are:

External diameter of G.C.	Φ = 227 mm
Wall thickness	B = 6.6 mm
Total length	L = 1510 mm

A structural steel (Cr Mo V) was used to made the G.C.

Mechanical Properties

Mechanical properties of the steel were evaluated using specimens taken from a current product G.C., yielding the following results:

σ_{YS} MPa	σ_{TS} MPa	A %	J_{R} KJ/m^2	K_{Ic} MPa$\sqrt{m}$	C_o m/cycle MPa$\sqrt{m}$	n	K_{th} MPa$\sqrt{m}$
886	994	18	222	214	2.2E-10	3.15	10

Analysis of the applied stress

To evaluate the applied stress level for a given internal pressure within the G.C. (P=200 bar) a simulation was undertaken using a finite element technique with Mark II code and a UNISYS 1100/90 Computer.

The G.C. base was axial-symmetric; a model of this was made using a mesh of 240 elements in an arrangement of 324 nodes, fig.1.

The boundary conditions imposed are:

- simple constraint : second degree on symmetrical axis
- simple constraint : first degree on the wall
- internal pressure : P=200 bar
- material characteristics : taken from the mechanical qualification detailed.

Elastic calculation was performed.

In fig.2 the varaiation in the principal stresses in the G.C. wall is calculated inside the elements, 0.2 mm from the internal surface of the G.C..

The analysis suggests the following considerations:

- The internal surface of base G.C. is a convex shape and is subjected to a totally compressive stress.

The σ stress in the tangential direction to the curvilinear abscissa present a maximum at the junction of the base and body of the cylinder.

This fact, intuitively, is clearly demostrated in fig. 1 where the global deformation is reported. The base tends to increase its degree of curvature and the cylindrical part its radius causing a rotation of the body from the base/body junction as indicated by node 214.

- The external part of the base, with the exception of a small central zone, being subjected to both longitudinal and transversal tensile stress was found to be the critical part.

Evaluation of the stability of the base using fracture mechanics concepts

The main hypoteses were:
- Crack propagation : mode I (conservative)
- Work environment : air

In order to calculate the critical stress intensity factor K_{IC} (for instability) the level of the applied stress, the defect dimension and the geometric factor β must be considered. The geometric factor itself depends on the defects geometry, the constraint on the crack and the extention of the plastic zone at the crack tip.

The factor β can be calculated fo elliptical defects from the formula:

$$\beta = \frac{1}{\Phi} F_r \frac{1.12}{Q}$$

Factor Φ, F_r and Q take into account the elliptical form of the crack, the residual ligament and any plasticization of the cracked base respectively. The latter may be evaluated by the relationship between the applied stress and the yielding stress of the steel.

In the current project the following cases of stability of surface defects arising in those zones of the base most heavily stressed, were examined.

a) Elliptical defect positioned in the central external part of the base G.C., lying longitudinally and subject to a degree of applied stress of approximately 225 MPa. Thickness of the zone B=24mm

b) Elliptical defect in the margin zone of the cylindrical body base, applied stress $\sigma \approx$ 360 MPa. Thickness of the zone B=11.5 mm. For this case two different values of eccentricity have been taken into consideration C=2a and C=10a.

The fatigue life was considered only for the propagation phase.

The calculated values of the factor of form β was used as input data in the FATKRAK II programme for calculation of the fatigue life of stressed components with cyclic loads during the phase of gas filling. The prediction was made assuming the propagation of the defect of 0.2 mm (successive phase to that of initiation) until 10 mm for case a) and 8 mm for case b).

The following prediction were obtained:

For case a) N cycles = 5500 of pressurization were required to for the defect to be extended from 0.2 mm to 10 mm. For case b) approximately n cycles= 1200 were needed to extend the defect from 0.2 mm to 8 mm. It is not possible to predict the cycles of pressurization which are necessary for the initiation of the foreseen defect, but in general these are usually greater than those for the propagation phase.

If you consider that the vessel is subjected to one pressure cycle per day, very conservative case, it will have a fatigue life of 15 years in case a) and more than 3 years for case b). In the first case the critical defect has a dimension greater than the wall thickness (B≈20 mm) while in the second case the critical defect has approximately the following dimensions a=8.5 mm C=85 mm.

As the fatique life is so long the usual NDT could easily detect them.

Conclusions

The analysis of stability of the base of the gas cylinder ILVA_DALMINE PRS37 yielded the following results:

- The base at a working pressure of 200 bar, in the central part, is stressed under compression. The external zones are affected by tension but with tensile values which are fairly low. Any defects arising are stabilised indipendently of their dimension. In the area of the base maximum stresses are obtained. The analysis of the tolerability of defects has shown a rather slow rate of growth with significant critical dimensions.

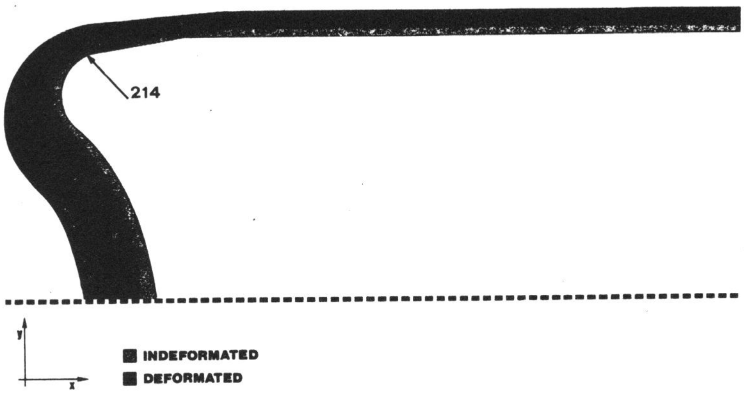

Fig.1 Deformated and indeformated mesh showing node 214.

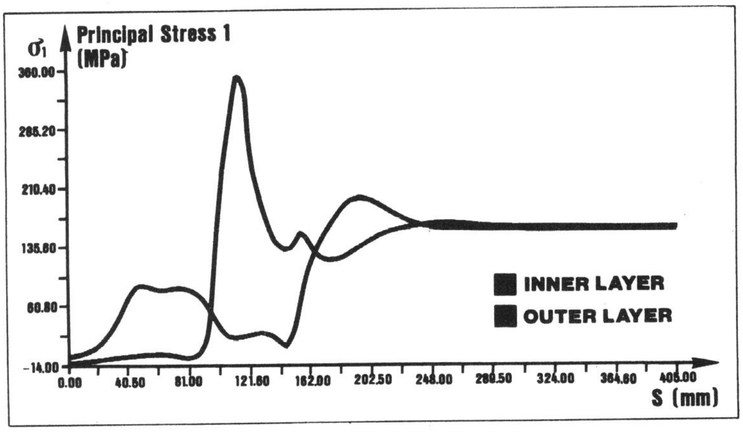

Fig.2 Variation in the principal stress (tangential) along the curvilinear abscissa.