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RESEARCH ARTICLE

Estimation of damage in cylinder subjected to shock pressure load using finite element analysis

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Abstract

The aim was to estimate the influence of shock pressure loading on the ring stiffened cylinder using finite element analysis. The fluid medium was molded based on Tait's equation of state. The equation of state from Jones-Wilkins-Lee (JWL) was used to describe the detonation products of explosives. The explosion and fluid were interfaced using Eulerian-Eulerian coupling and the fluid and shell were interfaced using arbitrary Lagrangian-Eulerian coupling. The damage has occurred in the cylinder surface exposed to explosion only.

INTRODUCTION

The inelastic behavior of structures to dynamic loads such as impulse, blast and underwater shock is of great importance in many fields such as marine, ocean, aerospace industries. The problem is fairly complex involving material and geometric non-liniearities. Santiago et al. (1986) have presented a comparison between the finite element transient response of a thin walled aluminum cylinder subjected to blast loads with experimental results in which the strains have been measured. Jiang and Olson (1991) have conducted the finite element approach for predicting the nonlinear behavior of isotropic and stiffened cylindrical shells under air blast loads. Keil (1961) has presented a complete over view of underwater explosion covering the various aspects of underwater events and associated damage such as hull damage, equipment and machinery damage. Gong and Lam (1998) have found that the stiffeners can increase the circumferential strength of the composite submergible hull.

Because the explosion process occurs rapidly, it suddenly increases the pressure, which in turn compresses the surrounding fluid medium. This compression propagates in the radial direction as a shock wave. Simultaneously, the gas bubbles formed by the gaseous products of the explosion expand in the radial direction at relatively slow as compared to shock wave. This gas bubbles can expand till the hydrostatic pressure exceeds the internal gas pressure. At this the gas bubbles contract. During this short interval, another compression wave is produced in the surrounding medium. This process of contraction and expansion is repeated till low intensity pulses are generated.

The objective of this paper was to estimate the influence of shock pressure loading on the ring stiffened cylinder using finite element analysis.

Material and Methods

The physical model considered in this investigation was a ring stiffened cylinder (figure 1) made of IS 220 mild steel. The dimensions of the ring stiffened cylinder (figure 1) are as follows:

Length between end flanges = 1.0 m
Inner diameter of cylinder = 0.60 m
Thickness of cylinder = 6.0 mm
Inner diameter of stiffener = 0.48 m
Thickness of stiffener = 8.0 mm
Outer diameter of flange = 0.75 m
Thickness of flange = 25.0 mm
Outer diameter of end plates = 0.75 m
Thickness of end plates = 25 mm

The total weight of the test setup with the cylinder is 350 kg in air. The cylinder was shock tested using explosive charges in the shock tank. A charge weight of 70 gram equivalent located at a distance of 0.5 m was exploded.

The finite element analysis of the test cylinder was carried out using DYTRAN non-linear finite element code. For the finite element analysis, the explosion, fluid and cylinder were modeled as an integral unit. The fluid and explosion were meshed with 8 node Eulerian solid element (figure 2a). The number of elements was 42400. The cylinder was discretized with 4 node Lagrangian element (figure 2b) (CR Alavala; 2008). For the finite element analysis, the fluid was modeled using Eulerian solid element with Tait's equation of state and the explosion was modeled using Eulerian solid element with JWL equation of state.

The material constants used in the Tait's equation of state are as follows:

$\rho = 1000\ kg/m^3$
$a = 9680.5421$
$b = 3.0E8$ Pa
$R = 7.15$

The equation of state from Jones-Wilkins-Lee (JWL) is used to describe the detonation products of explosives.

$$p = A\left(1-\frac{\omega}{R_1 V}\right)\exp(-R_1.V) + B\left(1-\frac{\omega}{R_2 V}\right)\exp(-R_{12}.V) + \frac{\omega e_0}{V}$$

The ratio $V = \rho_e/\rho$ is defined by using ρ_e is the density of explosive (solid part) and ρ is the density of detonation products. The parameters A, B, R_1, R_2 and ω are given below:

$\rho = 1610\ kg/m^3$
$A = 371.2\ GPa$
$B = 3.2306\ GPa$
$R_1 = 4.1$
$R_2 = 0.95$
$\omega = 0.3$

The material properties of the shell are given below:

$E = 2.1\ x10^5\ MPa$
$\gamma = 0.3$
$\rho = 7860\ kg/m^3$
$E = 250\ MPa$
$\sigma_y = 280\ MPa$

The analysis of the coupled field problem was solved using explicit integration scheme. Three incremental time steps of 0.05, 0.1 and 0.2 microseconds were used for the analysis. The explosion and fluid were interfaced using Eulerian-Eulerian coupling and the fluid and shell were interfaced using arbitrary Lagrangian-Eulerian coupling. The explosion was assumed on the centerline of the stiffened cylinder at a distance of 0.5 m from the centre of the cylinder. The initial conditions used in the explosion were specific internal energy (4.16 x 10^6 K/kg) and detonation velocity (6730 m/s).

Result and Discussion

The shock pressure loading of the fluid medium on the cylinder is shown in figure 3a. The pressure was applied on the surface of shell through arbitrary Lagrangian Eulerian coupling. The peak value was 125 MPa. The displacement-time history of the cylinder exposed to the explosion is shown in figure 3b. The deformation of the cylinder was obtained from the maximum displacement by subtracting the elastic deformation. The maximum displacement was 0.072 m at 3.8 milliseconds. The maximum displacement of the cylinder was 0.068 m. The displacement contours are shown in figure 4. The plastic displacement was found to be high on the cylinder side exposed to the explosion (figure 4a). The elastic displacement was found on the opposite of the explosion (figure 4b).

The permanent deformation profile along the axial length of the cylinder obtained from the finite element analysis was validated with experimental results (figure 5a). The displacement profile obtained from FEA is in close relation with the experimental results. The deformed shape of the cylinder due to shock loading can be seen from figure 5b which is nearer to that appeared in figure 4a.

4. Conclusions

The maximum structural damage of a ring stiffened cylinder obtained through FEA is about 8.25% deviation from the shock experiments. The damage has occurred in the cylinder surface exposed to explosion only.

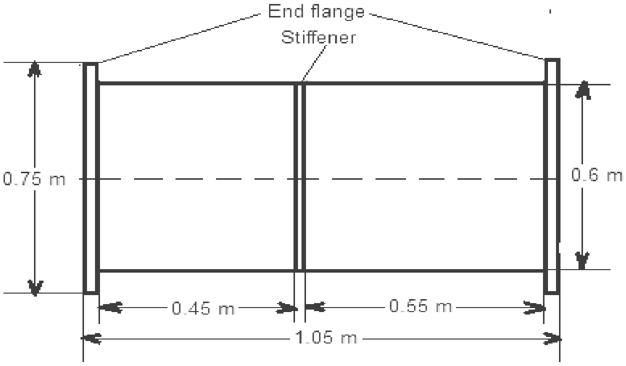

Figure 1: Dimensions of ring stiffened cylinder.

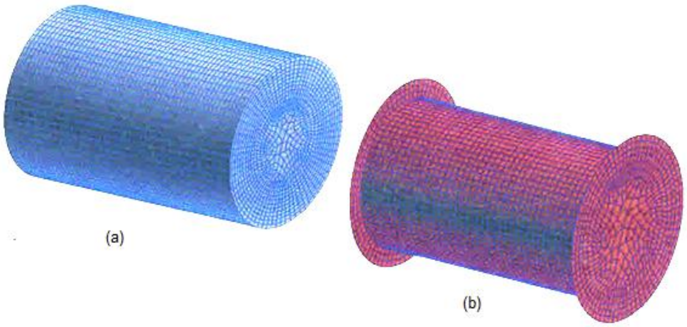

Figure 2: Discretization (a) fluid and explosion and (b) cylinder.

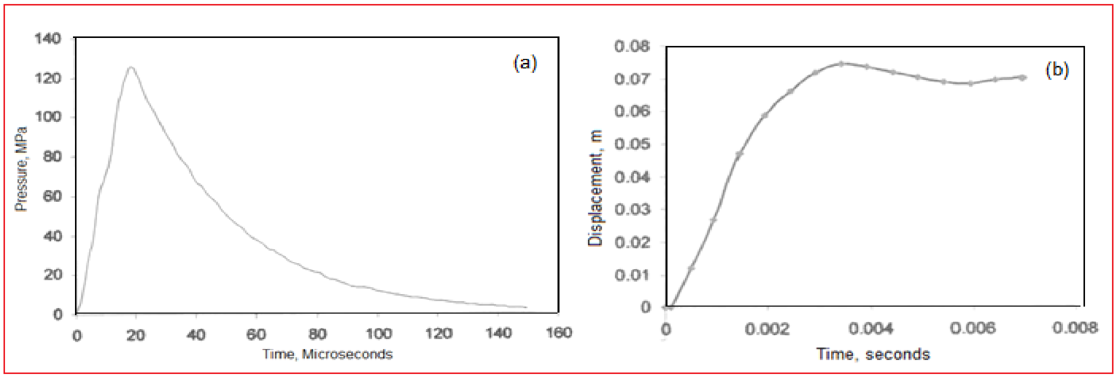

Figure 3: Pressure-time and displacement –time history diagrams.

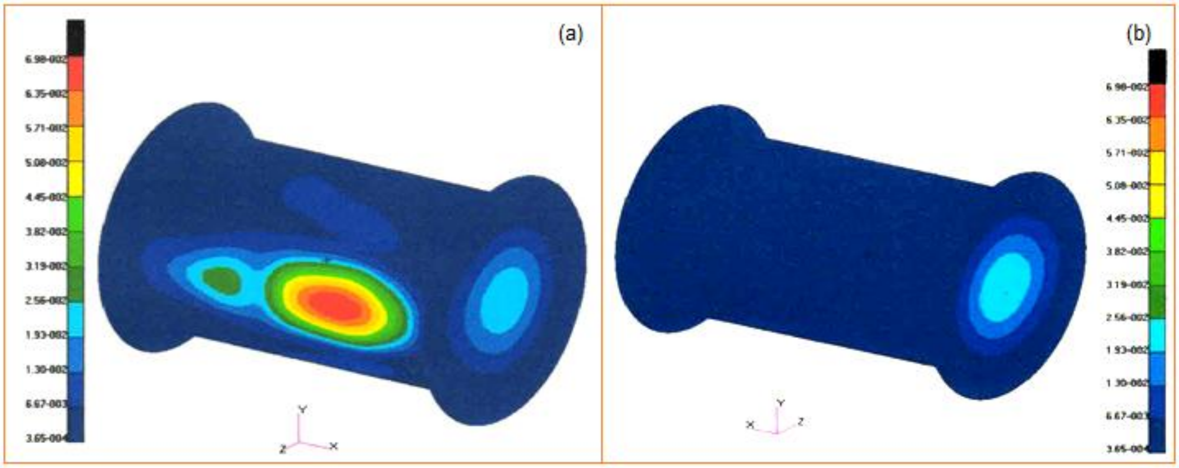

Figure 4: displacement contours of the cylinder.

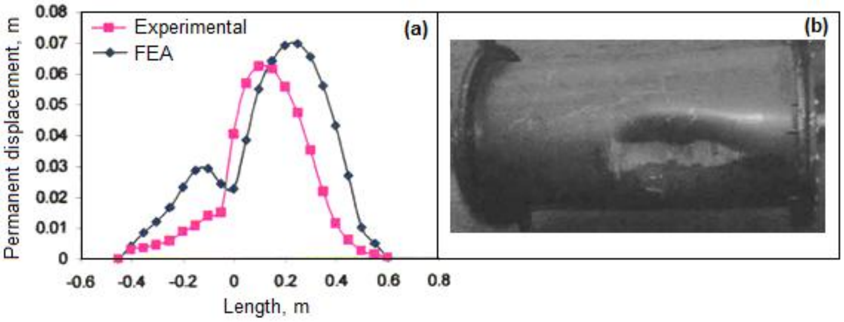

Figure 5: Experimental validation of damage in the cylinder

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