SAND2007-5593C

AN EXPERIMENTAL STUDY OF BUCKLING OF CYLINDRICAL SHELLS SUBJECTED TO STATIC AND DYNAMIC AXIAL IMPACT

A.I.ABAKUMOV, G.A.KVASKOV, V.P.SOLOVYEV, V.V.SINITSYN
RFNC-VNIIEF, Sarov, Nizny Novgorod region, Russia.
(abakumov@vniief.ru)

H.P. WALTHER
SNL, Albuquerque, USA
(hpwalth@sandia.gov)

Presented at the Sixth International Symposium on Impact Engineering, ISIE 2007
Daejeon, South Korea,
September 16-19, 2007

Introduction

The use of thin-wall cylindrical shells in studies of structure response to impact loading requires knowledge of energy absorption parameters of these structures and estimates of resistance forces. Buckling behaviors of cylindrical shells involve formation of both axisymmetric and non-axisymetric folds. An important part of the fold formation process, and, eventually, of the magnitude of energy absorbed, is repeatability of the buckling process in these shells. As shown by experimental results measured without stabilizing devices to prevent formation of non-axisymmetric folds (annular reinforcement, porous filling, etc.), repeatability can be achieved rather rarely.

Theoretical analyses of buckling in cylindrical test unit[1-3] show that the final shape of a deformed unit depends on the loading conditions, as well as geometry parameters and mechanical properties of the test units. In addition, a special role in the deformation of cylindrical shells is played by various kinds of imperfections induced by either the manufacturing process or by the deformation process.

This paper presents experimental results on static and dynamic axial loading of cylinder test units. The goal of this effort is to understand how buckling behaviors depend on test unit scale, material and loading velocity.

Experimental results presented in this paper provide a large scope of information required for investigation of cylindrical shell buckling under static and axial impact loading when axisymmetric or non-axisymmetric buckling shapes develop.

The experimental methodology

The experimental study of cylindrical shell deformation was conducted by subjecting to static and axial impact load cylindrical test units of three sizes: $\varnothing 10\times 0.5\times 30$mm (outer diameter, thickness and height), $\varnothing 20\times 1\times 60$mm and $\varnothing 100\times 5\times 300$mm, with a scale ratio of 1:2:10 (see Fig.1). Test units were made by turning of a whole perform 110mm in diameter of three materials (steel 09G2C and two aluminum alloys, AMg6 and AMc). After fabrication the cylinders were heat treated to relieve internal stresses.

Static loading of samples (loading velocity of ≈2m/min) was perfomed using an INSTRON testing machine (limiting loading force of 10tons) and a hydraulic rupture-test machine (limiting loading force of 100tons).

In impact loading tests, a cylinder unit fixed on a long measuring rod was hit by a projectile moving at a speed of Vo. The experiments were conducted at three impact velocities: Vo ≈10m/s, ≈50 m/s, ≈100 m/s. Loading devices of three types were used. In all these tests, a cylindrical projectile was accelerated in a barrel (the acceleration module) to the required velocity by compressed air pressure from the high-pressure chamber (fig. 2) or air pressure of detonation products from the explosive pressure generator (see Fig. 3,4), after which it hit the test unit.

In the loading device of type 1, (see Fig.2) the acceleration module made as a tube with an inner diameter of 20mm, permits loading of cylindrical projectiles 20mm in diameter and up to 500mm in length to velocities of 10÷100m/s.

Type 2 loading device (see Fig.3), with a working diameter of 8, 20 and 52 mm, can be used for loading of cylinder test units ∅10 and ∅20 mm of aluminum alloys AMc, AMg6 and steel 09G2C at loading velocities of 10, 50 and 100m/s.

Type 3 loading device was used for testing large-diameter cylinders ($\varnothing 100\times 5\times 300$mm) (see Fig.4). With the energy capability of this device, a projectile 360mm in diameter with a mass of ≈40-4000kg can be accelerated by detonation products pressure of a HE charge initiated in the explosive pressure generator to 100-10m/s, respectively. As shown by the operation experience, the optimum projectile mass for this device is within 100kg. A special receiver is used to ensure coaxiality between the projectile and the test unit. The receiver is mounted on the pushing device near the barrel edge.

To study repeatability of buckling for each type of test units differing in their dimensions, material and loading level, at least 5-10 tests were carried out.

Impact velocity and axial compression force history in test units were recorded in each test.

Cylinder test units were installed horizontally in the loading devices and coaxiality was ensured for three objects: projectile-cylinder-dynamometer. Fixation of a cylinder was achieved by placing it between two steel discs. Cylinder edges rested in annular groves in the steel discs with the groove depth $b=2.5h$ (h is cylinder wall thickness), one of the steel discs being rigidly fixed to the dynamometer (see Fig.5). Projectile mass was chosen so that to achieve relative compression of ≈30-50% at a given impact velocity.

Strain curves of the materials used in the tests (AMc, AMg6 aluminum and steel 09G2C) were drawn to analyze the behavior of the cylinder test units (see Fig.6).

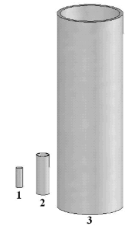


Fig. 1. Cylinder test units

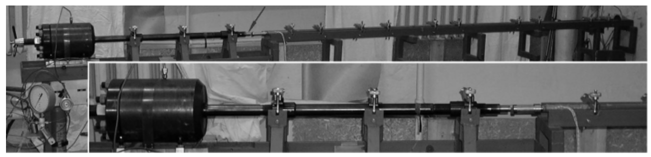


Fig.2. Type 1 loading device

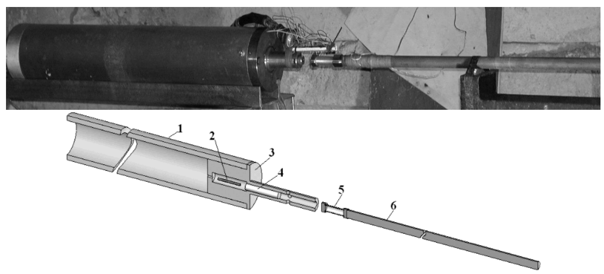


Fig.3. Type 2 loading device (1- protective cylinder; 2- HE charge; 3- casing;4- projectile; 5- cylinder test unit; 6- measuring rod)

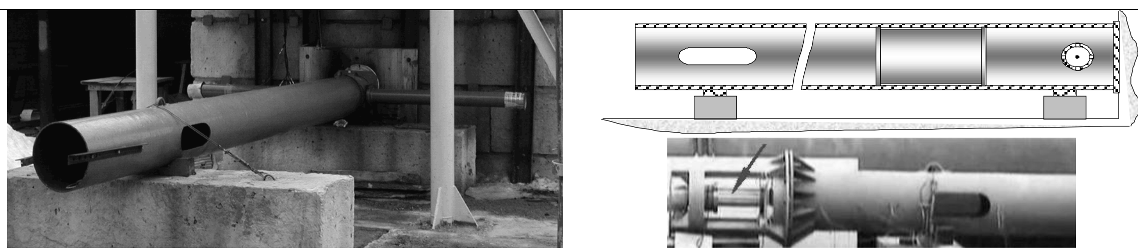


Fig.4. Type 3 loading device

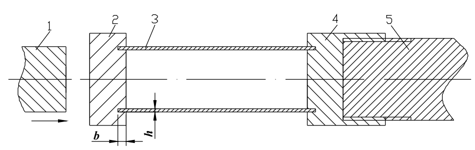
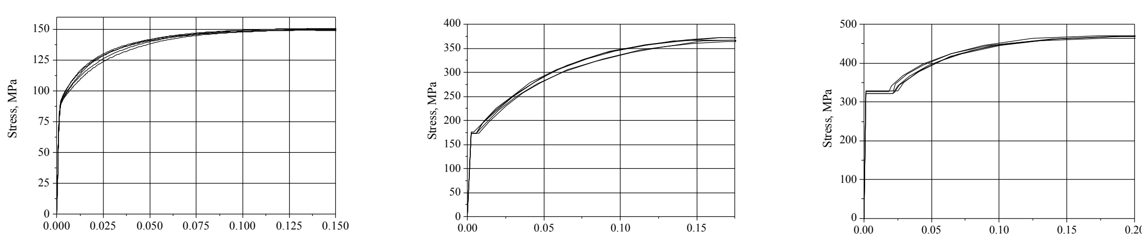


Fig.5. Fixation of a test unit (1-projectile; 2-disc; 3-cylinder test unit; 4-disc; 5-dynamometer)



AMc AMg6 09Г2С

Fig.6. Strain curves of AMc, AMg6 aluminum and steel 09G2C

It is seen from the analysis of the cylinder test results that:

- repeatability is observed only during the formation of the first fold, which is axisymmetric in shape. Further buckling behavior is, in most cases, non-axisymmetric;
- the relative energy absorption under impact loading increases with cylinder dimensions increasing;
- strain rate effect on the materials strength properties is rather clearly pronounced.

Experimental results for cylinders of diameter 10mm

Table 1. Material: aluminum alloy AMc

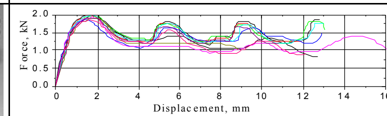
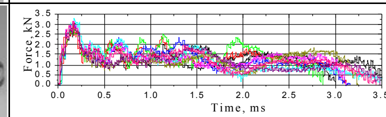
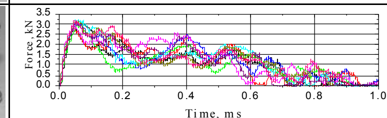
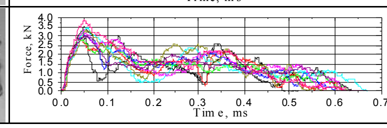
Loading mode	Residual shape	Deformation curves
Static loading		
V≈10m/s		
V≈50m/s		
V≈100m/s		

Table 2. Material: aluminum alloy AMg6

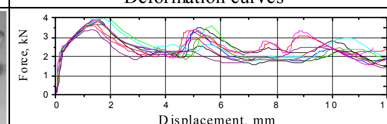
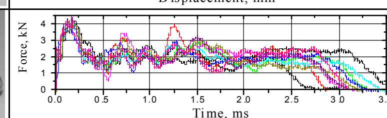
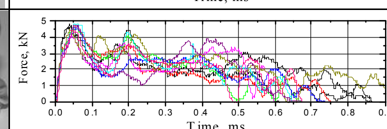
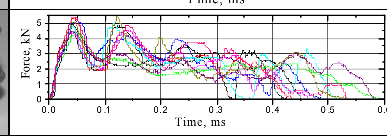
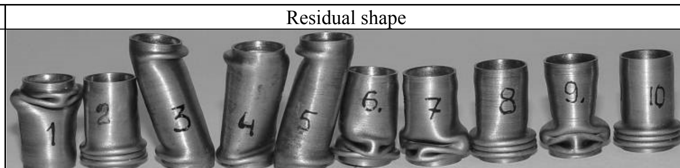
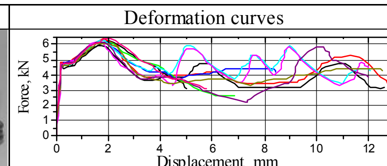
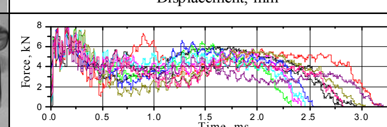
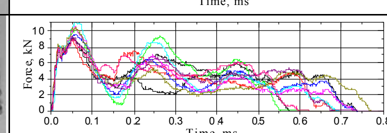
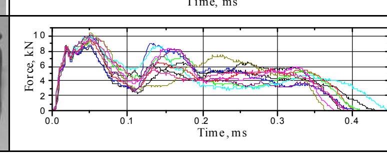
Loading mode	Residual shape	Deformation curves
Static loading		
V≈10m/s		
V≈50m/s		
V≈100m/s		

Table 3. Material: steel 09G2C

Loading mode	Residual shape	Deformation curves
Static loading		
V≈10m/s		
V≈50m/s		
V≈100m/s		

Experimental results for cylinders of diameter 20mm

Table 4. Material: aluminum alloy AMc

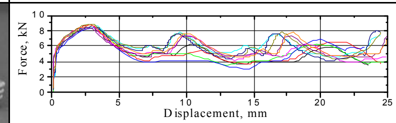
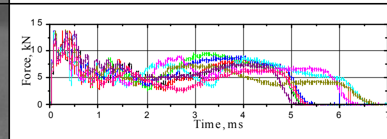
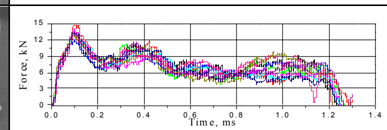
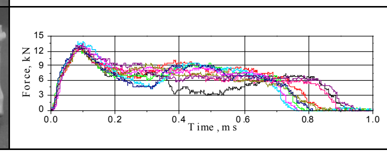
Loading mode	Residual shape	Deformation curves
Static loading		
V≈10m/s		
V≈50m/s		
V≈100m/s		

Table 5. Material: aluminum alloy AMg6

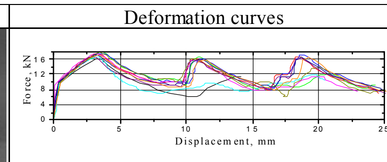
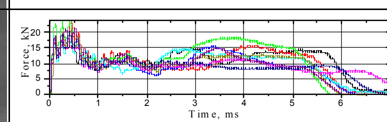
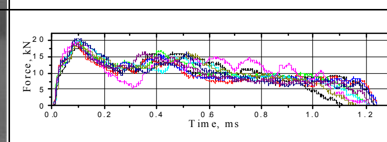
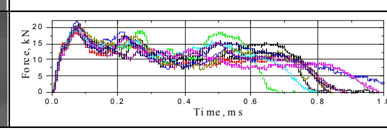
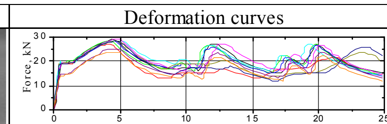
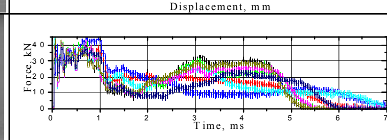
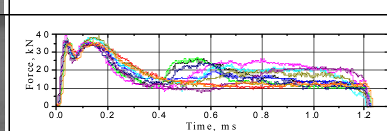
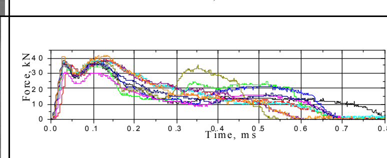
Loading mode	Residual shape	Deformation curves
Static loading		
V≈10m/s		
V≈50m/s		
V≈100m/s		

Table 6. Material: steel 09G2C

Loading mode	Residual shape	Deformation curves
Static loading		
V≈10m/s		
V≈50m/s		
V≈100m/s		

Experimental results for cylinders of diameter 100mm

Table 7. Material: aluminum alloy AMc

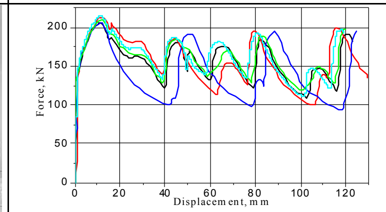
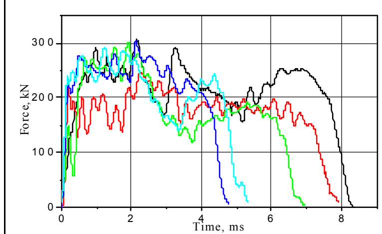
Loading mode	Residual shape	Deformation curves
Static loading		
V≈50m/s		

Table 8. Material: aluminum alloy AMg6

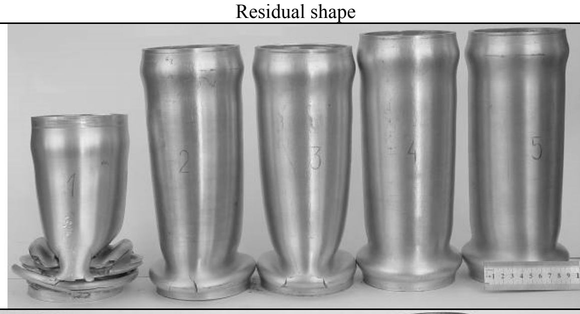
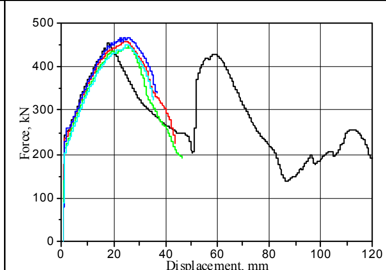
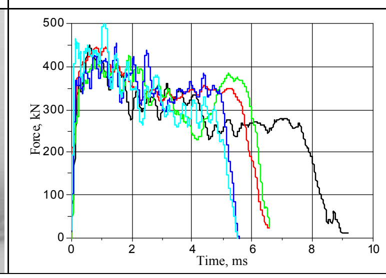
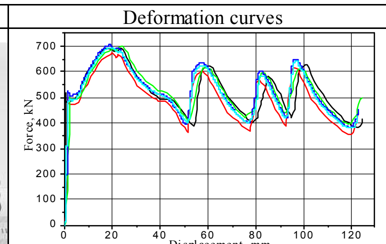
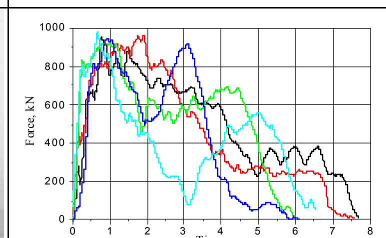
Loading mode	Residual shape	Deformation curves
Static loading		
V≈50m/s		

Table 9. Material: steel 09G2C

Loading mode	Residual shape	Deformation curves
Static loading		
V≈50m/s		

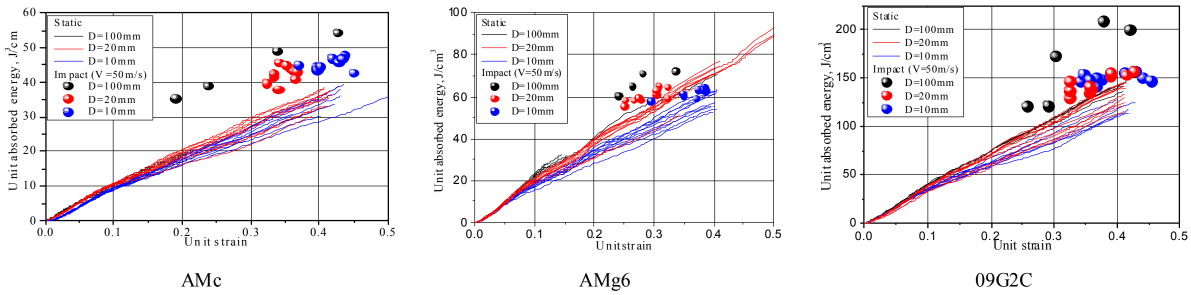


Fig. 7. Relative energy absorbed by test unit as a function of its relative compression under static and impact axial compression for the three materials

Acknowledgements

The work was carried out in the framework of Contract #86220 between SNL (USA) and VNIIEF (Russia)

References

1. K.R.F. Andrews, G.L. England and E. Ghani, *Int J Mecht Sci*. **25**, 613 (1983).
2. Z.G. Wei, J.L. Yu, R.C. Batra. *Int J Impact Eng*. **32**, 575 (2005).
3. D. Karagiozova, M. Alves, N. Jones. *Int J Impact Eng*. **24**, 1083 (2000).

RFNC – VNIIEF

Russian Federal Nuclear Center - The All-Russian Research Institute of Experimental Physics (RFNC - VNIIEF) **-** is a Federal State Unitary Enterprise (FSUE).

SNL - Sandia National Laboratories

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000