International Journal of Impact Engineering 39 (2012) 28–41

Contents lists available at SciVerse ScienceDirect

International Journal of Impact Engineering

journal homepage: www.elsevier.com/locate/ijimpeng

Experimental investigation of axial impact buckling response of pseudo-elastic NiTi cylindrical shells

Zhiping Tang[a,b,*], Dan Li[b,1]

[a] State Key Lab for Explosion Science and Technology, Beijing University of Technology, Beijing 100081, China
[b] Department of Modern Mechanics, University of Science and Technology of China, Hefei 230027, China

ARTICLE INFO

Article history:
Received 17 December 2010
Received in revised form
5 September 2011
Accepted 12 September 2011
Available online 21 September 2011

Keywords:
Cylindrical shells
Impact response
SMA
Phase transformation hinge
Buckling mode

ABSTRACT

The axial dynamic buckling responses of pseudo-elastic NiTi alloy cylindrical shells were investigated experimentally for various length/diameter ratios and end constraint conditions by using a modified single pulse SHPB apparatus. The results show that under single pulse axial loading it will first appear the axisymmetrical buckling waviness and then transit into non-axisymmetric buckling mode. This multiple buckling mode and mode transition behavior is possibly due to the wave effect under dynamic loading. The non-axisymmetric buckling patterns are significantly related to the length/diameter ratio and end constraint condition. The initial defect distribution will affect even dominate the non-axisymmetric buckling pattern. It was observed that multiple phase transition hinges (THs) formed in the specimen, which can increase the energy absorption efficiency. The critical buckling threshold and the energy absorption efficiency under impact loading are much greater than that under quasi-static loading. The THs and the dynamic buckling folds are recoverable for NiTi specimens due to the thermo-elastic austenite–martensite phase transition, which differs substantially from the behavior of the conventional elastic–plastic shells.

1. Introduction

Cylindrical shell structure is one of the basic elements for shock resistance and energy absorption devices and has been studied systematically and applied extensively [1–5]. However, the shock resistance elements made of conventional elastic–plastic metals normally can be used only for once due to the permanent residue deformation and cannot work repeatedly. As a special smart material the shape memory alloy (SMA) is not only a functional material but also an excellent structural bearing material. Its most remarkable features are the ability of large deformation recovery and its original shape remembering, which is supposed to be able to subject multiple impacts. The mechanism of deformation and energy absorption of SMA is due to the thermo-elastic austenite–martensite phase transition. Once the phase transition happens a SMA structure will be composed of a heterogeneous material with different phases. The space–time evolution of phase composition in the structure will affect its dynamic response and generate some new phenomena. To explore these features of SMA structures will be a complicated but interesting problem of mechanics and mathematics.

Only a small amount of literatures regarding the impact responses of basic structural elements with phase transition are reported so far. Zurek et al. [6] conducted the Taylor bar tests for U–Nb (6%) alloy and found that the entire bar had nearly homogenous deformation without forming a mushroom-like end. Similar results were observed in the symmetric impact experiments of NiTi cylindrical bars at SME (shape memory effect) state with a gas gun facility and analyzed with phase transition wave theory by Guo et al. [7] and Xu et al. [8] more systematically. More recently Tang et al. [9] and Zhang et al. [10,11] conducted a series of impact experiments and numerical simulations for NiTi cantilever beams with circular and rectangular cross-sections at PE (pseudo-elastic effect) state and proposed a concept of “Phase transformation hinge, TH”.

Sun et al. [12–14] studied the quasi-static behavior of pseudo-elastic NiTi micro tubes under tensile loading and their work concentrated on the formation and evolution of phase transition zone. Rivin et al. [15] measured the recoverable deformation as great as 60% on thin-walled Nitinol superelastic tubes under radial compression and called it as “giant superelasticity effect”. Recently,

---

[*] Corresponding author. Department of Modern Mechanics, University of Science and Technology of China, Hefei 230027, China. Tel./fax: +86 551 3606754.
E-mail address: zptang@ustc.edu.cn (Z. Tang).

[1] Permanent address: School of Civil Engineering and Architecture, Southwest University of Science and Technology, Mianyang 621900, China.

0734-743X/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijimpeng.2011.09.005

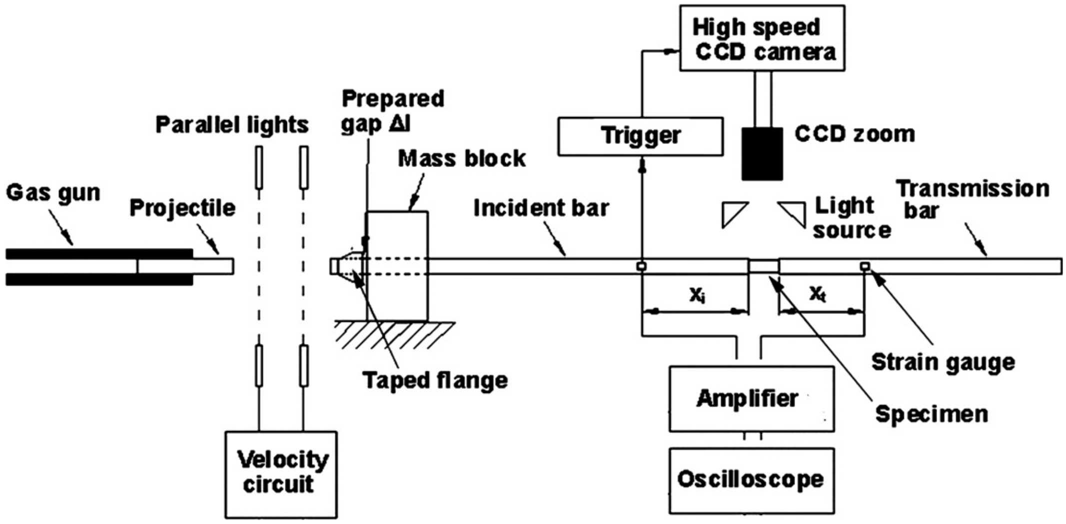

Fig. 1. Schematic of single pulse loading facility and measuring system for axial compression experiments of cylindrical shell specimens.

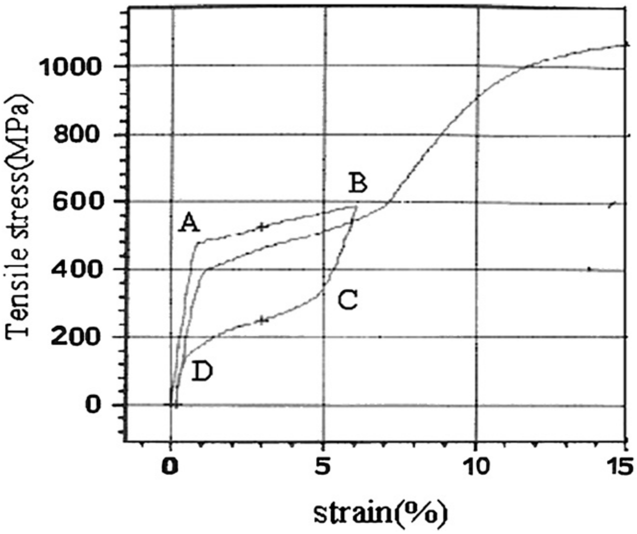

Fig. 2. Test stress–strain curves at $T = 24.3$ °C by NDC.

Tang et al. [16] studied the quasi-static axial buckling features of NiTi thin-walled cylindrical shells and learned the relationship of buckling mode and energy absorption efficiency with different geometries and end constraint conditions. Nemat-Nasser et al [17–19] conducted the quasi-static and impact axial compression investigation for NiTi thin-walled tubes and observed the buckling mode transition from symmetry to non-symmetry. However their SHPB tests did not obtain the entire unloading process due to the multiple loading by the reflected stress waves. The systematic study regarding the whole loading and unloading response and the characteristics of shock resistance and energy absorption for cylindrical shells with phase transition by a single stress pulse has not been reported at the present time.

In this article a modified SHPB apparatus was applied to conduct the single pulse axial impact experiments systematically for NiTi cylindrical shells with various length/diameter ratios and end constraint conditions. A high-speed CCD camera and the plastic strain gauges were used to record the structural buckling process and wave response of the specimens in detail.

2. Experiments

2.1. Experimental setup and measuring methods

For a conventional SHPB apparatus the specimen may subject to multiple loadings due to the stress wave propagation back and forth in the incident bar. Nemat-Nasser et al [20] proposed a method for SHPB to produce a single loading pulse. Song et al. [21] made further simplification. We modified the SHPB apparatus in the lab based on the scheme of Song et al to produce a single loading pulse in the tests as shown in Fig. 1. As the impacting process of projectile on the incident bar has finished the displacement of the flange fixed on the incident bar is just equal to the prepared gap Δl, so the flange will just touch the mass block at that time. When the tension wave reflected from the interface between the incident bar and the specimen comes to the left end of the incident bar and begins to become a right traveling compression wave again, because of the restriction of the mass block against the flange it will generate a right traveling tension wave instead of compression wave to avoid the second compression loading on the specimen. The prepared gap Δl can be calculated as

Table 1
Material parameters of specimens.[a,b]

Type	T_{As} (C)	T_{Af} (C)	σ_{MS} (MPa)	ε_{MS} %	σ_{MF} (MPa)	ε_{MF} %	σ_{AS} (MPa)	ε_{AS} %	σ_{AF} (MPa)	ε_{AF} %	E_A (GPa)	ε_L %
I	−24.78	−4.38	478	0.75	580	5.60	302	4.78	170	0.25	63.7	3.0
II	−23.83	−13.88	446.8	0.85	656	7.67	296	6.60	134	0.40	52.6	5.4

[a] T_{As} and T_{Af} - start and finish temperatures for martensite to austenite transformation, respectively; σ_{MS}, ε_{MS}-martensitic transition start stress and strain; σ_{MF}, ε_{MF}-martensitic transition finish stress and strain; σ_{AS}, ε_{AS}- austenite transition start stress and strain; σ_{AF}, ε_{AF}-austenite transition finish stress and strain; E_A-Young's modulus of austenite phase; ε_L-strain caused by phase transition.

[b] From NiTinol Devices and Components Co.