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Experimental study of SS316L cantilevered cylindrical shells under cyclic bending load

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ABSTRACT

In this research, softening and ratcheting behaviors of SS316L cantilevered cylindrical shells under cyclic bending load were investigated. Experimental tests were carried out by a Servo-Hydraulic INSTRON 8802 machine. Force-control and displacement-control loadings were applied and the effects of displacement amplitude, mean force, loading history and cutout position were examined. Under displacement-control loading, softening behavior was observed due to growth of ovalization and it was shown that as the displacement amplitude increases, softening rate and density of plastic energy increase. Accumulation of the plastic strain or ratcheting phenomenon occurred under force-control loading with nonzero mean force. Increase of the mean force accompanied with an increase in the accumulation of the plastic deformation and its rate. In loading history, it was seen that prior load with higher force amplitude retards the ratcheting behavior and plastic deformation of subsequent load with smaller force amplitude. In addition, due to sensitivity of cutout to the bending moment, as the position of the cutout changes from the middle of shell towards the cantilevered end, the accumulation of the plastic deformation increases.

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1. Introduction

Recently, major parts of structures in different industries are made of shells. Owing to their light weight and high strength, the shells are extensively used in industries. For instance, the shells are employed in aircraft structure, fuselages, wings and tail skinning of airplane, missile bodies. Using the shells is also common in other industries such as automotive, oil and gas reservoirs in petrochemical industries, pipelines, liquid storage tanks, storage silos for plants and cereals grains, pressure vessels, covers, header, etc. The Shells are subjected to different cyclic loads during their lifetime. Although the plastic strain in a cyclic loading might be low, their accumulation in one direction during loading is considerable. This phenomenon is known as cyclic plasticity or ratcheting. Since the ratcheting is a cycle-to-cycle accumulation under cyclic stress with nonzero mean stress, it is difficult to simulate and determine its precise behavior. Moreover, the cyclic structural models derived from experimental results are not able to predict the ratcheting completely. Therefore, the issues of the ratcheting and plastic deformation have been studied seriously for the last two decades. One of the hurdles in experimental studies on the cylindrical shells is the manufacturing of their special fixtures which makes it relatively less studied. Chen et al. [1] conducted some experimental tests concerning the examination of the fatigue and the ratcheting of high-nitrogen steel X13CrMnMoN18-14-3 under uniaxial loading and studied the effects of the stress amplitude, mean stress, loading history and rate of stress on the ratcheting behavior of such steels. Kang et al. [2] studied the effects of the ratcheting and fatigue of SS304 stainless steel in uniaxial loading under force-control conditions at room temperature. They observed that its ratcheting strain and fatigue lifetime greatly depend on the mean stress, stress amplitude and stress ratio. Jain et al. [3] investigated the effect of connection flexural strength and member on the hysteresis behavior of square tubes with welded gusset plates under cyclic axial loading. In another work, they [4] carried out experimental tests on steel tubes under cyclic axial loading to study the effect of mode of buckling and the shape of cross section on the hysteresis behavior and energy dissipation through hysteretic cycles. Also under cyclic loading with non-zero mean stress, some of the structures are equipped with cutout or crack. In this case, the crack growth occurred near the imperfection and the rate of ratcheting was increased [5]. Shariati and Hatami [6] conducted an experimental study on SS304 stainless steel cylindrical shells under cyclic axial loading. They observed the ratcheting phenomenon in force-control loading with nonzero mean force and

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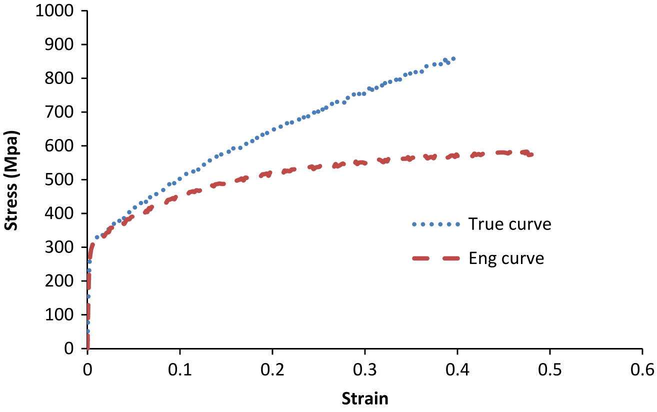

Fig. 1. Stress–strain curve of SS316L specimen.

Table 1
Geometrical and mechanical properties of SS316L.

External diameter	$D=34$ mm
Thickness	$t=1$ mm
Length	$L=187$, 235, 160, 165 mm
Modulus elasticity	$E=187.7$ (Gpa)
Yield stress	$\sigma_y=290$ MPa
Ultimate stress	$S_u=859.61$ MPa
Poisson's ratio	$0.33=\nu$

the softening behavior in displacement-control loading which increased due to buckling in compressive loading. Also cutout gives rise to an extreme ratcheting behavior in cylindrical shell. An increase of cutout radius intensified the ratcheting strain as well.

Bending load acting on a long cylindrical shell could widely be found in engineering applications. Therefore the majority of experimental tests on cylindrical shells [7–13] were performed under the cyclic bending load conditions. Kulkarni et al. [14] studied the ratcheting behavior of straight tubes using four-point bending and three-point bending fixtures and compared the results with Chaboche model in ANSYS [15]. Ferry et al. [16] studied the fatigue behavior of epoxy composite bars under the torsional and bending loads. Gao et al. [17] conducted an experimental study on the ratcheting behavior of carbon steels using quasi three-point bending fixture. In multistep bending loads, they observed a raise in the rate of ratcheting strain with increasing the load. Syed et al. [18] focused on the radial and circumferential ratcheting strain behaviors of a steel straight tube under the bending load and steady internal pressure. By drawing a moment-displacement diagram, it was seen that it is more desirable to simulate the ratcheting strain using structural multi-linear models. Zakavia et al. [19] studied the ratcheting behavior of stainless and carbon steel pipes with minimum diameter-to-thickness (d/t) ratio within the range of 8–28. The pipes were exposed to the cyclic bending moment and the ratcheting strains were observed. They studied the ratcheting behavior of the shell using finite element analysis through nonlinear isotropic/kinematic hardening model. Comparison of the numerical and experimental results showed that the rate of initial ratcheting strain is very high and decreases as the number of cycles increases. Zhu et al. [20] carried out an experimental study on the tensile and the ratcheting properties under the cyclic bending load for Z2CND18.12 steel bar and studied the relationship between the Young's modulus and temperature. They observed that the ratcheting strain depends on the rate of temperature. Kyriakides and Shaw [21] observed that on unloading a tube bent into the plastic range, a residual permanent ovalization of the cross section could be measured. Also, they [22] provided some experimental results of inelastic buckling for aluminum and steel tubes under cyclic bending histories. They found that under curvature-symmetric loading histories the tube progressively ovalizes to a critical value at which it buckles.

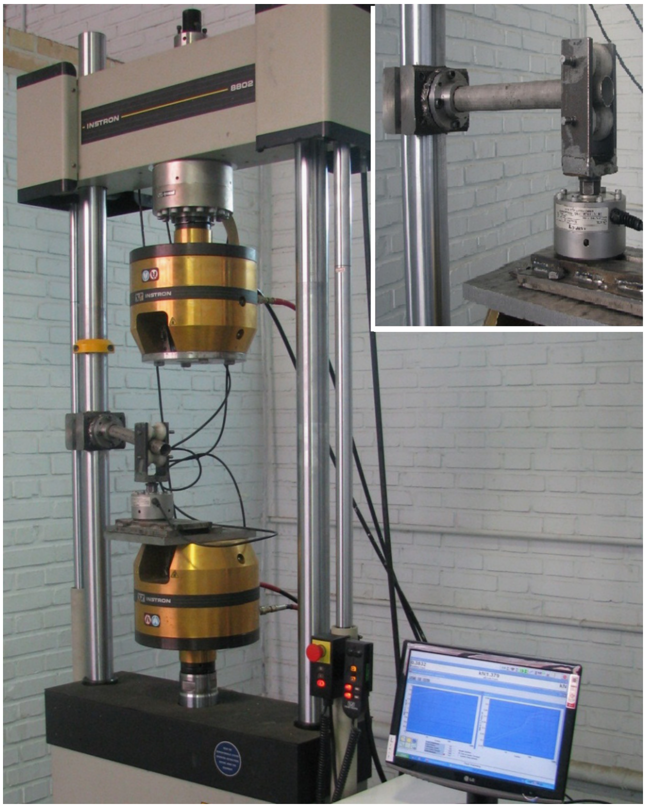

Fig. 2. INSTRON 8802 servo-hydraulic machine.

This article studies the cantilevered cylindrical shells under force-control and displacement-control cyclic bending loads and the effects of ovalization, mean force and loading history are discussed. Also creating a circular cutout at different positions along cylindrical shells shows that the rate of accumulation of plastic deformation is higher in the samples with cutouts at cantilevered end points where the highest bending moment is presented.

2. Geometry and mechanical properties of cylindrical shell

The samples under the test were cylindrical shells made of SS316L steel. The standard tensile test was used according to ASTM-E8 standard to obtain the mechanical properties of the steel shell [23]. Fig. 1 shows the stress–strain curve of SS316L steel obtained from the standard tensile test.

The yield stress of SS316L steel is determined by drawing 0.2% line. In this research, the length of cylindrical shell is shown by L and the distance between the cantilevered end of the shell and the center of cutout is shown by L0. Dimensions and the mechanical properties of the shell are shown in Table 1.

3. Experimental procedure and results

The tests were performed by a 250 kN Servo hydraulic INSTRON 8802 machine. In order to apply low-force, a loadcell with load capacity of 25 kN was used (Fig. 2). An extensometer was used in the standard tensile test to measure the displacement with higher accuracy. The experimental tests were conducted

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