ISME2012-XXXX

Experimental investigations on the softening and ratcheting behavior of steel cylindrical shell under cyclic axial loading

Hossein Hatami[1], Mahmoud Shariati[2], Mohammad Damghani Noori[3]

[1]Semnan University, Mechanical Faculty; h64hatami@gmail.com
[2]Shahrood University of Technology; Mechanical Faculty, mshariati44@gmail.com
[3]Semnan University, Mechanical Faculty; damghani63@gmail.com

Abstract
In this paper we analyze the behavior of hysteresis curves of CK20 alloy steel cylindrical shells under various types of axial cyclic loadings. Due to occurrence of local buckling in sections which are under compressive loads and also due to decrease of cross section in regions which are under tensile loads, hysteresis curves show different behavior in compression and tension regions over cyclic loadings. Under displacement-control loading condition, by increasing of displacement amplitude we can see softening behavior in specimens. Softening rate is higher in regions which are under compressive loading due to creation of local buckling. Under axial asymmetric force-control loading condition, we can see ratcheting behavior in shells and by increasing of displacement amplitude, ratcheting rate is increased and the shell is failed over few cycles.

Keywords: Cylindrical shell, Hysteresis curve, Cyclic axial loading, Ratcheting, Softening

1.Introduction

Shells have numerous applications in aerospace industries as airplanes and missiles and also in pipelines, marine structures, power plants and nuclear plants. These shells are under various axial cyclic loadings over their life cycle which causes their life to be decreased. Earthquakes are natural loadings which can be applied on these shells [1]. There are just a few numbers of researches in this field due to difficulties of experimental tests especially in this field. A study has been done on stainless steel shells and showed that the displacement amplitude and buckling of shells which are under axial cyclic loadings is less than that of monotonic compressive loadings [2]. Most of experimental studies on cylindrical shells have been carried out by employing cyclic bending loadings [3-6].

A recent study on cylindrical shells under internal compression has been revealed that some parameters including the number of loading cycles, mean stress and stress amplitude are critical factors resulting in the failure of specimens under axial cyclic loadings [7]. Also another experimental study has been done on cylindrical shells made from magnesium alloys under cyclic loadings. Also the behavior of hysteresis loops of this specimen has been also analyzed [8-11]. There is another experimental research about shells with square and rectangular cross sections under axial cyclic displacement-control loadings by which the buckling behavior of hysteresis loops are investigated [12]. Unfortunately, there are just few researches about ratcheting behavior of cylindrical shells under axial cyclic loading conditions, especially those which are made from steel alloys.

In this paper we analyze the behavior of hysteresis curves of cylindrical shells under various types of axial cyclic loadings conditions. We also investigate the influences of force amplitude and also mean force parameters on cylindrical shells that made from CK20 alloy steel. We apply various types of loadings on specimens, step by step and also study the influence of loading history on the behavior of hysteresis loops.

Experimental tests

Experimental tests are carried out by a INSTRON 8802 servo-hydraulic machine. Loads are applied on cylindrical shells in the form of cyclic loadings in both displacement-control and force-control conditions. The number of cycles applying on specimens ranges from 1 to 1000 cycles depending on test type. Fig. 1 shows the setup of experimental tests. In order to make sure that the fixtures will not be loosen during tests, in addition to threading specimen to fixture, we use a fastening pin to connect specimen to fixture as Fig.2. In Fig. 2, part no.1 is the fixture which should be fitted to the machine's jaw. Part no.2 is used to tight cylindrical shell in the fixture. We also use part no.2 for connecting the shell to the fixture because it is impossible to thread the cylindrical shell due to its thickness limitations. Part no.3 is partial of cylindrical shell specimen.

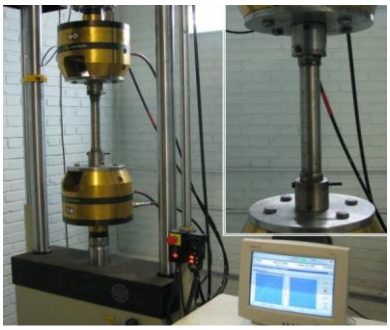

Figure 1: cylindrical shell under loading condition by servo-hydraulic machine model INSTRON 8802

2.Geometry and mechanical properties

Cylindrical shells specimens are made of CK20 alloy steel with dimensions shown in table 1. Mechanical properties of this material are obtained according to ASTM E8 standard [13]. Fig.3 shows stress-strain curve of this material.

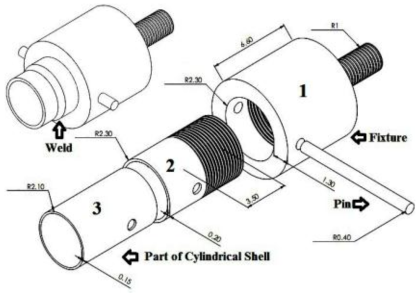

Figure 2: schematic layout of typical connections between shell and fixture through welding, thread and use of pin

Table1.Geometrical and mechanical properties of cylindrical shell

D(mm)	t(mm)	E(GPa)	σ_y (MPa)	S_u (MPa)	υ
42	1.5	201	405	590	0.33

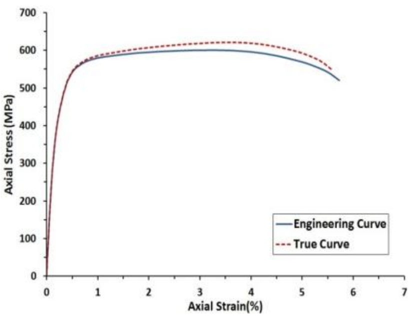

Figure 3: stress-strain curve of CK20 steel

3.Experimental results and discussion

3.1.Displacement-control tests

3.1.1.Influence of displacement amplitude on behavior of hysteresis loops

Loading under symmetric displacement-control are applied in three increment steps of displacement amplitude, i.e.: $\delta x/2$ =1.75, 2, 2.2mm, up to the failure of specimens.

Fig.4 shows maximum values of tension and compression forces in each cycle versus the total numbers of cycles up to the failure of specimens. We can see that by increasing of displacement amplitude, the slope of softening curve is increased in both tension and compression regions. Also the specimens are failed in few initial cycles. In these tests the failure was occurred in cycles 65, 25 and 13 corresponding to the order of increasing of amplitudes. In tension regions, hysteresis curves show hardening behavior within few initial cycles and then show softening behavior.

Fig. 5 shows mean force variations within each hysteresis loop versus the numbers of cycles up to the failure of specimens. Mean force for each hysteresis loop equals to the average of sum of maximum tension and compression forces in the same loop. Increasing of mean force shows that softening rate in compression regions of hysteresis curves, is higher than that of tension regions. In larger displacement amplitudes, the value of mean force is increased rapidly and with displacement amplitude 2.2mm, the value of mean force is a positive amount in final cycles. The value of mean force in first hysteresis loop is more negative for smaller displacement amplitudes. This behavior reveals that endurance capacity of compression sections is higher than tension sections, but in larger displacement amplitudes, the mean force of the first hysteresis loop is being approached to zero due to appearance of local buckling in compression sections of the specimens.

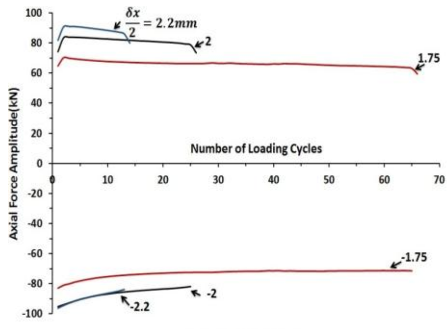

Figure 4: variations of force amplitude versus the numbers of cycles for cylindrical shells with 250mm length under displacement-control loading with amplitudes 1.75, 2 ,2.2 mm

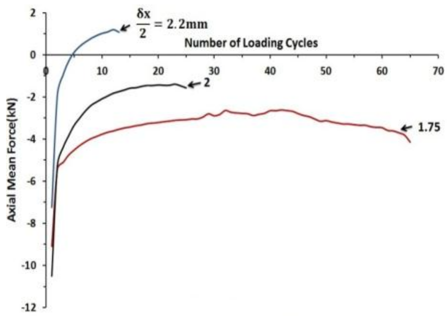

Figure 5: variations of mean force versus the numbers of cycles for cylindrical shells with 250mm length under displacement-control loading with amplitudes 1.75, 2 and 2.2mm.

3.1.2.Influence of increasing of displacement amplitudes step by step on softening behavior of specimens

A displacement-control loading is applied on a specimen with 250mm length step by step as follow: 5 cycles for displacement amplitudes 0.5 and 0.75 mm and 10 cycles for displacement amplitudes 1, 1.25, 1.5 and 1.75mm up to the failure of the shell. Fig. 6 shows variations of force amplitudes versus the total numbers of cycles in the same specimen. We can see that by increasing of displacement amplitude, softening rate in both tension and compression regions is increased, but in larger displacement amplitudes, softening rate in compression region is higher. This behavior is due to local buckling of compression regions. In larger displacement amplitudes, in few initial cycles, there is hardening behavior in tension regions, but after initializing, softening behavior is proceed.

3.2.Force-control tests

3.2.1.Influence of force amplitude on behavior of hysteresis loops

In Fig. 7, We can see that three cylindrical shells with length 250mm under symmetric force-control loading with amplitudes 70, 75 and 80 kN the displacement amplitude of tension regions is more than compression regions. By increasing of force, the increasing of displacement amplitude of tension regions would be higher than compression regions. Also in this case, specimens fail very fast. For example, regarding to the order of increasing of force, the numbers of cycles in which failure of specimen occurred, are 111, 58 and 18 respectively. Fig. 7 shows variations of displacement amplitudes versus the numbers of cycles up to the failure of specimens. It is clear that, by increasing of force, the displacement amplitudes of compression regions are not increased in accordance with tension regions and with forces 70 and 75 kN, the displacement amplitudes in compression region are nearly coincidence. In force equals to 85kN, the increasing of displacement amplitude is higher than numbers of cycles.

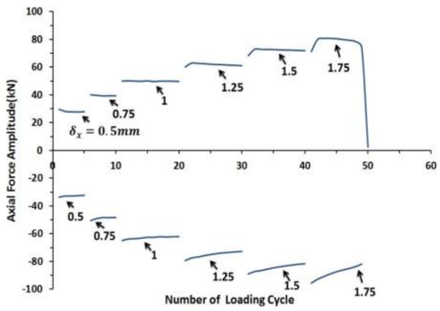

Figure 6: variations of force amplitudes versus the numbers of cycles in a specimen with 250mm length and increasing of amplitudes from 0.5mm to 1.75mm

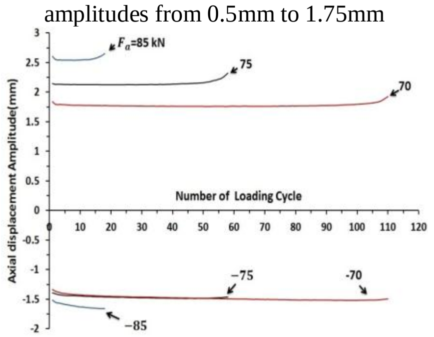

Figure 7: variations of displacement amplitudes versus the numbers of cycles for cylindrical shells with length 250mm under symmetric force-control loading with amplitudes 70, 75 and 80kN.

We can conclude from Fig. 7 that by increasing of the numbers of cycles, the increasing rate of displacement amplitude in compression regions is higher than tension regions. Also we can see in Fig. 8 that the displacement of center of hysteresis loops is decreased gradually and is increased immediately during failure. As displacement amplitudes of tension regions are always higher than compression regions, the value of displacement of center of hysteresis loops is always positive.

3.2.2.Influence of force amplitude and mean force on the ratcheting behavior of cylindrical shells

Fig. 9 shows two different tests carried out on cylindrical shells under force-control loading with non-zero mean force. Under this type of loading condition, these specimens show ratcheting behavior and during consecutive cycles up to failure of shells, the accumulation of plastic displacement is continued.

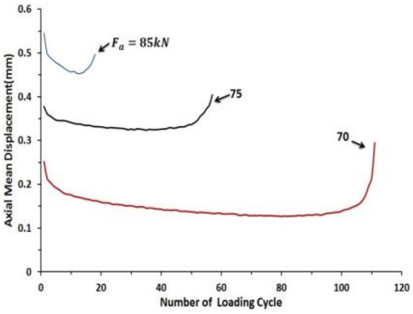

Figure 8: variations of center of hysteresis loops versus the numbers of cycles for cylindrical shells with length 250mm under force-control loading with amplitudes 70, 75 and 80 kN.

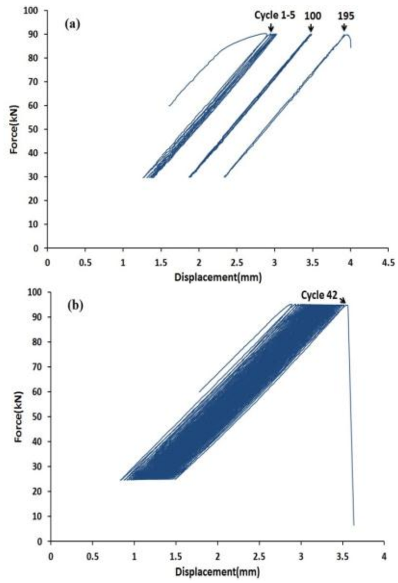

Figure 9: ratcheting behavior in cylindrical shells. a) specimen length 300mm, mean force value, 60kN and force amplitude, 30kN, b) specimen length 360mm, mean force value, 60kN and force amplitude, 35kN.

Fig. 10 shows different specimens under various types of loading conditions with mean force, 60 kN and various force amplitudes. We can see that in various lengths, by increasing of force amplitude, the slope of ratcheting displacement curve is increased resulting in failure of shells. Fig 10-a shows two specimens with lengths 300mm which are under force-control loading with mean force, 60kN and force amplitudes, 25 and 30 kN. We can see that the specimen which is under force amplitude, 30kN is failed in 195th cycle. The same specimen can withstand against failure up to 1000th cycle under force amplitude 25KN. We also can see in Fig 10-b that a specimen with length 360mm and under higher values of force amplitudes can withstand against 42 cycles before failure, whereas under force amplitude, 30kN, the same specimen can withstand against failure up to 1000th cycle.

As we use welding operation to join the cylindrical shells to the fixtures, the ultimate strength of shells is weak near to the welded spots and for this reason the failure of shells occurs generally in welded spots[12]. Also in compressive loadings, shells buckle near to fixtures. Fig. 11 shows a few numbers of specimens which has been failed near to welded spots and also buckling of shells.

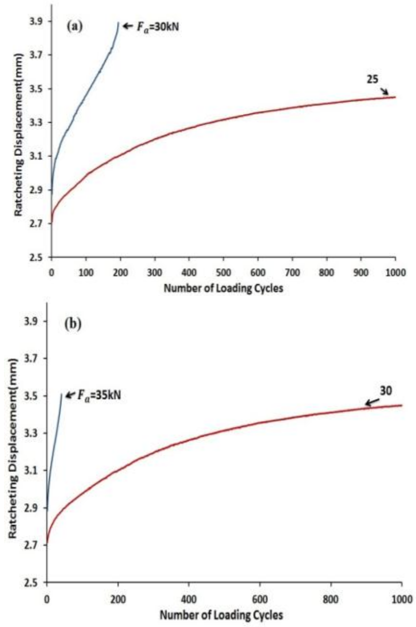

Figure 10: comparison of ratcheting behavior of cylindrical shells under mean force 60kN and various force amplitudes; a) specimen length, 300mm; b) specimen length, 360mm

Figure 11: a) a few numbers of tested cylindrical shells; b) failure of specimen near to the welded spots; c) buckling of specimens near to welded fixtures.

Conclusions

According to the experimental test carried out on cylindrical shells under axial cyclic loadings and by comparison of hysteresis loops, we can reach to following results:

1- Under axial symmetric displacement-control loading conditions, increasing of displacement amplitude leads to increasing of softening rate of specimens. In this case local buckling occurs in specimens in the compression region and softening rate in compression region will be higher than tension region. Also under this type of loading, the obtained mean force for each hysteresis loop is negative. The reason is this fact that in similar displacement amplitudes, the endurance capacity of specimens under compressive forces is higher than tensile forces. This behavior is due to mechanical properties of CK20 alloy steel.

2-Under axial symmetric force-control loading conditions, by increasing of force amplitude, displacement amplitude is increased rapidly and its value in compression region is higher than tension region. But before buckling of the specimens, they fail in tension region. For this, at first the displacement amplitude of centers of hysteresis curves is decreased and then is increased rapidly. As the displacement amplitude of tension region is higher than compression region during loading, the displacement amplitude of centers of hysteresis curves is always a positive value.

3-Under force-control loading conditions and in the presence of non-zero mean force, ratcheting occurs in shells. With similar lengths and mean force, by increasing of force amplitude, ratcheting behavior of shells is increased .

References

[1] Kulkarni, S.C., Desai, Y.M., Kant, T., Reddy, G.R., Prasad, P., Vaze, K.K., Gupta, C., 2004, "Uniaxial and biaxial ratcheting in piping materials experiments and analysis", International Journal of Pressure Vessels and Piping, 81, 609-617.

[2] Yoon, S., Hong, S.G., Lee, S.B., Kim, B.S., 2003, "Low cyclic fatigue testing of 429EM stainless steel pipe", International journal of fatigue, 8, 1301-1307.

[3] Chang, K.H., Pan, W.F., Lee, K.L., 2008, "Mean moment effect of thin-walled tubes under cyclic bending. Structural Engineering and Mechanics". 28(5), 495-514.

[4] Rahman, S. M. Hassan, T. Corona, E. 2008, "Evaluation of cyclic plasticity models in ratcheting simulation of straight pipes under cyclic bending and steady internal pressure", International Journal of Plasticity, 24, 1756-1791.

[5] Chang, K.H. Pan, W.F. 2009, "Buckling life estimation of circular tubes under cyclic bending", International Journal of Solids and Structures, Volume 46, Issue 2,Pages 254-270.

[6] Zakavi, S.J., Zehsaz, M., Eslami, M.R., 2010, "The ratcheting behavior of pressurized plain pipework subjected to cyclic bending moment with the combined hardening model", Nuclear Engineering and Design,240, 726-737.

[7] Jiao, R., Kyriakides, S., 2009, "Ratcheting, wrinkling and collapse of tubes under axial cycling", International Journal of Solids and Structures, Volume 46, Issues 14-15, Pages 2856-2870.

[8] Lin, X.Z., Chen, D.L., 2008. "Strain controlled cyclic deformation behavior of an extruded magnesium alloy". Materials science and engineering A, 496, 106-113.

[9] Li, Q., Yu, Q., Zhang, J., Jiang, Y., 2010. "Effect of Strain amplitude on tension-compression fatigue behavior of extruded Mg6Al1ZnA magnesium alloy". Scripta Materialia, 62, 778-781.

[10] Zhang, J., Yu, Q., Jiang, Y., Li, Q., 2010. "An experimental study of cyclic deformation of extruded AZ61A magnesium alloy". International Journal of Plasticity.

[11] Yu, Qin., Zhang, J., Jiang, Y., Li, Q., 2011, "Multiaxial fatigue of extruded AZ61A magnesium alloy",International Journal of Fatigue,33,437-447.

[12] Goggins, J.M., Broderick, B.M. Elghazouli, A.Y., Lucas, A.S., 2005. "Experimental cyclic response of cold-formed hollow steel bracing members". Engineering Structures. 27, 977-989.

[13] ASTM A370-05, Standard test methods and definitions for mechanical testing of steel products.