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The Investigation of Cyclic Behavior of SS316L Cubic Shells under Pure Torsional Load

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1. Introduction

Cylindrical and cubic shells are frequently used in the manufacturing of aircrafts, missiles, boilers, pipelines, automobiles, and some submarine structures because of their excellent properties, such as high strength and stiffness, light weight, and excellent loading-carrying efficiency.

In this paper, cubic shells were placed under torque-control and angle of torsion-control cyclic pure torsional loading and the effect of amplitude torque, angle of torsion and softening are investigated. The results obtained in this study are very useful to understand the cyclic behavior of cubic shells under pure torsional loading. Additionally, a finite element analysis with the nonlinear isotropic/kinematic hardening model is used to compare numerical results with those obtained from experimental set-up.

2. Material and Procedures

In this study cubic shells are made from SS316L with cubic cross section. The length and thickness of cross section are 30mm and 0.9mm, respectively. The experimental device used in this study was a 250 kN servo hydraulics INSTRON 8802 machine. In order to perform cyclic pure torsional load on cubic shells, a fixture is needed. It is able to apply a couple force in reciprocating directions that only impose a cyclic torsional torque on the free end of the shells. This kind of loading causes the rotation of shells around its axis (Figure 1).

3. Finite element method

The numerical simulation was carried out using the ABAQUS finite element software. In order to analyze the cubic shells which was subjected to cyclic torsional loading, a nonlinear isotropic/kinematic (combined) hardening model was used. When temperature and field variable dependencies are omitted, the kinematic hardening component is as follows:

$$\alpha = C\frac{1}{\sigma^0}\left(\sigma_{ij}-\alpha_{ij}\right)\dot{\varepsilon}^{pl}+\frac{1}{C}\dot{C}\alpha_{ij} \qquad (1)$$

In order to improve this equation, a nonlinear term was added to equation 1, so we can rewrite equation 1 as below:

$$\alpha = C\frac{1}{\sigma^0}\left(\sigma_{ij}-\alpha_{ij}\right)\dot{\varepsilon}^{pl}-\gamma\alpha_{ij}\dot{\varepsilon}^{pl}+\frac{1}{C}\dot{C}\alpha_{ij} \qquad (2)$$

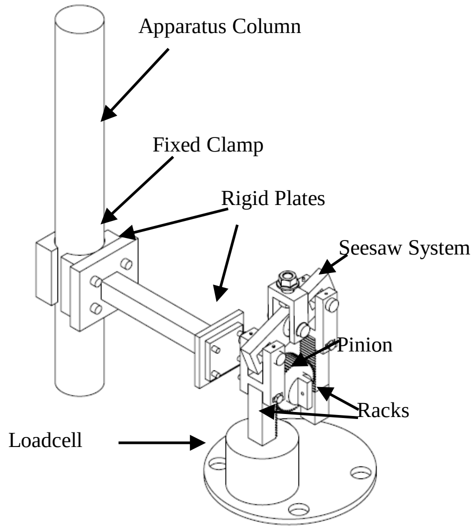

Fig. 1. Pure torsional loading fixture

The isotropic hardening behavior of the models defines the evolution of the current yield surface as a function of the equivalent plastic strain ε_{pl}. This evolution can be introduced by using the simple exponential law in Eq. (3):

$$\sigma^0 = \hat{\sigma}_0 + Q_\infty\left(1-e^{-b\bar{\varepsilon}^{pl}}\right) \qquad (3)$$

4. Experimental Results

Figure 3 shows the ratcheting angle of cubic shell under pure torsional load with different torsion amplitude and constant mean torsion load.

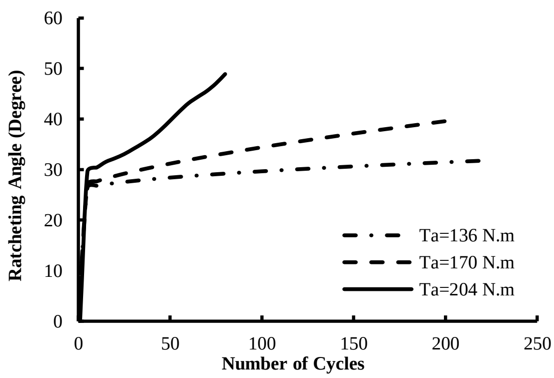

Fig. 2. Ratcheting angle vs. number of cycles for cubic shell with circular cutout in different positions

Results show that the ratcheting angle of cubic shells increases when torsion amplitude rises. The effect of

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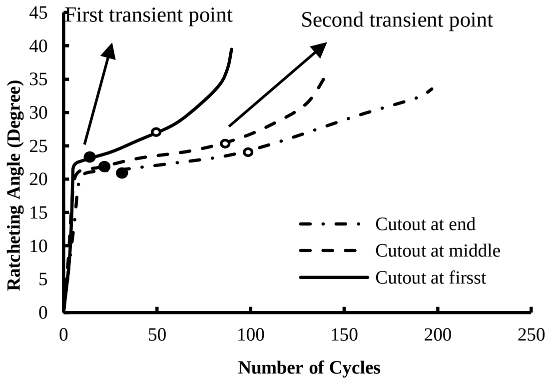
cutout position on the ratcheting behavior of cubic shells is investigated. Figure 3 shows the results of the position of cutout on the ratcheting behavior of cubic shells under pure torsional load.

4. Finite element method results

The results of finite element method using ABAQUS software for predicting the ratcheting behavior of cubic shells under pure torsional loading was in good agreement with the experimental results. For example Figure 4 shows the comparison of ratcheting angle predicted by FEM with experimental results.



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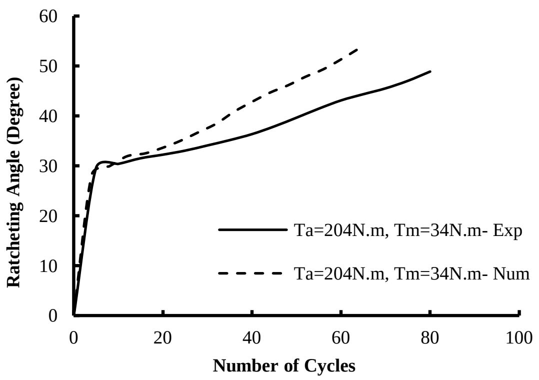
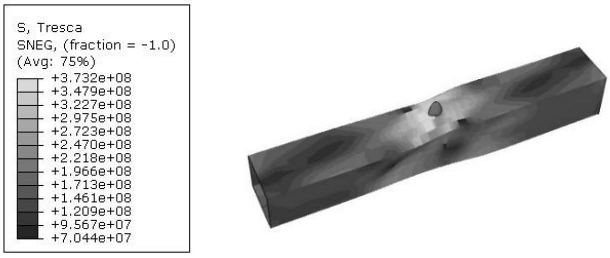


Fig. 4. Comparison of experimental results with finite element method of ratcheting angle for cubic shell under torsional loading with amplitude of 204N.m and mean magnitude of 34N.m

Figure 5 compares experimental and FEM results for deformation of cubic shell with circular cutout with diameter of 8mm in symmetric torque-control condition with amplitude of 170N.m and mean magnitude of 34N.m.

As shown in Figure 5, it can be concluded that using a nonlinear isotropic/kinematic (combined) hardening model can simulate deformation of cubic shells under pure torsion loading conditions.

(a)



(b)

Fig. 5. Deformation in cubic shell with circular cutout with diameter of 8mm in symmetric torque-control condition with amplitude of 170N.m and mean magnitude of 34N.m. a) Experimental result, b) Numerical result

5. Conclusion

1- Increasing in torsion amplitude magnitude causes an increase in ratcheting angle of cubic shells.
2- Experiments and finite element method results show that finite element method using a nonlinear isotropic/kinematic (combined) hardening model is able to predict ratcheting behavior of cubic shell with a good agreement with the experimental results.
3- Due to larger shear stresses around the cutout in cubic shell with larger cutout, ratcheting angle and its rate become larger and transition point will occur sooner.
4- Cubic shells under pure torsion loading in angle-control conditions show softening behavior and it was shown that in such a this conditions, there are three regions such as incubation, transition and steady-state.