A study on the Zircaloy ring tensile test

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1. Introduction

The fracture of Zirconium alloy cladding is mainly caused by load applied in the hoop direction. Therefore evaluation of mechanical properties in the hoop direction is required.

There are two methods for evaluating mechanical properties : ring tensile test and burst test. The ring tensile test has advantages over burst test, especially hot cell test, that is, requirement of smaller specimen volume, easier specimen preparation and set up in the test apparatus. However the main shortcomings of the ring tensile test are the non-uniform distribution of strain and stress in the specimen and presence of bending moment.

In this study, evaluation of mechanical properties in hoop direction was performed by ring tensile test with finite element modeling (FEM).

2. Experimental

2.1 Review of ring specimen

The ring tensile test results are depends on shape of ring specimen and mandrel. The smooth ring specimen and D-shaped 2 half mandrels are used in the classic ring test (Fig. 1(d)). However the method has the shortcomings which are the non-uniform distribution of strain and stress in specimen and bending moment. Also it does not have a gauge section. Therefore, notched specimen is generally used in ring tensile test. Arsene[1] proposed to minimized bending moment using dog bone shaped central piece with notched specimen which made uniform gauge section(Fig. 1 (b)). Also, Nagase[2] minimized bending moment by setting the gauge section on top of the 2 half mandrels (Fig.1 (d)). These two methods are widely used.

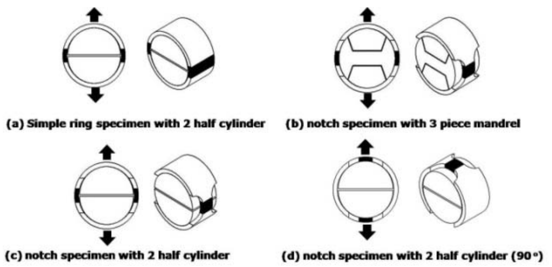
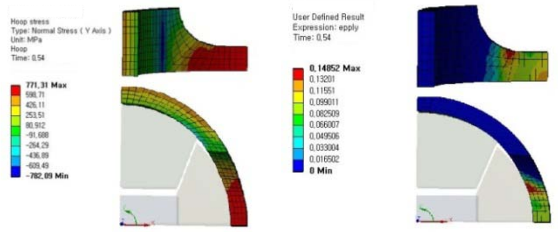


Fig. 1 Ring tensile test method

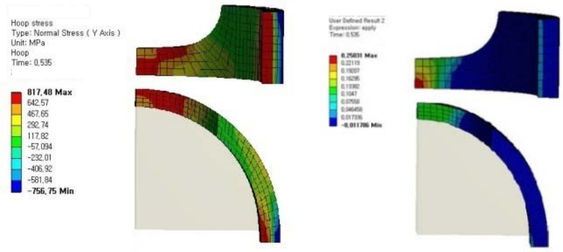
2.3 Finite element modeling

In order to find the best method for achieving uniform hoop stress and strain, in this study, FEM analysis of above four methods was performed using ANSYS. Considering symmetry of system, only 1/8 was modeled including specimen and grip.

Material property used in the modeling was uniaxial tensile test result of zircaloy-4 plate specimen. Also, it is assumed that materials are isotropic.



a)notched specimen with 3 piece manderel



b) notched specimen with 2 half cylinder(90°)

Fig. 2 Hoop stress (left) and hoop strain(right) results of FEM

As shown in Fig. 2 (b) and (d) method has uniform stress distribution at the gauge section. In case of Fig. 2(b) stress are more uniform compare with other method, however, a higher strain is generated at both ends of the gauge section. In case of Fig. 2(d), stress and strain are concentrated at the gauge section. In additions, this method has advantage, especially hot cell test, because of easier specimen set up.

As a consequence, in this study, (d) method is used to evaluate tensile hoop properties.

2.2 Ring tensile test procedure

In this study, specimen and grip were manufactured and ring tensile test were performed using Instron tensile machine 5582. The dimension of the ring tensile specimen and grip are shown in Fig 3.

The total displacement measured by the Instron machine is composed of device deformation and ring specimen deformation. Therefore actual displacement of ring specimen is expressed as equation (1).

$$\delta_{Specimen} = \delta_{Total} - \delta_{Device} \quad (1)$$

The deformation of device can be measured by using rigid ring. In order to estimate the deformation of device rigid ring were made of Inconel alloy and the test was performed at a crosshead speed of 0.1 mm/min in room temperature. As the deformation of device, δ_{Device} is function of load, δ_{Device} can be obtain following equation:

$$\delta_{Device} = 0.00732F^{0.50139} \quad (2)$$

Where F is loading force.

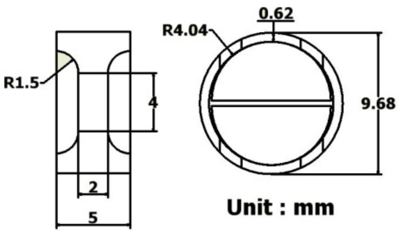


Fig. 3 Dimension of the ring specimen and grip

3. Results and Discussion

A typical curve of ring test, shown in Fig. 4, is generally S-shaped. This curve can be divided into four parts. In case of region I, tensile stress and compressive stress are simultaneously applied. With increasing displacement, the radial distribution of the stress is gradually decreased. The linear portion, region II, corresponds to the elastic behavior of the material. It is possible to calculate the Young`s modulus from the slope. With gradually increasing displacement, plastic deformation and necking is occurred (region III, uniform plastic elongation). Results of FEM modeling and ring tensile test show similar results as shown in Fig. 4.

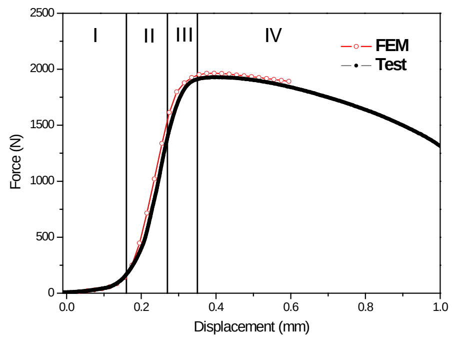


Fig.4 Load-displacement curve for ring tensile test and FEM modeling.

The mechanical properties such as ultimate tensile strength, Young`s modulus, and ductility can be obtained by converting load-displacement curve into stress-strain curve. However it is complicated process unlike uniaxial tensile test.

Displacement-strain curve obtained by FEM modeling at the gauge section is shown in Fig. 5.As bending moment is initially occurred, the strain changes little even though displacement is rapidly increased. However, the strain is proportional to displacement in the elastic region, that is, the following relationship can be described as

$$E = \frac{F}{d \cdot A} C \quad (3)$$

Where E=elastic modulus, F= loading force, d= displacement, A= cross section area, C= correlation constant.

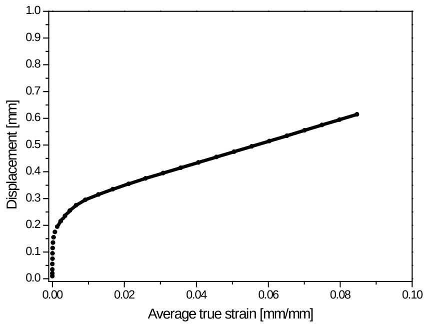


Fig. 5 Displacement vs. hoop strain

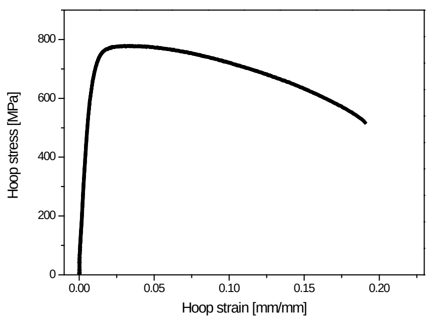


Fig. 6 Stress-strain curve

4. Conclusion

In this study, FEM modeling and ring tensile test of zircaloy-4 were performed to evaluate mechanical properties. As a results, it is turned out that the most appropriate method is turned notched specimen with semi-cylinder grip. FEM modeling and ring tensile test show similar results. Also, based on the results, hoop stress-hoop stress curve was obtained.

In the subsequent studies, FEM modeling and ring tensile test will be performed with coefficient of friction between specimen and grip. Also, test will be carried out in high temperature.

REFERENCES

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[2] Fumihisa NAGASE, Tomoyuki SUGIYAMA and Toyoshi FUKETA, Optimized Ring tensile Test Method and Hydrogen Effect on Mechanical Properties of Zircaloy Cladding in Hoop Direction, Journal of Nuclear Science and Technology, Vol. 46, p.545-552, 2009.