Abstract

Paper deals with ductile damage parameters identification of material used for nuclear parts construction under quasi-static and dynamic loading condition in the temperature range 20-300 °C. Based on the experience and extensive literature survey the design of suitable test specimen was performed [1,2,3]. Final design of each test specimen was evaluated by the numerical simulation. The damage process itself is evaluated based on the equivalent plastic strain which represents accumulated plastic deformation in the material at the moment of the fracture. The calibration experiment is performed with as constant as possible values of triaxiality, Lode parameter, temperature and strain rate. The evaluation of mentioned parameters is performed on samples using classical means as extensometer and load cell in combination with high speed camera, video-extensometer and DIC (Digital Image Correlation). The loading of the special type of samples is performed using custom-made testing devices as BUTTERFLY, NAKAZIMA or BIAXIAL (under development). The calibration of the plastic response curve and identification of the damage initiation criteria is based on the optimization script algorithm developed on CVUT [4,5,6,7]. The output will be ductile damage parameters which could be directly used in ABAQUS environment for numerical solution of the nuclear parts. Further subroutines will be elaborated to include more sophisticated damage models.

Keywords: abaqus, nuclear parts, ductile damage, identification

1. INTRODUCTION

Tested specimens were different in character of loading conditions and geometry to obtain different triaxiality conditions and values of Lode parameters Basaran [8], Hooputra [9] as can be seen from Fig. 1.

![Fracture curve and requested stress states covered by test specimen](image-url)
Following tests has been performed:

- Round tensile specimens of diameter 12 mm with various notch radius
- Flat tensile specimens with various notch radius
- Micro-tensile test with cross section of the sample 0.5 x 1.5mm
- Compression test of diameter 5 mm with various notch radius
- “Butterfly” test which is a test with special specimen originally developed in MIT.
- Shear test
- Small punch test
- NAKAZIMA test
- Fracture toughness test with CT specimen without initial crack
- Three point bend test

Tests were performed at room or at higher temperature with quasi-static or dynamic loading. Many tests were recorded by high-speed camera for further evaluation of damage parameters and for measured strain. All test has been modeled using FEM. Testing machines are in Fig. 2.

![Testing machine used for the tests](image)

**Fig. 2:** Testing machine used for the tests

### 2. TENSILE TEST

Tensile tests were performed at room temperature and at 100°C, 200°C and 300°C. All tests were done under quasi-static loading conditions on servo hydraulic testing system MTS 810. Four type of geometry were used for round tensile specimen. In order to obtain maximum information from the tests, next to standard mechanical extensometer also high speed camera was used for all tests, see - Fig. 3 as an example. The recordings enable later evaluation of strains at certain points and evaluation of necking during tensile tests.

![Tensile specimen R = 4 mm, a) start of the test, b) end of the test](image)

**Fig. 3:** Tensile specimen R = 4 mm, a) start of the test, b) end of the test
For better evaluation, the deformation was measured using video-extensometer. Advantage of video-extensometer is possibilities to measured big range of deformation and after the test post processing measuring of any point or line. The setup of video-extensometer is on the Fig. 4.

![Fig. 4 : Setup of the test with video-extensometer](image)

3. **SMALL PUNCH TESTS**

Small punch tests were performed on servo-hydraulic testing system Si-Plan of 10kN capacity.

![Fig. 5: Small punch test fixture](image)

Testing set up is depicted in Fig.5. Displacement of the penetrating ball is measured by the extensometer attached to the fixture. Tests were performed at room temperature.

4. **BUTTERFLY**

To cover wide range of the stress triaxiality and Lode angle parameter with a single specimen geometry, the Butterfly samples were used at angles 0, 10,20, 30, 45, 70, 80 and 90° in tension, see Fig 7.

The sample and custom – made testing device are based on the work of Mohr [10]. The performance of the SKODA-JS design was evaluated using FEM model.

![Fig. 6: Butterfly sample and testing device](image)
All current tests were done under quasi-static loading conditions at room temperature on servo-hydraulic testing system MTS 810.

In order to obtain maximum information from the tests, high speed camera was used for all tests. The recordings enable later evaluation of displacement and strains at certain points. In the case of butterfly samples displacements at six points directly on the sample was evaluated, see Fig 8. Records obtained for butterfly type of samples are shown in Fig 9.
5. NAKAZIMA

Nakazima tests are used to evaluate deformation under biaxial conditions in sheet metals. The load is applied by a hemisphere punch on metal blanks of different shape to fracture. Static and dynamic load is applied. The sample and custom-made testing device are based on the work of Walters [11] see Fig. 10. The performance of the SKODA-JS design was evaluated using FEM model.

Fig. 10: Testing device and specimen before and after test

The high speed camera was used for all tests. The fracture initiation and evaluation was observed via mirror, see Fig 11. Sequence of sheet plate deformation is on the Fig 12.

Fig. 11: Setup of dynamic and quazi-static and dynamic test of NAKAZIMA

Fig. 12: Sequence of the NAKAZIMA test

6. MICRO-TENSILE TEST

Micro-tensile tests were performed on servo-hydraulic testing system MTS BIONIX at room temperature. The geometry of micro-tensile test specimens can be found in the Fig 13 and the test set-up for the micro-tensile specimens can be found in the Fig 14. Deformation of the specimens was
measured by optical system ARAMIS. The specimen under load was viewed by one (2D) high-resolution digital CCD camera. The deformation was recorded by the CCD camera and evaluated using digital image processing. The example of the sequence of tensile test from ARAMIS is in the Fig. 15.

![Figure 13: Two geometries of micro-tensile test specimens](image)

![Figure 14: Set-up of micro-tensile test](image)

![Figure 15: The sequence of the micro-tensile test](image)

7. CONCLUSION
The paper deals with ductile damage parameters determination for different material used in nuclear industry as 15CH2NMFA, 08CH18N10T, zircon sheet alloys. Set of samples to cover various stress and strain condition has been proposed based on identification requirements. Relevant testing procedures have been identified including innovative design of appropriate test apparatus.

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LITERATURE


