LOW-CYCLE FATIGUE ANALYSIS OF ALUMINUM ALLOY GUSSET JOINTS AND LATTICED SHELL BASED ON CONTINUUM DAMAGE MECHANICS

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Abstract
Aluminum alloys have been widely used for structures in environments subject to corrosion. However, aluminum alloys have lower elastic modulus as compared to steels, and are more sensitive to low-cycle fatigue failure. This study performed low-cycle fatigue experiments of aluminum alloy gusset joints. A damage-coupled cyclic plastic constitutive model of 6061-T6 aluminum alloy was established based on continuum damage mechanics. Numerical simulations of the joints and a latticed shell were carried out incorporating the constitutive model. Low-cycle fatigue life of the joints and the latticed shell structure were estimated based on damage distribution calculated by the simulations.

1. Introduction

Due to the low elastic modulus of base material, the aluminum alloy latticed shell structure has relatively low flexibility and natural frequency, which makes it easy to resonance under cyclic loading, e.g. wind and seismic loads, and cause significant damage accumulation. Therefore, damage to the aluminum alloy latticed shells should be fully considered in the design. This study carried out experimental investigation on the failure mode and fatigue life of that gusset joints that are commonly used in aluminum alloy latticed shells. A damage-coupled cyclic plastic constitutive model of 6061-T6 aluminum alloy was proposed based on continuum damage mechanics. The model was implemented in ABAQUS through a user-defined material model subroutine (UMAT). The parameters of the constitutive model were determined based on cyclic uniaxial tests. Numerical simulations were conducted on the joints and a single-layer shell with the assist of the subroutine. The fatigue life of the latticed shell was estimated based numerical results.

2. Constitutive model

Damage to a material, component and structure is generally quantified by the parameter D, which is defined as follow:

$$D = 1 - \overline{E}/E \tag{1}$$

where $\overline{E}$ is the current modulus of damaged elasticity, and E is the initial elastic modulus of the material. The constitutive model is established and is consisted of the von Mises yield criterion and the Chaboche nonlinear kinematic hardening model with damage. The damage evolution model used in the model that was proposed by Lemaitre can be expressed as:

$$\dot{D} = \left[\frac{{\sigma_{eq}}^2 R_v}{2ES(1-D)^2} \right]^s \dot{p} \tag{2}$$

where σ_{eq} is the equivalent stress and R_v is a function of triaxiality which equals to 1 in the case of uniaxial loading; S and s are material parameters. The parameters needed in the constitutive model were determined from cyclic uniaxial tests.

3. Experiment and simulation

Fig. 1 shows the setup of the low cycle fatigue tests on aluminum alloy joints. Two kinds of loading protocols were employed, i.e., variable amplitude loading and constant amplitude loading. Fig. 2 shows that fracture occurred at the flange of the beam. The joint under variable amplitude loading failed at the 28th cycle while the joint under constant amplitude loading failed at the 60th cycle. Fracture initiation loci and fatigue lives of the joints were estimated through numerical modeling. Damage parameter D had the maximum value at about 0.3 at the outside edge of the bolt hole along the thickness direction of the flange, indicating fracture occurred at that site (red-contour area in Fig. 3). Distribution of damage implies that the crack was perpendicular to the longitudinal direction of the beam. Both the predicted fracture site and fatigue life of aluminum alloy joints were in a good agreement with test results. Fig. 4 illustrates the effective multi-scale finite element model of the latticed shell subassembly developed in this study, where critical joints and the remaining regions were modeled using three-dimensional solid elements and beam/truss elements, respectively.

Fig.1 – Experiment of the aluminum alloy joint.

Fig.2 – Fracture at the joint flange.

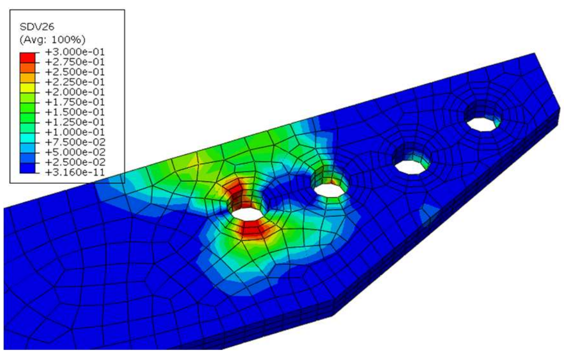

Fig.3 – Contour of damage distribution at the flange.

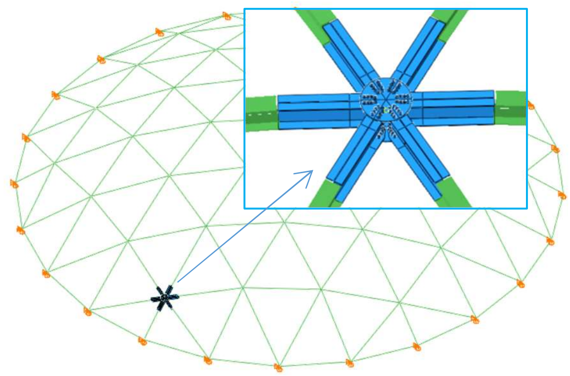

Fig.4 – FE model of the lattice shell.

4. Conclusion

Damage and low-cycle fatigue failure of Aluminum alloy structure can be considered in the FE analysis by continuum damage mechanics. The analysis method established in this study provided an effective tool to predict crack location and estimate the fatigue life of the aluminum alloy structure. However, due to the limited number of tests on the gusset joints, the damage model and the calibrated parameters require further in-depth investigation to ensure high accuracy of prediction.

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