Project funded by the European Commission under the 6th (EC) RTD Framework Programme (2002- 2006) within the framework of the specific research and technological development programme "Integrating and strengthening the European Research Area"

Project UpWind

Contract No.:
019945 (SES6)

"Integrated Wind Turbine Design"

Low-cycle fatigue analysis of single-fibre cell model

AUTHOR:	Huaiwen WANG
AFFILIATION:	China University of Mining and Technology (Beijing)
ADDRESS:	Xueyuan Road D11, Beijing 100083, P. R. China
TEL.:	+86 10 62331286
EMAIL:	zhw@cumtb.edu.cn
FURTHER AUTHORS:	H. W. Zhou, L. Mishnaevsky Jr., P. Brøndsted, L. L. Gui
REVIEWER:	
APPROVER:	

Document Information

DOCUMENT TYPE	
DOCUMENT NAME:	Low-cycle fatigue analysis of single-fibre cell model
REVISION:	
REV.DATE:	
CLASSIFICATION:	R1: Restricted to project members
STATUS:	

Contents

STATUS, CONFIDENTIALITY AND ACCESSIBILITY										
Status				Confidentiality				Accessibility	
S0	Approved/Released			R0	General public			Private web site	
S1	Reviewed			R1	Restricted to project members	R1		Public web site	
S2	Pending for review			R2	Restricted to European. Commission			Paper copy	
S3	Draft for commends			R3	Restricted to WP members + PL				
S4	Under preparation			R4	Restricted to Task members +WPL+PL				

PL: *Project leader* **WPL:** *Work package leader* **TL:** *Task leader*

Low-cycle Fatigue Analysis of Single-fibre Cell Model

1. Introduction

The traditional approach for determining the fatigue limit for a structure is to establish the S-N curves (load versus number of cycles to failure) for the materials in the structure. Such an approach is still used as a design tool in many cases to predict fatigue resistance of engineering structures. However, this technique is generally conservative, and it does not define a relationship between the cycle number and the degree of damage or crack length.

One alternative approach is to predict the fatigue life by using a crack/damage evolution law based on the inelastic strain/energy when the structure’s response is stabilized after many cycles. Because the computational cost to simulate the slow progressive damage in a material over many load cycles is prohibitively expensive for all but the simplest models, numerical fatigue life studies usually involve modelling the response of the structure subjected to a small fraction of the actual loading history. This response is then extrapolated over many load cycles using empirical formulae such as the Coffin-Manson relationship to predict the likelihood of crack initiation and propagation. Since this approach is based on a constant crack/damage growth rate, it may not realistically predict the evolution of the crack or damage.

A single-fibre cell model is modelled, as shown in Fig. 1. The dimensions of the cell models are 10×10×10mm3. The unit cells were subject to a uniaxial tensile displacement fatigue loading along the axis of fibre (Z axis direction). The boundary conditions for all simulations were as follows: 1) for the bottom side of the cell model, all degree of freedoms of point (0, 0, 0) were fixed, the 3rd degree of freedom of bottom surface with coordinate z=0 was restricted, and the 1st degree of freedom of line with x=0 and z=0 was restricted; 2) for the other five sides of the cell model, the sides of the cube were fixed in such a way that all the nodes were bound together. So, each side could move only as a plane. The volume content of fibre is 4% in single-fibre model, which result in that the fibre diameter is 2.26mm.

The model with VCCT criterion is analyzed using the Paris law to assess the low-cycle fatigue life when it is subjected to cyclic displacement loading.

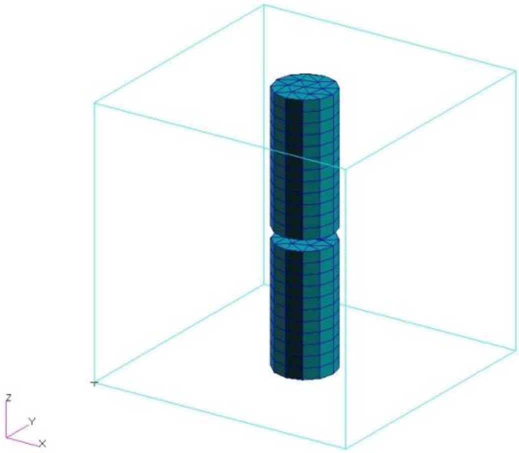

Fig 1. *Single-fibre FE fatigue* damage *model with one damageable layer in fibre*

2. Discussion on convergence Issues in ABAQUS/Standard while carrying out fracture analysis

As we know, it is high nonlinear when carry out damage and fracture analysis. Convergence issues appear in this model. Several methods can be employed to help solve these convergence problems. They are:

- Using viscous regularization
  Material models exhibiting softening behavior and stiffness degradation often lead to severe convergence difficulties. Abaqus/Standard provides a viscous regularization capability that helps in improving the convergence for these kinds of problems. Viscous regularization of the constitutive equations can cause the tangent stiffness matrix of the softening material to be positive for sufficiently small time increments.
- Using automatic stabilization
  Another approach to help convergence behavior is the use of automatic stabilization. It is useful when a problem is unstable due to local instabilities, in which case global load control methods are not appropriate. Abaqus/Standard provides an automatic mechanism for stabilizing unstable static problems through the automatic addition of volume-proportional damping to the model.
- Using nondefault solution controls
  Customized general solution controls are not needed in most nonlinear analyses. However, if extreme nonlinearities occur, customized controls may be needed to obtain a solution. General solution controls are intended for experienced analysts and should be used with great care.

3. Theory of low-cycle fatigue analysis using the direct cyclic approach

The direct cyclic analysis capability in Abaqus/Standard provides a computationally effective modelling technique to obtain the stabilized response of a structure subjected to periodic loading and is ideally suited to perform low-cycle fatigue calculations on a large structure. The capability uses a combination of Fourier series and time integration of the nonlinear material behavior to obtain the stabilized response of the structure directly.

The direct cyclic low-cycle fatigue procedure models the progressive damage and failure both in bulk materials (such as in solder joints in an electronic chip packaging) and at material interfaces (such as in laminated composites). The response is obtained by evaluating the behavior of the structure at discrete points along the loading history, as shown in Fig. 2. The solution at each of these points is used to predict the degradation and evolution of material properties that will take place during the next increment, which spans a number of load cycles, ΔN. The degraded material properties are then used to compute the solution at the next increment in the load history. Therefore, the crack/damage growth rate is updated continually throughout the analysis.

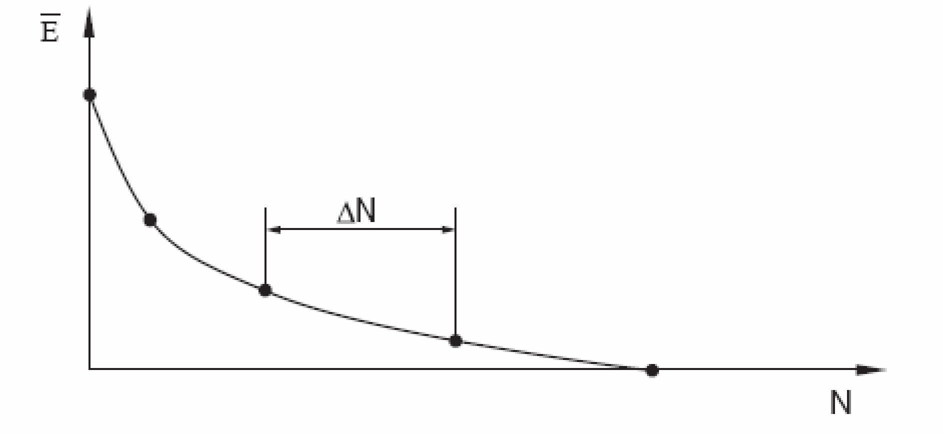

Fig. 2 *Elastic stiffness degradation as a function of the cycle number.*

The elastic material stiffness at a material point remains constant and contact conditions remain unchanged when the stabilized solution is computed at a given point in the loading history. Each of the solutions along the loading history represents the stabilized response of the structure subjected to the applied period loads, with a level of material damage at each point in the structure computed from the previous solution. This process is repeated up to a point in the loading history at which a fatigue life assessment can be made.

The modelling of fatigue damage in fiber reinforced composites is being simulated now. The simulation results will be obtained in the forthcoming works.