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The Experimental and Numerical Study on Aluminum Damage using a Non-linear Model of Continuum Damage Mechanics

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1-Introduction

Fracture mechanics is one of the most important fields in solid mechanics engineering. Failures have occurred for many reasons, including uncertainties in the loading or environment, defects in the materials, inadequacies in the design, and deficiencies in construction or maintenance. Design against fracture has a technology of its own, and this is a very active area of current research. Failure parameters and failure modeling are studied by several researchers.

Fracture in structures can be divided into two types: ductile and brittle fracture. Ductile failure has significant importance in practical engineering, and the possibility to develop a criterion able to predict the fracture processes associated with large plastic deformation fields has attracted the interest of many authors.

Continuum Damage Mechanics (CDM) is a powerful tool to solve problems such as large plastic deformation. Fracture mechanics is feeble to analyze its effects. Continuum damage mechanics is extracted in terms of the internal variable theory of thermodynamics and this model is based on the experimental results performed on material properties.

In the present paper, a constitutive model for plasticity damaged material, using a dissipation potential formulation, is used. The model discussed in this paper can be implemented in a finite element code in order to follow ductile crack growth according to a fully coupled calculation scheme.

In this respect, Aluminum has an important role in designing and constructing aerospace structures and device, since its density and strength are suitable for aerospace missions. Al 5083 is one of the most widely used materials in the construction of space vehicles and sound rocket structures. In this paper, the continuum damage mechanics principles are studied. Nucleation, development and propagation of damage in Al 5083 are investigated based on the Bonora model as a non-linear model along with several experimental cases.

2- Non-linear damage model

Damage is a thermodynamics state variable that takes into account the progressive loss of the load carrying capability of the material as a result of irreversible modifications, such as but not exclusively, the nucleation and growth of micro-voids, initiated under plastic material deformation.

From the physical standpoint, damage can be defined as the reduction of the nominal section area of a given reference volume element (RVE) as a result of the nucleation and growth of micro-cavities, micro-cracks, etc.:

$$D_{(\vec{n})} = 1 - \frac{A_{eff}^{(\vec{n})}}{A_0^{(\vec{n})}} \qquad (1)$$

Where for a given normal n, D is the damage parameter, $A_0^{(\vec{n})}$ is the nominal section area of the RVE and $A_{eff}^{(\vec{n})}$ is the effective resisting area reduced by the presence of micro-flaws and their mutual interactions.

Several authors have tried to model and determine D. Bonora proposed a model as equation (2) to describe D in the proportional loading condition. This model is implied in this study.

$$D=D_0+(D_{cr}-D_0)(1-[1-\frac{\ln(P/p_{th})}{\ln(\varepsilon_{cr}/\varepsilon_{th})}]^s) \qquad (2)$$

In this model, D_{cr} is determined by experimental test and D_0 is assumed zero. The threshold strain under multi-axial stress, p_{th} is taken to be equal to that in the uniaxial case, $e_{th.}$

3- Experimental study

This model requires knowledge of the parameters to be applied. To determine these parameters for Al 5083, several tests should be done. Also, for verification of this model, the authors have used 3 types of tests (simple tensile, cyclic and test with hole). Fig.1 shows a component with a hole after the tensile test.

Fig.1 The fracture of the component with a hole in the tensile test

4- Numerical simulation

The Abaqus software package is used for the numerical study of ductile damage in aluminum alloy 5083. Subroutine USDFLD is developed for D parameter determination and material behavior modelling. C3D8 element is used in the simulations.

5- Verification of the model

According to the experimental test, the parameters used in the model are extracted as shown in Table1.

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Table1. Parameters of damage model

$\varepsilon_{Threshold}$	$\varepsilon_{Rupture}$	D_{Cr}	α	*E (GPa)*	υ	*s*
0.0129	0.11164	0.36	0.75	70	0.3	0.5

In the simple tensile test, according to the loading condition, the agreement between simulation and experiment is good. When the "s" parameter is changed to 0.7, compatibility is increased and the accuracy is improved.

In the second case, in plastic deformation zone a cyclic load was applied to a component. In this test, the force direction is constant. Fig.2 shows the experimental and simulation results of the second test.

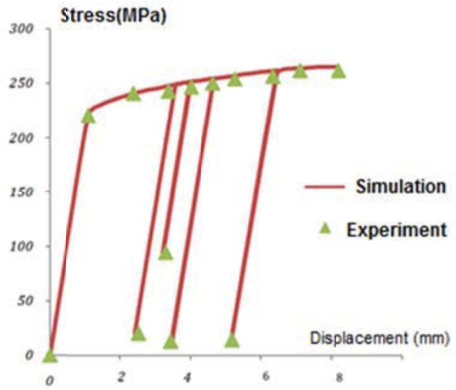

Fig.2 Test and simulation results for the second case

In the third case, to study the capability of the model to 3D stress modeling, a component with a hole is studied. In this case, stress distribution is varied around the hole due to stress concentration. Damage modeling is very complex and error is increased in the calculations. To reduce the errors, the average value of stress in two outer elements around the hole is used to determine stress and D parameter. Fig.3 shows the results in this case.

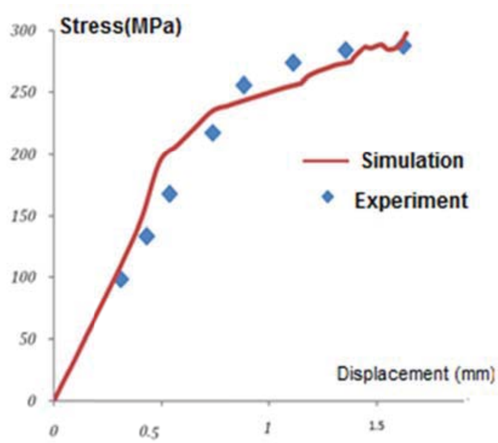

Fig.3 Test and simulation results for the third case

6- Conclusion

Continuum damage mechanics has received widespread acceptance as a reliable methodology due to the consistent modeling of the stress-strain history of material degradation. The coupled solution of the constitutive equation and damage ensures a proper description of the interaction of the involved phenomena. In this paper, the continuum damage mechanics principles are studied. Nucleation, development and propagation of damage in Al 5083 are investigated based on the Bonora model as a non-linear model. FE Simulation of material behavior during failures is carried out by the ABAQUS software package and USDFLD subroutine. The results are validated with experimental tests. This comparison shows that the simulation results are verified by experimental tests. Also the Bonora model (Non-linear damage model) can be used for damage modeling in AL 5083 .However, agreement of FEM results and the experiment in the 3-D stress case is lower than the one dimensional case. Therefore, in the next works, the effect of 3-D stress should be considered along with consideration of the coupling between the damage and plasticity dissipation potentials.