Numerical simulation of damage evolution and mechanical properties for ductile materials

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ABSTRAT:

The paper presents results of a numerical modelling of ductile fracture and failure of elements made of 5182H111 aluminum alloy steel subjected to dynamic traction. The analysis was performed using Johnson-Cook model based ABAQUS software. The aim of the research was to specify and test the mechanical properties during numerical simulations. The experimental test results for the mechanical properties of the studies steel are presented with a large description of the testing facilities. The test results were used to determine the temperature dependencies of the mechanical properties, yield strength, modulus of elasticity and thermal elongation.

Keywords: Mechanical properties, damage, structural steel, aluminum alloy

1. Introduction:

Ductile fracture is a geometry dependent event, whereas the fracture toughness or ductility of a material can not be directly transferred from one geometry to another. It depends on variation of geometry constraint level, therefore conventional fracture mechanics parameters. Ductile fracture process is controlled by nucleation, growth and coalescence of micro voids, so it is natural to link material fracture behavior to the parameters that describe the evolution of micro voids rather than conventional global fracture parameters [7]. Damage parameter is not incorporated into the constitutive equation and it is assumed that presence of voids does not significantly alter the behavior of the material. The von Mises criterion is most frequently used as yield criterion in uncoupled models, Damage parameter is incorporated into constitutive equation and crack growth simulation is automatically performed using a complete deterioration of elements in front of the crack tip [5]. One of the most widely used models is Johnson-Cook model for ductile materials. This model describing fatigue behavior of 5182 H111 Aluminium alloy under cyclic loading and their applicability for modeling of low-cycle-fatigue are discussed in this report. Numerical simulation has been used to study mechanical properties of materials such as the tensile strength, the yield strength and young's modulus depend the temperature because young's modulus of some tempered steels increases slightly at mid temperatures before decreasing at high temperature on mechanical properties is linked to transformations of the material structure due to various processes[1- 4]. In order to describe the cyclic behavior of the material for analysis with finite element method (FEM) based analysis code ABAQUS, the test data, i.e. stress-strain curves, have to be processed.

2. Numerical method:

To get a more complete understanding of the Mechanical properties of materials during testing, numerical simulations of the aluminum 5182 H111 alloy were performed. This is an approach, complementary to the experimental method describing by [1], to evaluate thermal loads at different locations on the surface as well as within the specimen. The latter is quite difficult to achieve from an experimental point of view. The numerical analysis using the ABAQUS, explicit dynamic finite element software, was made in two steps, in order to develop and implement strain rate sensitive constitutive models. First, thermal analysis was performed to reproduce the surface thermal loads and to obtain the temperature evolution in the specimen. Second, a mechanical analysis was performed, using a Johnson-Cook model. Here, the numerical simulation methodology assumes a weak coupling between thermal and mechanical analysises. Due to the axisymmetrical geometry of the specimen, only a quarter of the specimen is meshed with four node rectangular axisymmetric elements and used in the calculations. The sample geometry and the axisymmetrical meshing is shown in Fig. 1. From the numerical simulations, temperature-strain loops at several locations in the specimen were obtained, and they were compared to those from the experimental tests.
Johnson-Cook model that it's equations are given by [6]:

$$\sigma = \left[\mathrm{A} + \mathrm{B}\varepsilon_{pl}^{n} \right] \left[1 + C \ln \dot{\varepsilon}^{*} \right] \left[1 - T^{*m} \right]$$

Where ε_{pl} is the effective plastic strain, $\dot{\varepsilon}^{*} = \frac{\dot{\varepsilon}}{\varepsilon_0}$ is the dimensionless plastic strain rate for a reference strain rate, and T^{*} is a form of homologous temperature given as $\mathrm{T}^{*} = \frac{(\mathrm{T} - \mathrm{T}_{room})}{(\mathrm{T}_{melt} - \mathrm{T}_{room})}$.
The five material constants A , B, C, m, n are fit to data collected for a particular material.

3. Finite Element Mesh and Geometry

The materials considered in this study are the 5182 H111 Aluminium alloy, with length L= 210mm and the depth D=5mm and the width 56mm. Finite element modeling is performed by assuming 3D deformation. The mechanical loading results from applying displacement traction at the outside extremity of the 5182 H111 Aluminium alloy. The main mechanical and thermal Properties of tested specimens are summarized in Table1. The specimen's geometries are shown in Fig1. Specimens are especially prepared for thermographic measurements. They are polished and cleaned to remove any oxide and grease.

To obtain a thermal stress loading under homogeneous uniform temperature distribution, the 5182 H111 alloy was restrained against axial expansion by creating an interaction boundary condition at its outside edge (Figs. 3). In order to determine thermal strain in the analysis we have need to the thermal expansion coefficient α [2].Poisson's coefficient does not depend on temperature and takes the constant value $\upsilon=0.3$.

Figure 1: Geometry of the tested specimens 5182 H111 Aluminium alloy

Table 1. Mechanical and thermal properties of the tested specimens

Aluminium 5182 H111	
Tensile modulus MPa	2700
Tensile strength (Nmm^{-2})	284
Yield stress (MPa)	154
Mass thermal capacity (Jkg^{-1}K^{-1})	909
Thermal conductivity (Wm^{-1}K^{-1})	209-232

Fine meshes with 0.0012 mm elements and coarse meshes with 0.012 mm elements were used. The two meshes used are shown in (Figure 2).

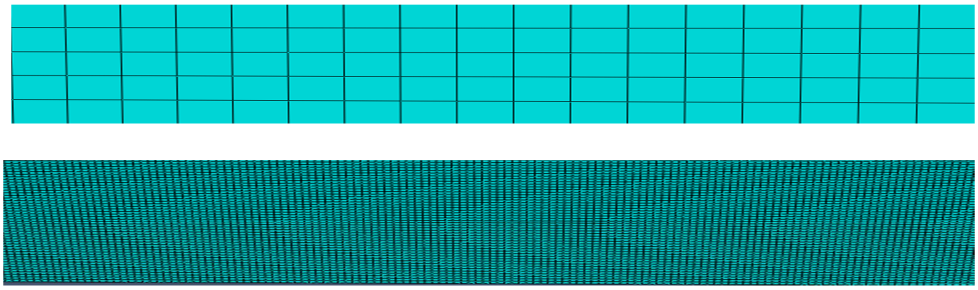


Figure 2: Fine meshes 0.012 (Upper) and coarse meshes 0.0012 (Lower)

4. Loads

A displacement boundary condition was applied to the grip end of the tensile specimen. The displacement was smoothly ramped up in the first portion of the test and then held constant as shown in Figure 3.

Figure 3: Load and boundary condition

5. Mechanical analysis of numerical simulation

The output of the mechanical analysis is the deformation field in the specimen during the mechanical cycling. An example is given in Fig. 4.

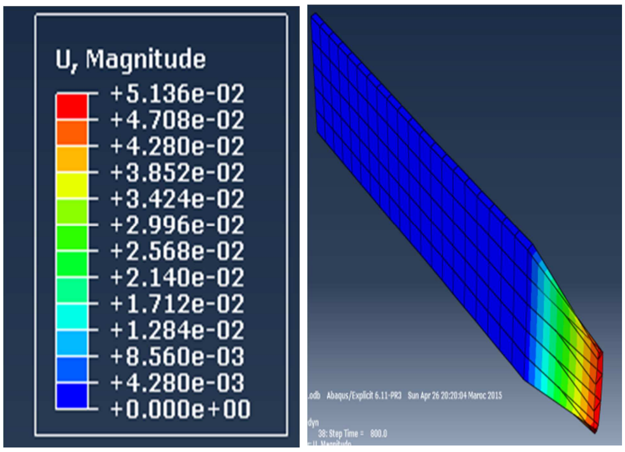
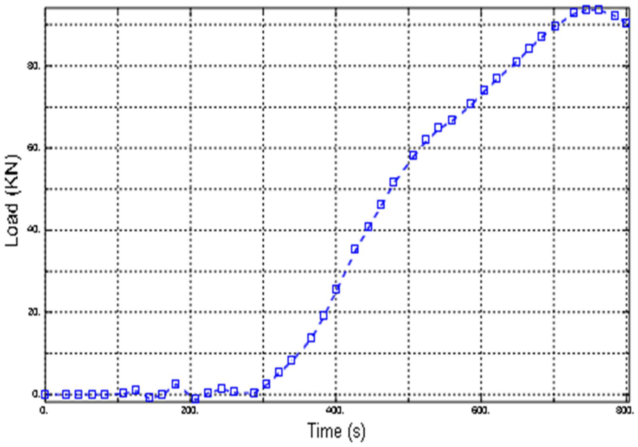


Figure 4: Example of The output of the mechanical analysis during the mechanical cyclic

6. Results and discussion:



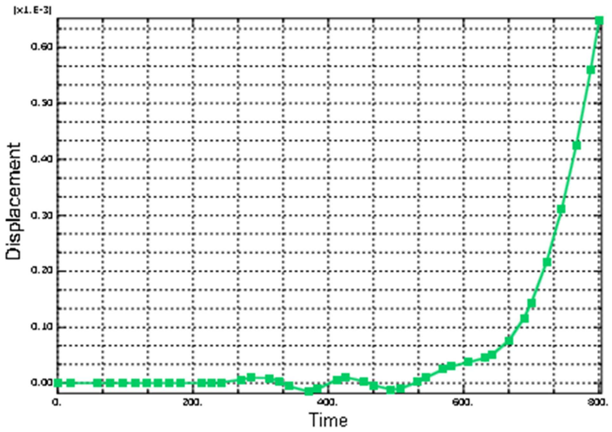


Figure 5: load vs. time for the 5182 H111 Aluminium specimen

Figure 6: displacement vs. time for the 5182 H11 Aluminium specimen

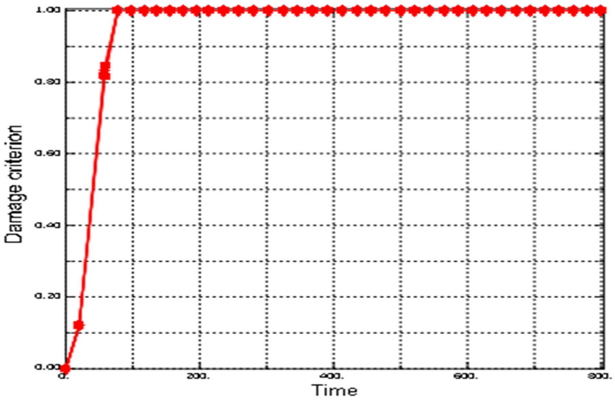


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Figure 7: Damage criterion vs. elongation for the 5182 H111 Aluminium specimen

The tensile behavior of the specimens was determined as the load–elongation relation during tensile loading. Furthermore, a change in the elongation during loading curve was obtained. Load start, i.e. elastic strain start, then plastic strain start point where the maximum force is reached, i.e. the end of homogenous plastic strain.

Figure 6 shows that the maximum elongation before final failure line started. Thus, the failure doesn't starting in this case because the plate not yet reached the state of rupture. Figure 5 shows the load vs. time the beginning of elastic deformation, the beginning of plastic deformation, reaching maximum force, the homogeneous plastic deformation to the final fracture of the specimen. The analysis of the results presented in Figs 5 show that in the first 350 seconds the force reaches 20 kN The maximum tensile force is about 95 kN. The total elongation is 6mm thus the Figure 6 shows the evolution of the displacement on the surface of the specimen.

7. Conclusion :

The Numerical results for the tensile properties of 5182 H111 Aluminium alloy, considered in this paper, indicate the fact that the testing of metal structures requires new contactless methods. The ABAQUS simulation using the Johnson-Cook methods of fracture mechanics were applied due to the safety assessment of metal structures. The Numerical results prove that Johnson-Cook model offers the possibility of non-destructive and real time testing to observe the physical process of metal degradation and to detect the occurrence of energy dissipation.

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