VERIFICATION OF CONSTITUTIVE MODELS USING THE ASAY IMPACT TEST (U)

CONF-980525--

Author(s):
Keith S. Haberman, ESA-EA
Joel G. Bennett, ESA-EA

Submitted to:
American Society of Civil Engineers (ASCE),
San Diego, CA, May 17-21, 1998

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED
DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.
Verification of Constitutive Models Using the Asay Impact Test

Keith S. Haberman* and Joel G. Bennett*

Abstract

Accurate analysis and the ability to predict the complete response of particulate composite materials requires accurate inelastic constitutive models. However, to be of maximum utility, these inelastic models must be validated using quantifiable experimental results. The Asay Impact Test is an impact experiment that provides the evolution of the two dimensional in-plane displacement field in a specimen undergoing dynamic inelastic deformation. The experimental displacement field may be directly compared with the predicted displacement field from a candidate inelastic constitutive model. In this paper, we report comparisons between experimental and predicted displacement fields in the energetic particulate composite material PBX-9501 during dynamic deformation, and describe the experiment and the constitutive modeling approach.

Introduction

PBX-9501 is an energetic heterogeneous material composed of an anisotropic HMX brittle crystal and a viscoelastic estane binder. Composition is 95% HMX and 5% estane. Two constitutive modeling approaches are being considered for PBX-9501. The first approach, VISCO-SCRAM2, is a macromechanical approach that combines Maxwell viscoelasticity with statistical crack mechanics. The second approach, Generalized Method of Cells, is a micromechanical approach where the constitutive models of the constituents are defined along with the behavior of the constituent interfaces. Both constitutive modeling approach have been implemented in the explicit lagrangian code DYNA3D. Constitutive model validation is based on the ability of a 3 dimensional model of the Asay Impact test to reproduce the evolution of the experimental displacement field on the surface on the impact specimen.

*Los Alamos National Laboratory, Los Alamos, NM 87545
Constitutive Models, VISCO-SCRAM

This model has been proposed by Johnson\textsuperscript{2,6,8} and combines Maxwell viscoelasticity with statistical crack mechanics approach of Dienes\textsuperscript{6}. The result is an macroscopic isotropic constitutive model that describes the behavior of a visco/brittle material. Statistical crack mechanics is a physically based micromechanical description for the large deformation of brittle materials. Consider an \( n \) component Maxwell model, where \( G^s \) is the shear modulus, \( \eta^s \) is the time constant for the \( n^{th} \) component and \( c \) is the crack radius. By superposition of strain rates, the total deviatoric strain rate is the sum of the deviatoric viscoelastic strain rate and the deviatoric cracking strain rate. The cracking strain is related to the deviatoric stress and the crack radius \( c \) using,

\[
2G e^t_{ij} = \left( \frac{c}{a} \right)^3 s_{ij}
\]

(1)

The stress rate in each Maxwell element now becomes,

\[
\dot{s}_{ij}^n = 2G^s \dot{e}_{ij}^n - \frac{\dot{s}_{ij}^n}{\tau^s} - \frac{G^s}{G} \left[ 3 \left( \frac{c}{a} \right)^2 \frac{\dot{c}}{a} s_{ij} + \left( \frac{c}{a} \right)^3 \dot{s}_{ij} \right]
\]

(2)

Where,

\[
\dot{s}_{ij} = \frac{2G \dot{e}_{ij} - \sum_{n=1}^{n} \frac{s_{ij}^n}{\tau^s} - 3 \left( \frac{c}{a} \right)^2 \frac{\dot{c}}{a} s_{ij}}{1 + \left( \frac{c}{a} \right)^3}
\]

(3)

The Visco-SCRAM approach provides a computational expedient constitutive model. Full development of this model and the crack radius evolution equations are given in Bennett\textsuperscript{4} and Haberman\textsuperscript{8}.

Constitutive Models, Generalized Method of Cells

The Generalized Method of Cells\textsuperscript{1} is a physically based unified micromechanical modeling approach used to predict the elastic and inelastic macroscopic behavior of a heterogeneous materials. The microstructure of the composite material is idealized by a representative volume element (RVE), Figure 1, which is composed of subcells that represent the individual phases. The constitutive behavior of the constituent subcells

\[
\sigma_{ij} = C_{ijkl} \dot{e}_{kl} - \hat{1}_{ij}
\]

(4)

is defined along with constitutive behavior of the constituent interfaces

\[
[u_i] = f(\sigma_{ij} n_j)
\]

(5)

Each subcell interface may be described using an interface constitutive law, Figure 1(c), similar to the decohesion laws proposed by Needleman\textsuperscript{11}. Employing continuity of displacements and continuity of tractions at the interfaces between the subcells of the RVE, results in a set of linear algebraic equations which may be solved for the rates of deformation in each subcell. The stress rate in each subcell is determined
using the subcell strain rate and the appropriate subcell constitutive law, Equation 4. The macromechanical behavior is obtained from appropriate averages of the behavior of the constituents and the behavior of the constituent interfaces. This procedure has been successfully used by Haberman et al. on fiber reinforced composite materials. Full development is given in Aboudi.

Figure 1. (a) A general 3X3X3, RVE, (b) possible 3X3X3 RVE selections for PBX-9501, (c) bi-linear decohesion model for the subcell interface.

Experimental Verification, Asay Impact Test

The dynamic impact experiments were conducted and reported elsewhere in which a projectile was fired at the nominal velocity of 185 m/s at pushers of various geometry, Figure 2(a). The in plane displacement field on the surface of the explosive is measured using laser-induced fluorescense speckle photography. The measured displacement field can be directly compared with the displacement field predicted using the DYNA3D simulation using a candidate constitutive model. Constitutive model validation and modification is based on the ability of the constitutive model to reproduce the evolution of the experimental displacement field. Figure 2(a) shows the impact test geometry. Figure 2(b) shows the DYNA3D finite element model that faithfully reproduces the geometry of the Asay Impact Test.

Figure 2. (a) Asay Impact Test, experimental setup, (b) DYNA3D model
Figure 3, shows the experimental displacement field on the surface of the PBX-9501 specimen at 15 and 18 microseconds after the projectile has impacted the Pusher. Figure 4(a) shows the predicted displacement field using the Visco-SCRAM constitutive model with an initial crack radius $c$ of 30 microns. Figure 4(b) shows the predicted displacement field using the Visco-SCRAM constitutive model with an initial crack radius $c$ of 3 microns.

![Figure 3. (a) Experimental displacement field.](image)

![Figure 4. Predicted displacement field at 18 microseconds, (a) initial crack radius 30 microns, (b) initial crack radius of 3 microns](image)

Displacement field comparisons for the Generalized Method of cells will appear in a later publication.

References
6. DYNA3D, UCRL-MA-107254, LLNL, 1993

Haberman