VIII International Conference on Computational Plasticity
COMPLAS VIII
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DEVELOPMENT AND VALIDATION OF MODEL FOR PENETRATION IN HYDROCODES

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Key words: Hydrocode, constitutive model, penetrator

Summary *The accurate simulation of ballistic penetration events requires the constitutive model to be capable of describing the behaviour of materials at high strain rates, high strains and high temperature, as well as fracture processes under these conditions. It is desirable that the generic models for a class of material are developed from precise quasi-static and dynamic material tests and validated against experiments in the regimes of interest. The specific material properties within this class can then be derived from more standard material tests. This paper outlines the development and validation of constitutive and fracture models within QinetiQ, which have been used for the simulation of penetration events. It also discusses current work to make these models more accurate, robust and efficient.*

These models are implemented in both Lagrange (i.e. DYNA) and Euler (i.e. GRIM) hydrocodes and used very successfully, as illustrated by a range of case studies. The validation process requires a full integration of hydrocode and experiment and is designed to enhance the confidence level when the models are used for new scenarios, often when precise full-scale experimental trials are not possible.

A major lesson is that the model development must be intimately linked to the numerical scheme within the hydrocode to avoid issues of inconsistency. The validation process has also highlighted a number of gaps in the understanding of the basic behaviour of materials subjected to ballistic loads. These gaps are significant since the ever increasing performance demands for penetrators require the development of materials with enhanced properties and more imaginative penetrator concepts.

Furthermore, it is vital that simulations are used as part of the design process to drive the experimental trials at both sub-scale and full-scale. This process ensures both that the experimental work is addressing the regions of interest and that data suitable for model development and validation is captured.

1 INTRODUCTION

The role of a gun launched kinetic energy (KE) projectile is to perforate the armour of main battle tanks (MBTs). The projectile generally consists of a main penetrator made from a dense material of high strength and modulus such as depleted uranium (DU) or an alloy of tungsten (WHA), which is surrounded during gun launch by sabots which discard at muzzle exit.

The design of gun launched kinetic energy projectiles relies on the computer modeling of the penetration of the armor to provide validated predictions of the performance of the armor and the penetrator. This modeling requires accurate and robust models to be developed so that the complex interactions between the projectile and the armor can be resolved. For this approach to be successful it is crucial that the material models in the hydrocode are validated in the regimes of interest. This paper outlines the developments of constitutive and fracture models for hydrocodes and the validation methods used to obtain the maximum confidence levels in their use in complex KE applications.

2 THE ROLE OF COMPUTER MODELING

QinetiQ is researching means of improving the performance of KE ammunition. In order to design a projectile with improved terminal performance the following areas require analysis:

- the interactions between the penetrator and armor
- penetrator performance requirements
- new penetrator materials and design concepts

This analysis generally takes the form of a combination of material testing, firing trials and computer simulation. It is important that there is a consistent approach undertaken in these activities such that the maximum benefit is gained.

The accuracy and robustness of the computer modeling during this research is of paramount importance because the design, manufacture and experimental trialing of candidate projectiles is time consuming and relatively expensive. It is also necessary to fire a relatively large number of projectiles in order to quantify the experimental errors which can occur. By using computer simulation, in conjunction with carefully selected experimental work to provide validation, more variations of projectile design and material can be tested. This approach should also allow the influence of small variations in material or design to be evaluated without the results being compromised by experimental differences.

3 CONSTITUTIVE AND FRACTURE MODEL DEVELOPMENT

The constitutive models are based on the modified Armstrong-Zerilli model[1, 2] appropriate to body centred cubic (bcc) metals and some alloys. The constants for the model are determined using interrupted tensile tests over a range of strain rates and temperatures. The model is of the form: -

$$\sigma = \left(C_1 + C_5 \varepsilon^n\right)\frac{\mu_T}{\mu_{293}} + C_2 \exp\left[\left(C_3 + C_4 \ln \dot{\varepsilon}\right)T\right] \tag{1}$$

Where C1 to C5 and n are constants and σ, ε , $\dot{\varepsilon}$ and T are respectively stress, strain, strain rate and temperature in K. Also μ_{293} is the shear modulus at 293K and μ_T is the shear modulus at the current temperature. The fracture model used was the Goldthorpe Path Dependent Fracture (PDF) Model[3]. This model has been developed for ductile fracture processes and has been applied to the growth and nucleation of voids under different stress systems. The model accumulates damage according to the following relationship:-

$$dS = 0.67\exp[1.5\sigma_n - 0.04\sigma_n^{-1.5}]d\varepsilon + A\,\varepsilon_s \qquad (2)$$

Where σ_n is stress triaxiality (or Pressure/Yield), $d\varepsilon$ is the effective plastic strain, ε_s is maximum principle shear strain, A is a constant determined from torsion test and S is damage.The damage is then incremented by S=S+dS. Fracture occurs when the damage reaches a critical value Sc, which is determined from examining the neck region in a quasi-static tension test. It is important to realise that the measurement to determine Sc has a 5-10% error, however, the variation in the actual value of Sc in a batch of material can be 20-30% or higher depending on the material. This is due to inherent directional effects, even though the deformation is more or less isotropic.

4 VALIDATION

These models have been implemented into the QinetiQ Eulerian hydrocode GRIM and the Lagrangian hydrocode DYNA. The validation of the models consists of comparison with high strain rate deformation and fracture tests and selected ballistic penetration experiments. The models give good results for high rate deformation and fracture tests[4]. Results for normal and oblique semi-infinite penetration of tungsten alloy rods against RHA targets are shown in figure 1 for various velocities.

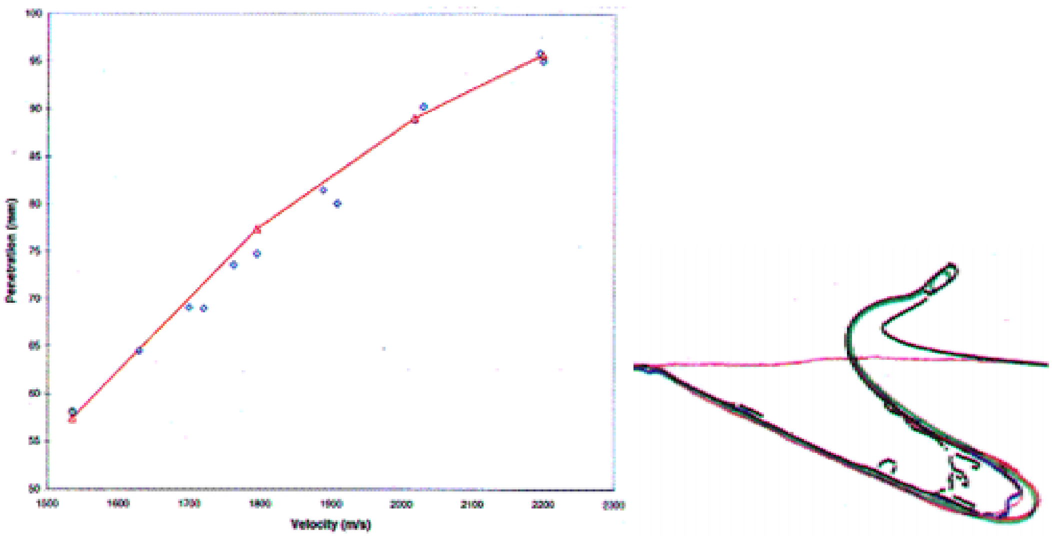

Figure 1 (left) GRIM Prediction (red) of Semi-infinite Penetration of W alloy against RHA and (right) Level of Agreement for 3D Oblique Impact

Both materials had been fully characterised and the experimental agreement was very good for penetration depth, hole profile and residual penetrator length. The 3D simulations indicated a need to measure the yaw and pitch angles at more points in the flight path of the projectile.

5 NOVEL PROJECTILE DESIGNS

It is widely understood that DU provides a close to ideal material for a penetrator due to its high density, strength, ductility and toughness. However, there are currently perceived health hazards relating to the radiation and toxicity effects of DU. The UK MoD is funding a research programme on DU in which there is an investigation into alternatives to DU ammunition that are capable of meeting the required penetration performance levels. Designs such as jacketed rods[5], segmented and telescopic penetrators have been reported as providing improvements in penetration. Such penetrator designs provide new challenges for the computer model in that additional materials, projectile designs and interfaces are introduced.

6 CONCLUSIONS

Hydrocodes featuring advanced constitutive and fracture models have a key role to play in the general design process, but it is crucial they are validated in the regimes of interest. KE penetration is a complex process requiring a full integration of experiments, modelling and materials testing to address the feasibility of replacing DU projectiles with alternative concepts, providing an equivalent or increased level of performance.

7 ACKNOWLEDGEMENTS

The support of UK MoD is acknowledged for this work.

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