Constitutive model parameter determination from generic EFP warhead tests

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JOURNAL DE PHYSIQUE IV
Colloque C8, supplément au Journal de Physique III, Volume 4, septembre 1994

Constitutive model parameter determination from generic EFP warhead tests

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Resumé: La détermination des paramètres de modélisation constitutive du matériau de revêtement, basés sur les résultats de quatre tests EFP, avec différentes géométries de revêtement, est décrite dans cet article. Cet article présente une approche pour déterminer un "ensemble approprié" de paramètres du matériau pour décrire le comportement déviateur du matériau de revêtement. Les modèle constitutifs de Johnson-Cook et Steinberg-Guinan sont évalués avec le modèle de Steinberg mis en évidence comme étant le mieux adapté en raison de sa limite supérieure sur la contrainte d'écoulement. Un ensamble de paramèters de durcissement par contrainte d'écoulement est défini, fournissant une excellente corréllente corrélation avec les quatre configurations différentes d'ogives EFP.

Abstract: The determination of liner material constitutive modeling parameters based on the results of four EFP tests, with different liner geometry's, is described in this paper. This paper presents an approach for determining an "appropriate set" of material parameters to describe the deviatoric behavior of the liner material. The Johnson-Cook and Steinberg-Guinan constitutive models are evaluated with the Steinberg model shown to be more suitable because of its upper limit on the flow stress. A set of flow stress hardening parameters are found that provide excellent correlation to the four different EFP warhead design configurations.

1. GENERIC WARHEAD DESCRIPTION

The generic EFP warhead used in this study has an 89 mm diameter, L/D of 0.5, contains 300 g of LX-14, and an 82 g copper liner. The EFP projectile created by the warhead is shown in Figure 1[1]. It has a velocity of 2520 m/s, length of 58 mm, with nose and tail diameters of 18 mm and 24 mm respectively.

2. LINER MATERIAL

The liner material used in the warhead is fabricated using a multi-step forge/anneal/coin process. The starting OFHC copper material is a thick disk machined from ASTM-B-153 half hard bar stock. The forging process transforms the 20 mm thick by 25 mm diameter "puck" of copper into an 89 mm diameter flat plate with the desired liner thickness profile. The plate is annealed, followed by a multi-step coining process to achieve the desired liner curvature. The limited material characterization tests that have been conducted on the liners show the grain size ranges from 15μ to 20μ and the yield strength ranges from 60 MPa to 80 MPa. These known material properties were not sufficient to determine a complete set of constitutive parameters for use in computer modeling of the warhead.

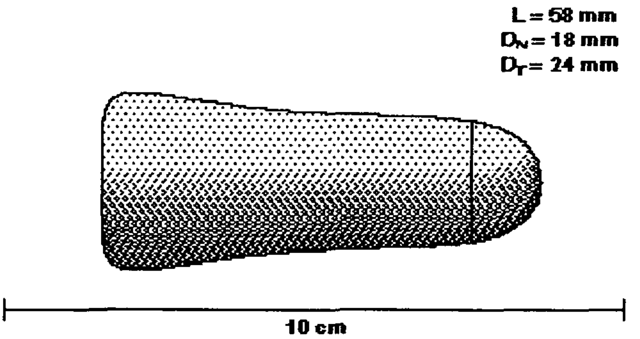


Figure 1. Projectile created by the EFP warhead.

3. COMPUTATIONAL MODEL STUDIES

The DYNA2D[2] mesh used in the calculations is shown in Figure 2. The explosive is modeled with 30 elements in the radial direction and 40 elements in the axial direction. The liner is modeled with 60 elements in the radial direction and 5 elements through the thickness. The thick steel case surrounds the HE but not the liner. The lack of edge confinement around the liner allows a portion of the liner to spall causing the recovered projectiles from experiments to weigh approximately 4 grams less than the original liners. The finely meshed region of the liner treats the spall effect. The LX-14 explosive is modeled with a JWL EOS[3] and the steel case is simulated with a Steinberg-Guinan[4] deviatoric model. The Steinberg-Guinan and the Johnson-Cook[5] models were both considered for simulating the deviatoric response of the copper liner with the bulk response simulated using a Gruneisen EOS[6,7].

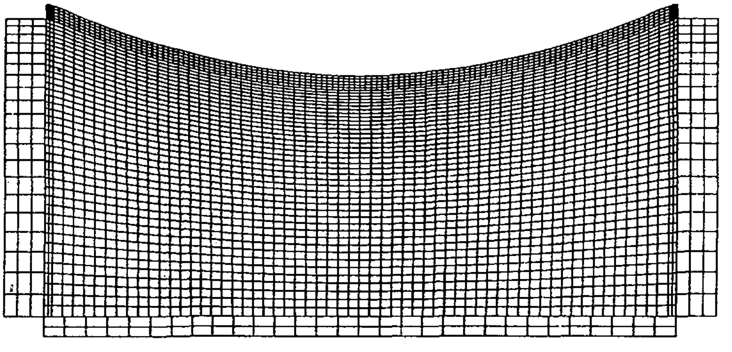


Figure 2. Mesh used in the DYNA2D analysis.

4. CONSTITUTIVE MODEL PARAMETER DETERMINATION

The liner material modeling study evaluated the strain hardening portions of the Steinberg-Guinan and Johnson-Cook material models implemented in the DYNA2D code. Both of these models treat the flow stress as a function of strain, pressure, and temperature. The Johnson-Cook model also treats the flow stress as a function of strain rate, while the Steinberg model assumes the strain rate is sufficiently high that the flow stress is rate independent. This study examined the effect that the strain hardening parameters have on the flow stress and subsequent EFP velocity, length, tip diameter, and tail diameter. The strain hardening portions of the flow stress equations for the two models are given on the following page.

Steinberg-Guinan: $Y = Y_o[1+\beta(\varepsilon_P)]^n \leq Y_m$ (1)

Johnson-Cook: $Y = A + B(\varepsilon_P)^n$ (2)

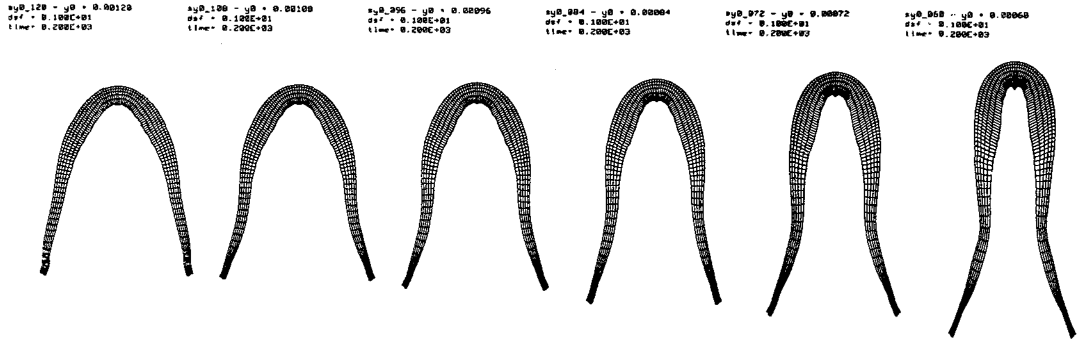
These two forms of modeling the effect of strain hardening are similar, however, the Steinberg model includes a limiting value on the flow stress. The upper limit on the flow stress was found to be important for matching the experimental profile of the EFP shown in Figure 1. The limited computational study using the two models indicated that the Steinberg deviatoric model should be used for this liner material as it provided the best correlation to the experimental results. The computational results using the Steinberg model are presented and compared to the experimental results in the remainder of the paper.

4.1 Effect of Y_0 in the Steinberg Deviatoric Model

The first series of calculations with the Steinberg model was a comparison of the effect of Y_0 in the deviatoric model. Y_0 was varied from 120 MPa to 120 MPa with β, n, and Y_m held constant at 36.0, 0.45. and 640 MPa respectively. The material property values and calculated EFP parameters are listed in Table 1. A graphical comparison of the EFP shapes at 200 μsec is shown in Figure 3. These calculations show that as Y_0 is decreased from the baseline value (for 1/2 hard OFHC copper) of 120 MPa to 60 MPa, the resulting EFP becomes more elongated and narrower. The Y_0 = 72 MPa analysis provided good correlation to the length of the experimental EFP, however, the tip diameter is a bit to small. A value of Y_0 = 77 MPa was selected to use in the Y_m sensitivity study summarized in Section 4.2.

Table 1. Material property values and resulting EFP velocity & length from Y_0 study.

	(a)	(b)	(c)	(d)	(e)	(f)
Y_0 (MPa)	120	108	96	84	72	60
β	36.0	36.0	36.0	36.0	36.0	36.0
n	0.45	0.45	0.45	0.45	0.45	0.45
Y_m (MPa)	640	640	640	640	640	640
V (m/s)	2535	2536	2541	2542	2545	2548
L (mm)	47	49	51	56	58	65



(a) 120 (b) 108 (c) 96 (d) 84 (e) 72 (f) 60

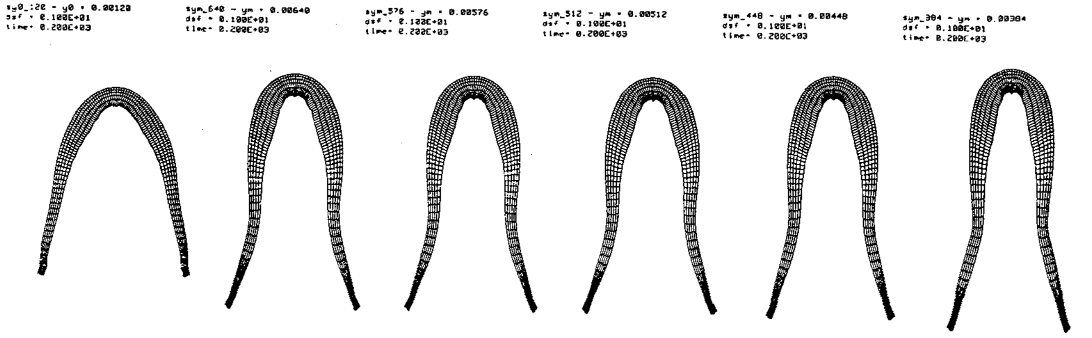
Figure 3. Calculated EFP geometry as a function of Y_0 in the Steinberg deviatoric model.

4.2 Effect of Y_m in the Steinberg Deviatoric Model

The second series of calculations with the Steinberg model was the effect of Y_m in the deviatoric model. The Y_0 parameter was held constant at 77 MPa. The value of Y_m was varied from 640 MPa to 384 MPa, with β, n, and Y_0 held constant at 36.0, 0.45, and 77 MPa respectively. The material property values and calculated EFP parameters are listed in Table 2. A comparison of the EFP shapes at 200 μsec for this series of calculations is shown in Figure 4. The two best correlation's to the experimental data (tip diameter, tail diameter, and overall length) were found with Y_m = 512 & 448 MPa. The values for Y_0 and Y_m of 77 & 50 MPa respectively were used in all subsequent simulations along with the published values of β & n.

Table 2. Material property values and resulting EFP velocity & length from Y_m study.

	(a)	(b)	(c)	(d)	(e)	(f)
Y_0 (MPa	120	77	77	77	77	77
β	36.0	36.0	36.0	36.0	36.0	36.0
n	0.45	0.45	0.45	0.45	0.45	0.45
Y_m (MPa)	640	640	576	512	448	384
V (m/s)	2535	2545	2544	2545	2546	2547
L (mm)	47	58	58	58	60	65



(a) 640 (b) 640 (c) 576 (d) 512 (e) 448 (f) 384

Figure 4. Calculated EFP geometry as a function of Y_m in the Steinberg deviatoric model.

4.3 Correlation with Experimental Results

The baseline EFP warhead geometry shown in Figure 2 was used to determine the "best" set of constitutive material model parameters as described in the previous sections. This set of constitutive properties (Y_0 = 77 MPa and Y_m = 500 MPa) was then used to simulate the three other EFP warheads with different liner geometry's. These EFP warheads were developed and tested by Alliant Techsystems[8]. This data was provided to LLNL after the completion of the material model characterization studies discussed in Sections 4.1 & 4.2. All four warhead design configurations were the same, except for the liner thickness and liner contour variations. A tabulated comparison of the computer simulations and experimental results is given in Table 3. A graphical comparison is shown in Figure 5.

Table 3. Comparison of analysis and experimental results for 4 EFP designs.

Design	1402		1403		1404		1406	
	calc	test	calc	test	calc	test	calc	test
V (m/s)	2545	n/a	2544	2520	2524	2526	2480	2472
L (mm)	50	48	57	58	59	60	65	68

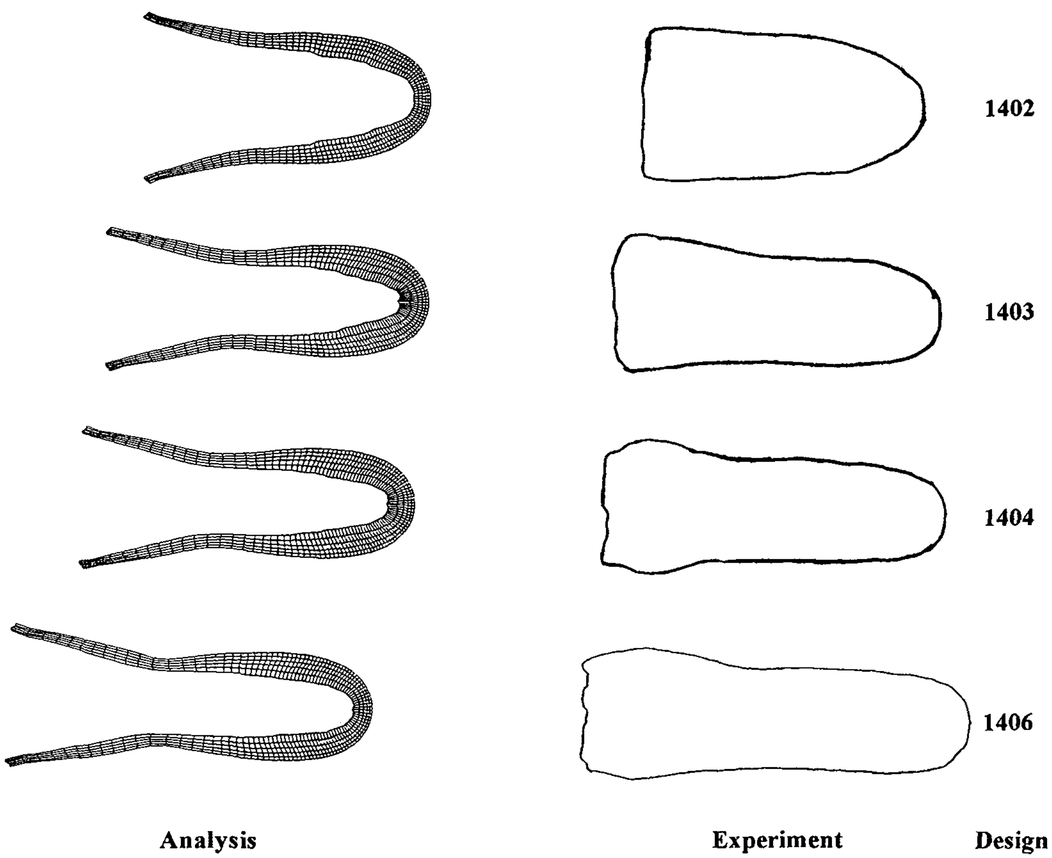


Figure 5. Calculated and experimental EFP geometry's for 4 different liner designs.

5. CONCLUSIONS

This computational study has shown that an "appropriate set" of constitutive material model parameters can be determined independently from a set of EFP warhead experiments. The constitutive parameters for the forged/annealed/coined copper are reasonable when compared to the published Steinberg values which are for 1/2 hard OFHC copper. However, these values may not be the "correct" values, but rather, they are a set of values that provide the best match to this set of EFP experiments.

In the next phase of this study, we will investigate the suitability of using nonlinear optimization methods coupled with DYNA2D to automatically determine the "best" set of constitutive parameters. We will use a coupled nonlinear optimization code coupled with DYNA2D to reverse engineer some or all of the material parameters for the Steinberg-Guinan, Johnson-Cook, and Zerilli-Armstrong constitutive models [9].

6. ACKNOWLEDGMENT

The accomplishments on this project were the result of the support and efforts of several individuals and organizations. I would like to thank Milton Finger, Suzanne Lake, and Dennis Baum (LLNL) for the overall direction and support of these efforts within the LLNL Advanced Munitions Technology Program, the Joint DoD/DOE Munitions Technology Development Program and the members of Technical Coordination Group IV, Richard Fong and Brian Travers (US Army, ARDEC) and Fred Wagoner (Alliant Techsystems) for their interactions on the generic EFP studies.

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