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INVERSE MODELING OF PENETRATION INTO 12.7 CARTRIDGES

NILSSEN Jan R, MOXNES John F

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Bjarne Haugstad
Director of Research

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FORSVARETS FORSKNINGSINSTITUTT
Norwegian Defence Research Establishment
P O Box 25, NO-2027 Kjeller, Norway

FORSVARETS FORSKNINGSINSTITUTT (FFI)
Norwegian Defence Research Establishment

P O BOX 25
N0-2027 KJELLER, NORWAY

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8) ABSTRACT

In this article a study of the forces caused by penetration of steel penetrators into cartridges of brass has been carried out. Experimental data was compared with simulations using the Nike-2D code and with solutions from a provided cavity expansion theory for thin cylindrical shells.

The Nike-2D simulations gave good agreement with the experimental results. By using an inverse modeling technique a constitutive model of the brass was established.

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CONTENTS

INVERSE MODELING OF PENETRATION INTO 12.7 CARTRIDGES

1 INTRODUCTION

The Norwegian armed forces use the Multipurpose 12.7 ammunition. Nammo Raufoss AS is the inventor of the Multipurpose (MP) concept, and the MP technology was developed during the end of the 60s. The first series production started in the beginning of the 70s.

During 2001 a contact between FFI and the Norwegian Army was signed. One of the objectives was to analyze in more detail some of the mal-functions of the gun, which has been observed during launch. Of special interest were events behind gunpowder gas leakage caused by rupturing of the cartridge during launch. In order to analyze this phenomenon by numerical calculations, the material model of the brass cartridge must be established.

In order to find the material model of the brass cartridge during large extension, a new non-standard test where a steel penetrator was forced into the empty cartridge has been analyzed. Simulation results from the Nike 2D[1] code and from analytical calculations were compared with the experimental results of the force and displacement of the penetrator entering into the brass cartridge. A material model of the brass was achieved by searching for a material model that gave close agreement with the experiment and the numerical calculations, a so-called inverse modeling technique. The constructed material model is in good agreement with other models reported in the literature and with the hardness test.

2 THE EXPERIMENTAL SET-UP

In figure 2.1 the experimental set-up is shown.

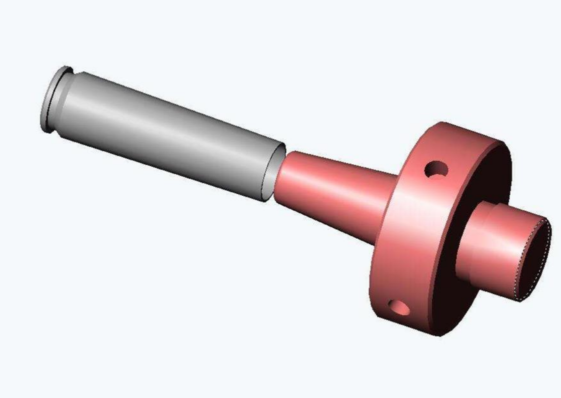

Figure 2.1 The experimental set-up of the penetrator entering a cartridge

The experimental recording was the force and the displacement of the penetrator.

3 THE ANALYTICAL PENETRATION THEORY

This section gives a short description of the constructed penetration theory for penetration into thin cylindrical shells.

Assume that initially the inside diameter of cylindrical shell is equal to the diameter of the conical penetrator so that physical contact is established.

Let F be the force on the penetrator. The sum of mechanical and friction forces give the total force, i.e. $F \overset{def}{=} F_s + F_f$. According to the standard cavity theory, which applies to a semi-infinite medium the normal stress on the surface of the penetrator is

$$\sigma_n \overset{mod}{=} (2/3)Y_t\ (1+Log[2\ G/Y_t]) \tag{3.1}$$

where

σ_n: Normal stress
G: Shear modulus
Y_t: Yield limit in target

This normal stress is different for a cylindrical shell. Assume the parameters

R : Average radii of the cylindrical shell
h: Thickness of the shell

The stresses during the initial elastic phase is at the inside surface of the shell given by

$$\begin{gathered}\sigma_{\theta\theta} = \sigma_{\vartheta\vartheta} \overset{mod}{=} (1/2)\,p\ R/h, \sigma_{rr} \overset{mod}{=} -p \\ s_{\theta\theta} = s_{\theta\theta} \approx (1/6)\,p\ R/h, s_{rr} \approx -(1/3)\,p\ R/h\end{gathered} \tag{3.2}$$

where

p: Inside pressure of the shell

Assuming that after the initial elastic phase the shell yields essentially over the complete thickness, gives from (3.2) and assuming a Mises material, that

$$(3/2)(s_{rr}{}^2 + s_{\theta\theta}{}^2 + s_{\vartheta\vartheta}{}^2) \overset{mod}{=} Y_t^2 \Rightarrow p = 4Y_t h/R \tag{3.3}$$

The average radial stress over a thickness of the shell is given as ,$\bar{\sigma}_{rr} \approx (1/2)\ p$. Using this value as the normal stress gives the mechanical strength force as

$$F_s = \int_{\Omega} \sigma_n Cos(\theta)dA = \int_{A_p} \sigma_n dA_p = 2Y_t\ (h/R)A_p \tag{3.4}$$

where

θ := angle between the normal stress vector on the surface of the penetrator and the axial direction
Ω : contact surface between the penetrator and the steel plate
dA : surface element
dA_p : projected surface element
A_p : projected contact area between the penetrator and the plate in the direction of penetration

The friction force is given as

$$F_f = \int_{\Omega} \sigma_n \mu Sin(\theta)dA \tag{3.5}$$

where

μ : coefficient of friction

Assuming conical half angle ψ it follows that the friction force is given by

$$F_f = \mu F_s / Tan(\psi) \tag{3.6}$$

Let $A_p(d)$ be the projected area of the penetrator into the target as a function of the penetration depth after contact between the hollow cylindrical shell and the conical penetrator. Equations (3.4) and (3.6) then give the total force as

$$F(d) = 2Y(h/R)(1+\mu/Tan(\psi_1))A_p(d), A_p(d) \approx \pi(R+Tan(\psi_1)d)^2 - \pi R^2 \tag{3.7}$$

where the projected area can be established from a simple drawing of the situation.

4 NIKE RESULTS, ANALYTICAL RESULTS AND EXPERIMENTAL RESULTS

In this section simulations with Nike-2D will be compared with experiments and with results from the presented penetration theory. Figure 4.1 shows the Lagrange grid of the target and of the penetrator.

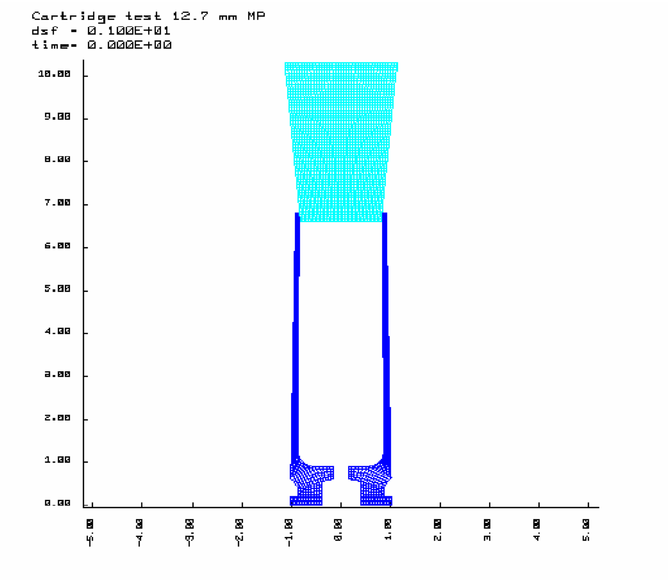

Figure 4.1 The simulated Lagrangian grid

Figure 4.2 shows three different curves. The simulated force, the experimental force, and the analytical force from equation (3.7), all as a function of the penetration depth.

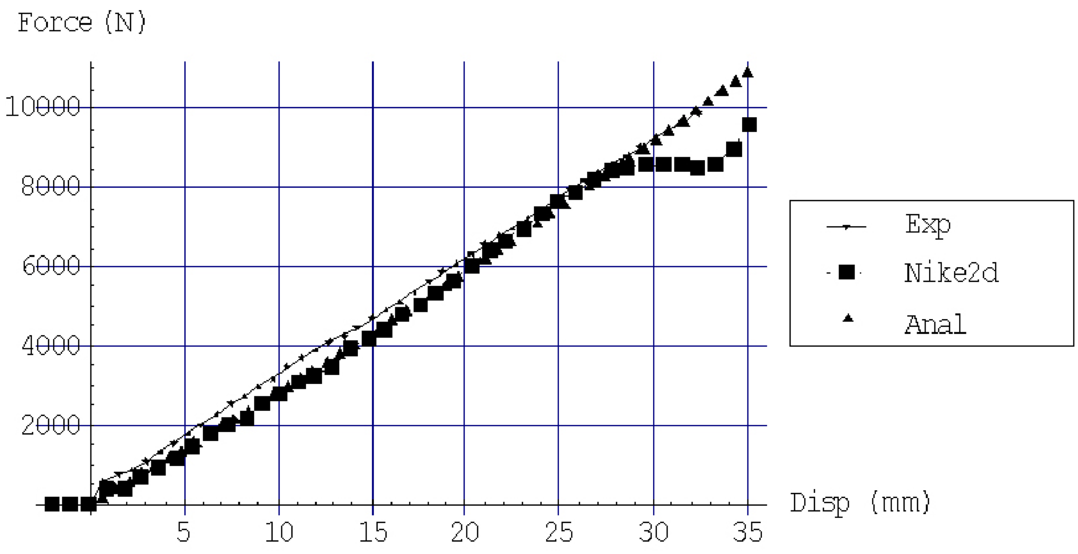

Figure 4.2 The force as a function of the displacement

We observe that the agreement between the curves is very good. The simulation result deviates from the experimental results in the final part of the penetration process. The effect is probably caused by numerical instability. The established material parameters are given in appendix A.

5 CONCLUSION/DISCUSSION

We found in the last section that the Nike-2D and the analytical theory show good agreement with experiments. The provided inverse modelling technique also gave good agreement with the constructed analytical theory. The material properties of the brass are in agreements with values in the literature. The Brinell hardness in area 10 is close 150,which gives a yield strength of 340 MPa for Cu.

References

[1] Nike-2D user Manual.

Acknowledgement: We thank Eva Friis at Nammo Raufoss for helping us with the input to the Nike 2d code, and Svein W Eriksen and Finn Risebrobakken at FFI for doing the hardness tests.

A APPENDIX

The following material parameters were found for the brass

Brass density: 8.31 g/cm^3,Youngs modulus: 1.15 10^11 Pa, Poison ratio: 0.3
Yield function (piece wise linear): Strain: 0.0, 0.1, 0.2, 0.3,0.5,0.8,1.1,5.0
Stress (GPa):0.335, 0.371,0.398,0.418,0.449,0.485,0.514,0.712
The material properties is in good agreement with other brass materials (Jacket 12.7). A yield strength of 340 MPa corresponds with a hardness of 150 Brinell for Cu.

B APPENDIX

Hardness and chemical analyses of 12.7 cartridges.

Hardness as a function of position from the cartridge edge is measured for 3 different used cartridges. The chemical analysis is performed by using the electron microscope.

Cartridge-1:FNB 00, Cartridge-2:FNB 00,Cartridge-3:FNB 91

Cartridge-3 has a crack. The measurements in series 2 go along this crack.
Dates 7-10 are near the crack (approximately 5 mm from the crack)

Cartridge-1	1	2	3	4	5	6	7	8	9	10
Series-1 110	139	126	149	165	171	170	156	151	141	Brinell

Cartridge-2	1	2	3	4	5	6	7	8	9	10
Series-1 134	137	148	158	-	-	-	-	-	-	Brinell
Series-2 100	117	139	148	147	-	-	-	-	168	Brinell

Cartridge-3	1	2	3	4	5	6	7	8	9	10
Series-1 137	135	123	130	147	160	164	165	159	151	Brinell
Series-2 146	132	136	140	144	159	170	-	166	153	Brinell

- means no measurements

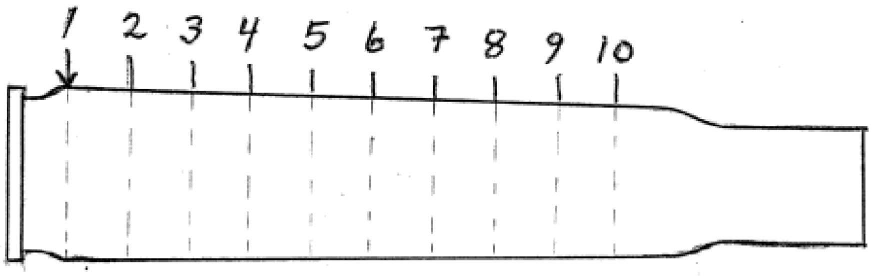

Figure B.1 Cartridge with the marked areas

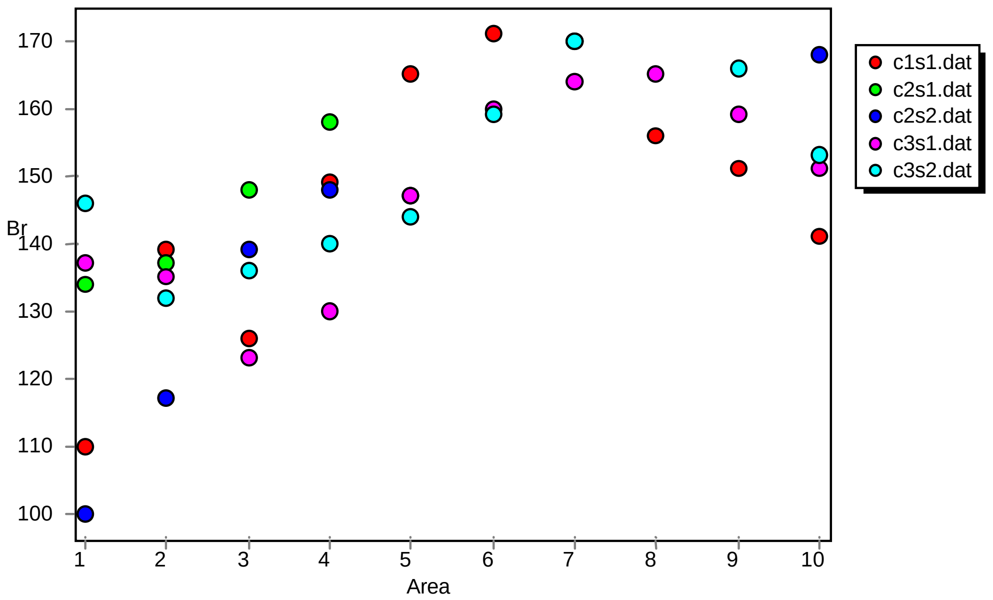

Figure B.2 Brinell hardness as a function of area

Chemical analysis of cartidge-3

Series-1 (close to the crack):	Cu	70.71 % - 69.41 %,	Average: 7
	Zn	29.29 % - 30.59 %,	Average: 29.94 %
Series-2	Cu	70.53 % - 69.45	Average: 69.99 %
	Zn	29.47 % -	

The density is given by the formulae

$$1/\rho_{CuZn30} = 0.7/\rho_{Cu} + 0.3/\rho_{Zn} \tag{B.1}$$

where

ρ_{CuZn30}: Density of cartridge

$\rho_{Cu} = 8.94\,10^3 kg/m^3$: Density of Cu

$\rho_{Zn} = 7.14\,10^3 kg/m^3$: Density of Zn

(B.1) then gives that

$$\rho_{CuZn30} = 8.31\,10^3 kg/m^3$$

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