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Extension of the xHVRB Reactive Burn Model for Graded Density Explosives

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Abstract. A new capability for modeling graded density reactive flow materials in the shock physics hydrocode, CTH, is demonstrated here. Previously, materials could be inserted in CTH with graded material properties, but the sensitivity of the material was not adjusted based on these properties. Of particular interest are materials that are graded in density, sometimes due to pressing or other assembly operations. The sensitivity of explosives to both density and temperature has been well demonstrated in the literature, but to-date the material parameters for use in a simulation were fit to a single condition and applied to the entire material, or the material had to be inserted in sections and each section assigned a condition. The reactive flow model xHVRB [1] has been extended to shift explosive sensitivity with initial density, so that sensitivity is also graded in the material. This capability is demonstrated for use in three examples. The first models detonation transfer in a graded density pellet of HNS, the second is a shaped charge with density gradients in the explosive, and the third is an explosively formed projectile.

INTRODUCTION

Historically, pressure-based reactive flow models were fit using Pop plot data [2], which recorded run distance and time to detonation as a function of the input pressure for a given explosive density. The reactive flow model xHVRB and its predecessor HVRB were fit to this data, and the explosive would transition to detonation according to that pressure-run distance relationship, regardless of the density at which the explosive was inserted. Adjusting the sensitivity of the explosive in the model required refitting of the model parameters to data that applied to the new density, which could then be applied in the model to the entire explosive.

Here the xHVRB model has been extended to incorporate the initial density of the explosive into the physics model, shifting the sensitivity in every cell of the calculation according to the density at which the explosive is inserted in the calculation. This allows the user to bypass refitting parameters when modeling explosives at densities off-nominal. In addition, by adjusting the explosive at the problem outset in each cell, explosives of graded density can be modeled. This new functionality is demonstrated on three problems of general interest in the explosives community – a pressed explosive pellet, a shaped charge, and an explosively formed projectile, both with a graded density.

MODEL DESCRIPTION

xHVRB was added to CTH in 2016 based on the work of Starkenburg [1] in order to add the capability to CTH to capture desensitization due to preshock. This capability has been demonstrated in other publications [3-4]. Because explosive sensitivity demonstrates a dependence on density, it is desirable that a reactive flow model would adjust the sensitivity of the explosive in the model based on the density. Kerley suggested that the PR parameter of the HVRB model in CTH could be scaled using an exponential of the ratio of the initial density to the nominal density [2]. This relationship, given in Equation 1, has been used to shift the PR value in each cell containing explosive, using the density as inserted in the simulation as ρ and the nominal density of the explosive ρ_0 (which corresponds to the Pop plot data to which the parameters were originally fit).

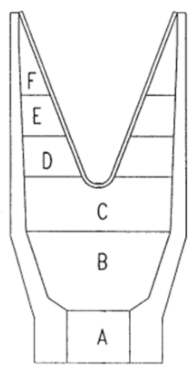
$$\frac{P_r}{P_{r0}} = \left[\frac{\rho}{\rho_0}\right]^4 \quad \text{Eqn (1)}$$

By using the initial density of the explosive in the simulation to set the PR value in each cell, the explosive can have a graded sensitivity that corresponds to a graded density. Even in cases in which the explosive has a consistent density throughout but is being used at a density that differs from the nominal case used to fit the model parameters, CTH will shift the density of the explosive accordingly without the need to refit. The quantitative evaluation of this shift in comparison with data will be examined in the future. In this study, the qualitative usefulness of the capability is evaluated against realistic scenarios.

METHODOLOGY

Models were constructed in CTH in 2-dimensional axisymmetric space to represent two cases. The first of these is a pressed pellet that resulted in a density gradient in the pellet. The pellet is ignited by a column of explosive with sufficient detonating pressure to reliably cause detonation in the pellet at its nominal density, which for this case is 95% of the theoretical maximum density (TMD). As pressed, the pellet could vary in density from 100% of TMD to 89% of TMD, with the densest region meeting the donor explosive.

The second case modeled is shaped charge. This case was documented in 1989 in which a shaped charge was evaluated to have a density gradient [5], and the solution for modeling the gradient was to divide the explosive charge into sections and assign each section a unique density (see Figure 1). If this were modeled with HVRB, each section would require unique rate parameters to accurately represent the sensitivity of the explosive in each section. In this study the shaped charge will be run with a uniform density and two variations of graded density.



Region	Density	HMX/TNT
A	1.800	65/35
B	1.810	70/30
C	1.815	72/28
D	1.822	75/25
E	1.832	79/21
F	1.850	85/15

FIGURE 1. Graded density shaped charge broken into sections as a simplified representation of the gradient [5].

The final case examined is an explosively formed projectile (EFP). In this case PETN is ignited in three configurations – a uniform density of 1.6 g/cc, and two graded densities similar to those used in the shaped charge case described above. The features of the projectile are examined to determine the effect of the density gradient on the effectiveness of the EPF.

RESULTS

The first results showing detonation transfer in a pressed pellet are given in Figure 2. The first example represents the ideal pellet if pressed as desired (left), with a uniform density of 95% TMD throughout. The model shows that the pellet detonates successfully. The second and third examples include the density gradient (89-100% TMD) in the pellet which could occur during the pressing operation. If the material is inserted with the gradient in density but not in sensitivity (PR is not shifted in the model), the pellet still detonates successfully (Fig 2, center). However, if the sensitivity is also graded with the density, according to Equation 1 above, the surface of the acceptor pellet is at 100% TMD, making it muchless sensitive. In this case the acceptor pellet fails to detonate.

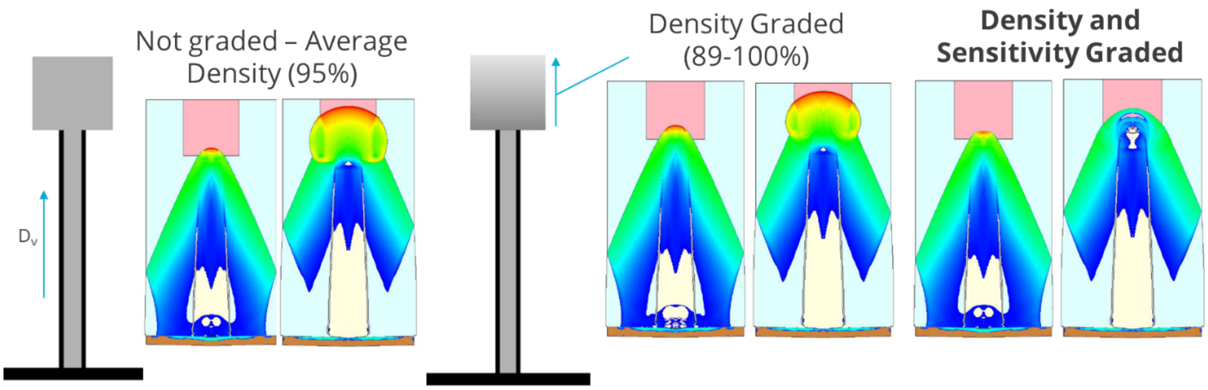


FIGURE 2. Results of pressed pellet simulations showing pressure contour for three cases.

This result can be qualitatively compared to the detailed view in Figure 3, which captured images of the detonation front in a uniform density pellet and in a pellet with graded density from 89-97% of TMD. The snapshot at 640 ns simulation time shows the detonation wave shortly after leaving the donor explosive and initiating the acceptor pellet. The second snapshot at 760 ns shows the steady detonation wave propagating through the acceptor explosive. The dark regions at the bottom of the large pellet are highly compressed solid explosive that has not reacted (dead zones). In the case of the uniform density pellet (left), the detonation quickly grows spherically from the ignition location, with very little dead zone. This is due to the relatively high initiation sensitivity of the acceptor pellet under nominal conditions (uniform density). In the case of the pellet with graded density, the pellet has a lower initiation sensitivity at the donor/acceptor interface due to the locally higher density. Although the detonation wave successfully transfers into the acceptor explosive, it also displays tunneling behavior. The detonation slowly spreads radially outward and results in larger dead zones and more curvature in the detonation front. These two examples illustrate how a gradient in the explosive pellet can affect detonation breakout and curvature of the wavefront.

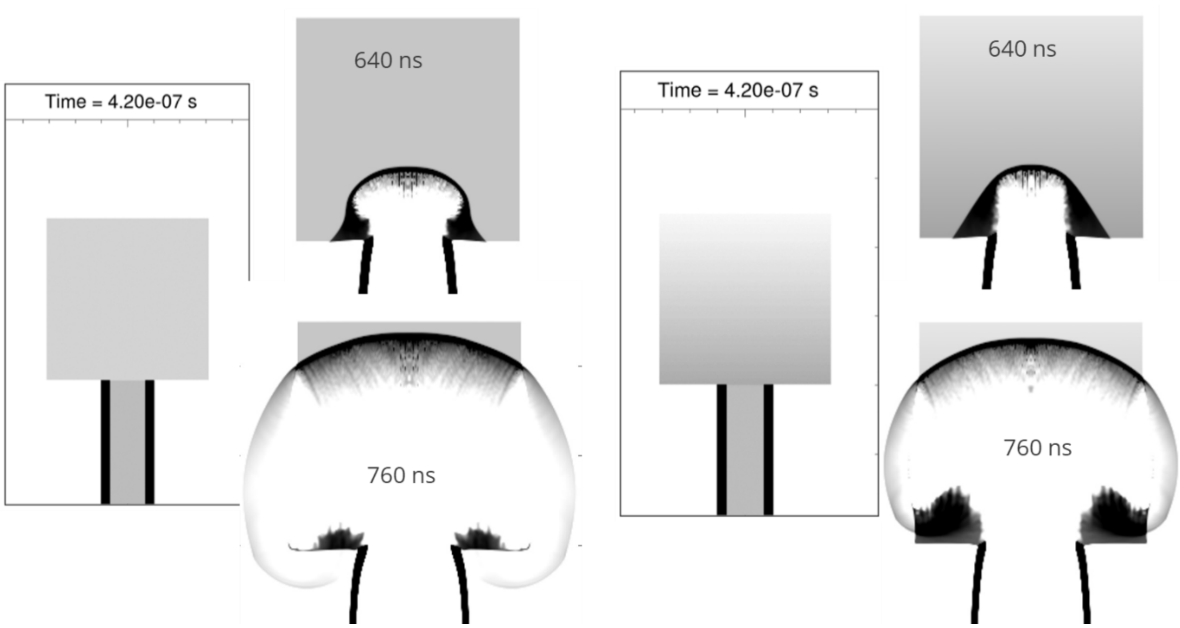


FIGURE 3. Results of pressed pellet simulation showing difference in detonation breakout with density gradient.

The next case examines density gradients in the shaped charge from Figure 1 [5]. Qualitatively all the cases appear similar, with different time of arrival and jet formation observable in the images in Figure 4. The center case shown in Figure 4 used a graded density in which the lowest density (1.5 g/cc, exaggerated from the comparison case for demonstration purposes) was at the ignition point (below the apex of the liner) and the highest density, 1.85 g/cc, was at the opposite end (liner skirt). This resulted in a slight drop in jet tip velocity of about 2%. The final example shown in Figure 4 (right) inverted the density gradient such that the highest density explosive was at the ignition location, and the density decreased down the charge. In this case the jet tip velocity dropped more significantly, almost 10%.

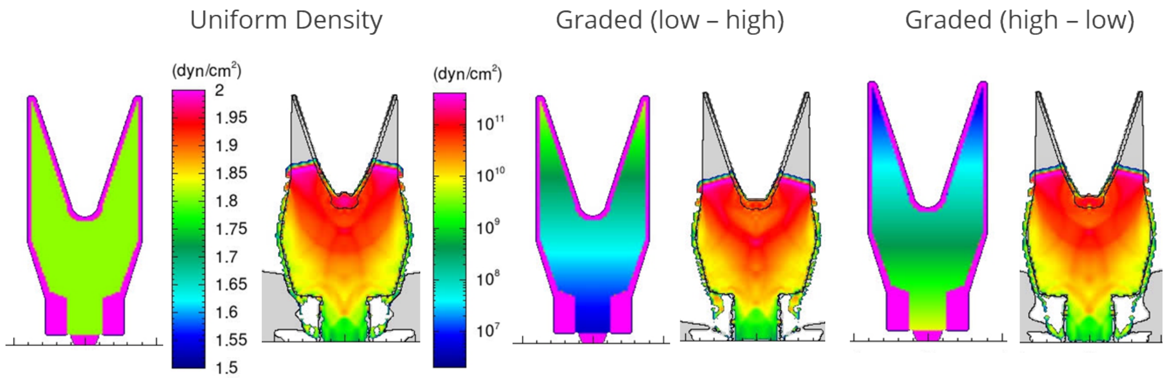


FIGURE 4. Results of shaped charge simulation showing density (left in each pair) and pressure contour (right in each pair) for three density gradient cases.

The final case studied here is an EFP using a PETN charge. The results of the three cases run are shown in Figure 5. The first (left) is a uniform density of 1.6 g/cc with the sensitivity shifted to correspond to the lower density, and in this case the detonation in the main charge is promptly established. The center case used a density gradient from 1.774 g/cc at the ignition location to 1.6 g/cc at the other end, but the sensitivity shift was turned off so that the material all reacted at its nominal sensitivity. The detonation is a little delayed in establishing due to the lower sensitivity of the nominal PR value (which was fit for a density of 1.72 g/cc). The last case (right) used the same density gradient but the sensitivity shift was turned on so that the material adjacent to the ignition location was at 1.774 g/cc and had lower sensitivity, and the material at the projectile end had higher sensitivity. In this case, the low sensitivity of the higher density material results in a longer run distance, and it takes much of the length of the charge to establish the detonation. The projectiles for these three cases, which are shown in Figure 6, show differences in shape that have resulted from the use of the density and sensitivity gradient. In the case in which sensitivity was shifted (right) the lateness of the detonation caused the projectile to split at the center.

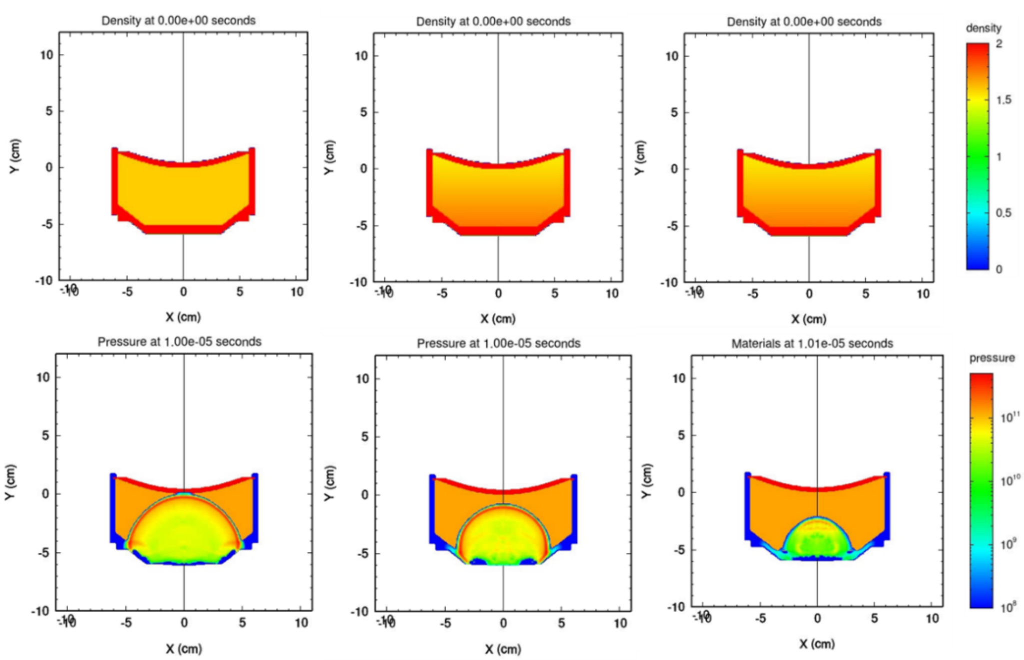


FIGURE 5. Results of diameter effect simulations for PBX9502 for HVRB (left) and xHVRB (right).

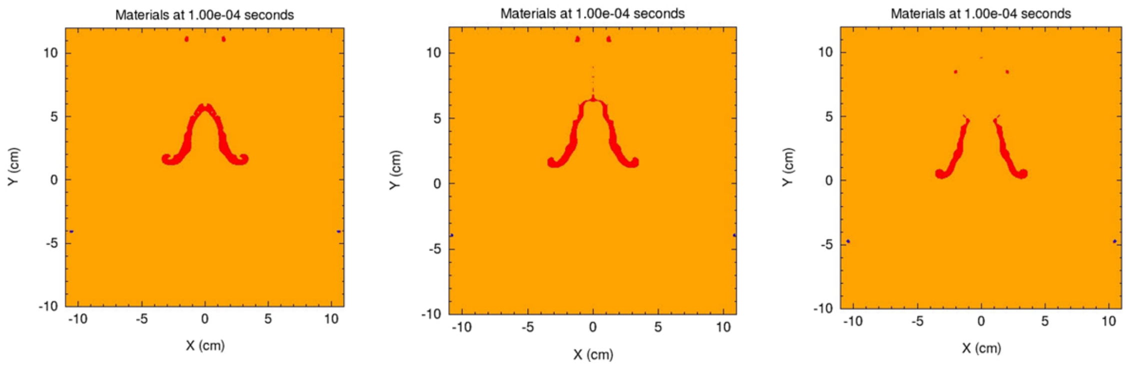


FIGURE 6. Results of diameter effect simulations for PBX9501 for HVRB (left) and xHVRB (right).

DISCUSSION

The effects of simulated density gradients and the corresponding shift in sensitivity have been demonstrated in three cases. Applying the sensitivity gradient can better and more physically represent pressed charges and other explosives that are subject to density variations, accounting for delays in detonation establishment, and in some cases predicting failure to detonate due to the presence of gradients. xHVRB can be used to apply a sensitivity gradient in CTH. In the future this capability will be quantitatively tested against experimental data.

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REFERENCES

1. J. Starkenberg, *Proceedings of the 15th Int. Detonation Symposium*, San Francisco, CA, 2014, p. 908
2. Kerley, G. I., Sandia National Labs internal report, SAND92-0553, 1992
3. Tuttle, L., et al., *AIP Conf. Proc.*, **1979**, 100044 (2018), DOI:10.1063/1.5044916
4. L. W. Tuttle, R. T. Marinis, R. G. Schmitt, D. E. Kittell, E. N. Harstad, *Proceedings of the 16th Int. Detonation Symposium*, Cambridge, MD, July 2018, p. 618
5. Michael J. Murphy, 11th International Symposium on Ballistics Brussels, Belgium, May 09-11, 1989