A THRESHOLD CRITERION FOR IMPACT IGNITION

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It is generally accepted that impact ignition comes about through plastic flow and thermal localization at adiabatic shear bands. Frey modeled this localization in plane geometry and showed that: 1) shear band thickness is of the order of 1 μm, and 2) temperature rise in a shear band increases with pressure and shear rate. Boyle, Frey and Blake then showed, using a dynamic pressure-shear apparatus, that ignition threshold depends on both pressure and shear rate. As shear bands are so thin, it is yet impossible to predict impact ignition with 2D simulations. To circumvent this difficulty we propose here to predict impact ignition by assuming an ignition threshold criterion, to be calibrated from impact test results. We use the two well-known tests, Susan test [5] and Steven test [4]. We calibrate the threshold criterion for the explosive formulation LX04 (85% HMX and 15% Viton A) from both tests. Our threshold criterion for impact ignition of LX04 is PD=0.0235 GPa/μs, where P is the pressure and D is the effective plastic strain rate.

INTRODUCTION

It has been shown many times that upon low velocity impact an energetic material (EM) may be ignited. The resulting combustion wave may or may not develop into a violent event, depending on confinement relative to reaction kinetics.

It is generally accepted that impact ignition comes about through plastic flow and thermal localization at adiabatic shear bands. Frey [1] modeled such localization in plane geometry, and Partom [2] did the same in 1D cylindrical geometry. They found that:

- Shear band thickness is of the order of 1 μm.
- Temperature rise in a shear band increases with pressure and shear rate.

Boyle, Frey and Blake [3] used a dynamic pressure-shear apparatus to check the 1D-model predictions. They found that ignition threshold depends on both pressure and shear rate. They measured the threshold curve (in pressure/shear-rate plane) for several EMs and found that for all the EMs tested, the threshold curve was hyperbola like (pressure decreases when shear rate increases and vice versa).

As shear bands are so thin, it is yet impossible to predict ignition in 2D situations. We propose to circumvent this difficulty by calibrating an ignition criterion from impact test data.

The main two low velocity impact tests found in the literature are Susan test [4] and Steven test [5]. In the Susan test a projectile containing the EM sample is accelerated against a rigid wall. In the Steven test, developed much more recently, a steel projectile is shot at a target containing a disc of the EM sample. In both tests ignition threshold is determined in terms of impact velocity, and violence of the event is measured as a function of impact velocity.

Based on the results in [3] we assume that an appropriate threshold criterion for impact ignition would be: PD=const.=$(PD)_{ig}$, where P is the pressure, D is the effective plastic strain rate (representing shear-rate in the pressure-shear apparatus tests), and $(PD)_{ig}$ is a constant characterizing the EM.

In what follows we calibrate $(PD)_{ig}$ for the explosive formulation LX04 (85% HMX and 15% Viton A). We use LX04 because ignition threshold velocity for this EM has been determined with both Susan test (43 m/s [4]) and Steven test (45 m/s [5]).

To calibrate, we run a hydrocode (we use PISCES2D) for the test configurations and with the threshold velocities. At the end of every time step of such a run we scan the mesh to look for $(PD)_{max}$ and obtain a $(PD)_{max}$ history curve. The maximum of this history curve is the threshold criterion $(PD)_{ig}$.

SIMULATIONS

We perform the simulations with PISCES2D. The configurations of the Susan and Steven tests simulations are shown in Figs. 1 and 2 respectively.

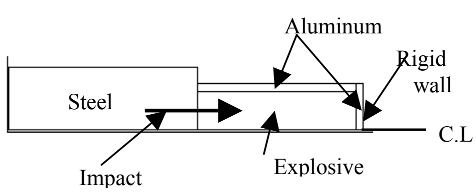

FIGURE 1. SIMULATION CONFIGURATION FOR SUSAN TEST. STEEL: 120/80 MM. EM: 100/50 MM. ALUMINUM: 5 MM THICK.

For Susan test we use the Lagrange processor. For Steven test we use the Euler processor for the projectile and the Lagrange processor for the target. The mesh is 1×1 mm×mm. We checked for convergence by running a 0.5×0.5 mm×mm mesh. Nevertheless we recommend to use in application runs the same mesh as in the calibration runs. For all the materials we use the Mie-Gruneisen equation of state with constant $\rho\Gamma$ (density and Gruneisen coefficient), and a constant flow stress Y.

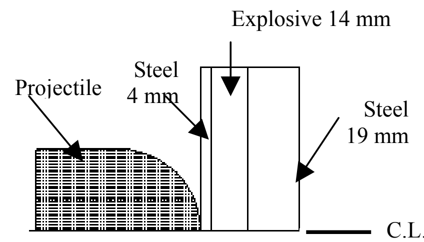

FIGURE 2. SIMULATION CONFIGURATION FOR STEVEN TEST. PROJECTILE: 60/60 MM. STEEL AND EM DISCS: 102 MM DIAMETER.

The flow stress of explosive formulations at high strain rates in compression is generally not known. In [6] they used a split Hopkinson pressure bar (SHPB) to measure the flow stress of several EM formulations at strain rates up to 2000/s. They found that Y increases from 10 Mpa at 0.5/s to 50 Mpa at 2000/s. For Susan and Steven tests a typical strain rate is around 10^4/s and it is plausible to assume that Y>50 Mpa. Running simulations with different values of Y we find (much to our surprise) that $(PD)_{max}$ increases with Y. We also find that the rate of increase is different for the two tests.

In Fig. 3 we show history curves $(PD)_{max}(t)$ for different values of Y for Susan test with an impact velocity of 43 m/s.

Fig. 4 is the same as Fig. 3, but for Steven test with an impact velocity of 45 m/s.

From Figs. 3 and 4 we see that:

- The $(PD)_{max}$ histories for the two tests are entirely different. In Susan test the curves rise quickly to a short duration peak and then decrease slowly. In Steven test the curves rise slowly to a plateau and stay there for a long time before going down.
- The peak value of $(PD)_{max}$ in the two tests is about the same at Y=80 Mpa. According to [6] this is a reasonable value at high strain rates.

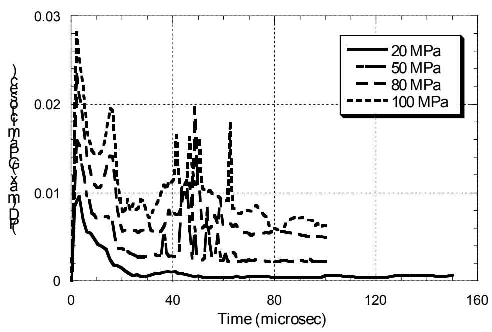

FIGURE 3. SUSAN TEST. $(PD)_{MAX}$ HISTORIES FOR LX04 WITH DIFFERENT VALUES OF Y.

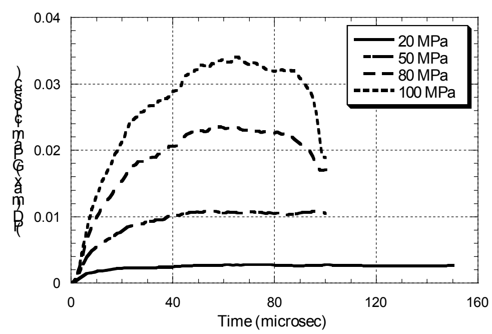

FIGURE 4. STEVEN TEST. $(PD)_{MAX}$ HISTORIES FOR LX04 WITH DIFFERENT VALUES OF Y.

In the following simulations we therefore use Y=80 Mpa. With this value we check the influence of the spall strength parameter P_{min}. Changing P_{min} from –10 to –50 Mpa we find that:

- In Susan test the maximum does not change, and the late time noise disappears.
- In Steven test the maximum changes slightly (from 0.024 to 0.028 GPa/μs).

As there are no data on spall strength of explosive formulations, and because the influence of P_{min} is small, we stay with the value of P_{min}=-10 Mpa.

The important lesson from these checks is that when applying the ignition criterion to a different configuration we need to use the same material parameters that we have used in the calibration process.

As explained above, all that we conclude from the tests in [3] is that the ignition threshold criterion ia a hyperbolic curve in the PD plane. Until now we used the simplest curve possible which is PD=const.. We check now to what extent a different curve would be more appropriate. To this end we run additional simulations in which we output histories of $(P^nD)_{max}$ with different values of n.

In Figs. 5 and 6 we show $(P^nD)_{max}$ history curves for n=0.5, 1 and 2 for Susan and Steven tests respectively.

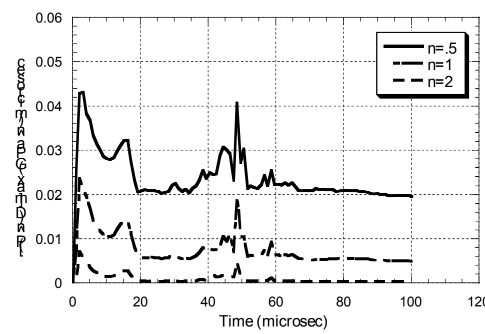

FIGURE 5. SUSAN TEST. $(P^nD)_{max}$ HISTORIES FOR n=0.5, 1 AND 2.

We see from Figs. 5 and 6 that the curves for different values of n are similar but shifted vertically. Comparing Figs. 5 and 6 we see that for each value of n the maxima of the corresponding curves in the two figures are approximately equal. We conclude that Susan and Steven tests alone do not yield enough information to determine n. With these two tests for calibration there is no advantage in using a particular value of n, and we can stay with n=1.

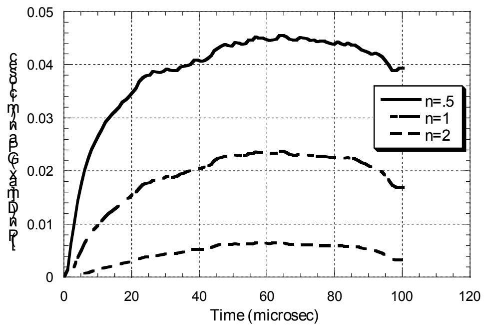

FIGURE 6. STEVEN TEST. $(P^nD)_{max}$ HISTORIES FOR n=0.5, 1 AND 2.

CALIBRATION RESULTS FOR LX04

The material parameters we use for LX04 are:
ρ_0 = 1.865 g/cm^3
C_0 = 2.36 km/s
S = 2.43
Γ_0 = 1
G = 5 GPa
Y = 80 MPa
P_{min} = -10 MPa

where ρ_0=initial density, C_0 ,S=unreacted Hugoniot parameters, Γ_0=initial Gruneisen coefficient, G=shear modulus, Y=flow stress, P_{min}=spall strength.

In Fig. 7 we show $(PD)_{max}$ histories for the two tests with the impact velocities mentioned above. We see from Fig. 7 that the ignition threshold criterion is $(PD)_{ig}$ = 0.0235 GPa/μs.

SUMMARY

Based on the results obtained in [3] using a dynamic shear apparatus, we assume that impact ignition threshold can be described as PD=const.=$(PD)_{ig}$, where P=pressure, and D=effective plastic strain rate. We calibrate $(PD)_{ig}$ by running simulations of Susan and Steven test configurations with the appropriate threshold velocity for ignition. We do this for LX04 for which the threshold velocities are 43 and 45 m/s for Susan and Steven tests respectively. We also run simulations for different values of Y (flow stress), P_{min} (spall strength) and n (an additional parameter in a more general threshold curve (P^nD=const.). We conclude that:

- $(PD)_{max}$ histories for Susan and Steven tests are significantly different. From this aspect the two tests complement each other.
- $(PD)_{max}$ histories strongly depend on Y. We use Y=80 GPa for which Susan and Steven tests give the same value of $(PD)_{ig}$.
- $(PD)_{max}$ histories are almost independent on P_{min}.
- Once the maximum of $(PD)_{max}(t)$ for the two tests agrees for one value of n, it agrees for other values. There is no advantage in using n≠1.

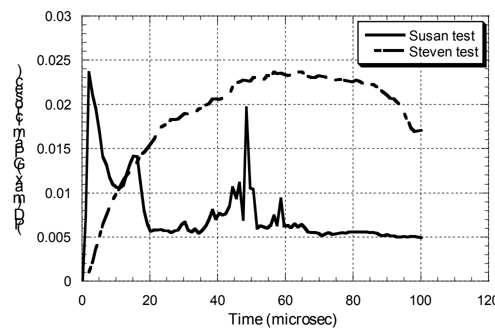

FIGURE 7. COMPARISON OF $(PD)_{max}$ HISTORIES FOR SUSAN TEST (WITH 43 M/S IMPACT VELOCITY) AND STEVEN TEST (WITH 45 M/S IMPACT VELOCITY) FOR LX04.

- It is important, when applying the impact ignition criterion to an operational configuration, to use exactly the same material parameters used in the calibration simulations.
- We find that for the explosive formulation LX04 the impact ignition criterion is $(PD)_{ig}$=0.0235 GPa/μs.

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