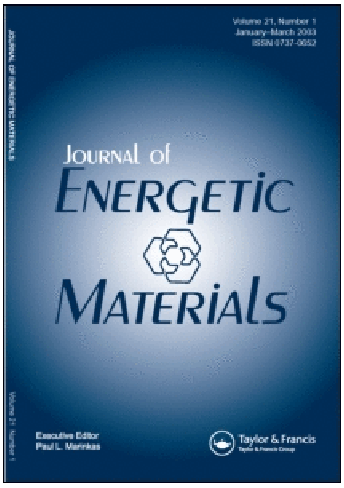

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An analysis of dynamic response of explosives due to impact and computer simulation of hot spot forming in explosives

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AN ANALYSIS OF DYNAMIC RESPONSE OF EXPLOSIVES DUE TO IMPACT AND COMPUTER SIMULATION OF HOT SPOT FORMING IN EXPLOSIVES

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Abstract—In accordance with the hot spot/initiation mechanism, the amendment of Perzyna's model of material behavior and elasto-viscoplastic analysis of explosive column due to impact are conducted in this paper. The flow parameter and Young's modulus are thought to be related with temperature. To test this developed model, the comparison between the experimental results and calculation values are done. The inhomogeneity of material is modeled by introducing a void at the center of the column. The numerical results show the elevated temperature near the voids. The effects of the shape and size of voids on local high temperature forming are also discussed.

1. INTRODUCTION

Trinitrotoluene (TNT) is an important military explosive. During the casting and cooling process, defects, such as cracks, porosities and larger voids or cavities, are often introduced. These defects are thought to play a critical role in premature ignition during artillary launch or any other dynamic loading.

It is generally accepted that the reason of initiation to occur in crystalline explosives due to impact is heat in origin. Many experiments have shown that under impact an excessive amount of energy is localized in the explosive[1~4]. These localized high-energy sites are sources of high temperature and called hot spots. A lot of investigators have proposed different models of hot spot formation which include gas compression in the cavity (or microporosity), hydro-dynamic cavity collapse, friction between adjacent grains and viscoplastic cavity collapse. Bowden & Yoffe[5] demonstrated that under some conditions gas compression in pores could cause ignition. They thought that when a small volume of gas is compressed rapidly, a high temperature reservoir (hot spot) of gas can create which may subsequently heat the adjacent explosive surface to the point of autoignition. Frey[6]

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applied cavity collapse model to investigate the effects of pressurization rate, cavity size and material parameters on hot spot formation in high density explosives. Field et al[7] have shown that catastrophic shear failures can cause ignition. Evidence was given for ignition by adiabatic heating of trapped gas, adiabatic shear of the explosive, friction and viscous flow. Based on their experiments on microparticle high velocity impact of silver and lead azide crystals, Winter and Field[8] concluded that the heat generated by plastic deformation is also a viable mechanism. Using the azide crystals as a model material under subcritical impact, it was shown that deformation is concentrated in narrow bands of material by adiabatic shear. Chou et al[9] performed the finite element simulation for shear band and hot spot formation. Three types of impact were simulated, including drop-weight indentation, high-speed impact and shock compression of a specimen with a void inclusion. The calculations show that the high temperature(hot spots) appear in regions where adiabatic shear bands arise.

Our experiments[10] showed that there exist clear effects of temperature and strain rate on material behaviour for TNT explosive, so elasto-viscoplasticity analysis has to be done for the dynamic response of explosive due to impact in the paper. The effect of strain rate on material behaviour can be represented very well by Perzyna's constitutive model, but the effect of temperature has hardly ever taken into account in it. In accordance with the hot spot/initiation mechanism for premature ignition, the improvement of Perzyna's model of material behaviour and elasto-viscoplastic analysis of explosive specimen due to impact are conducted in this paper. The flow parameter and Young's modulus are thought to be relevant with temperature. To check this developed model, the comparison between the experimental results and calculation values are done. Meanwhile, the inhomogeneity of material is modeled by introducing a void at the center of the specimen. The contour plots and distributions of temperature show the elevated temperature near the voids. The effects of the shape and size of voids on local high temperature forming are also discussed.

2. FORMULAS OF THE PROBLEM

The total strain rate is assumed to be the sum of elastic and viscoplastic parts

$$\{\dot{\varepsilon}\} = \{\dot{\varepsilon}_e\} + \{\dot{\varepsilon}_{vp}\} \tag{1}$$

The elastic strain rate is related to the total stress rate by the rate form of the Hooke's law

$$\{\dot{\varepsilon}_e\} = [D]^{-1}\{\dot{\sigma}\} \tag{2}$$

where $[D]$ is the elasticity matrix.

For the viscoplastic part, we consider a Von Mises material obeying the flow rule

$$\{\dot{\varepsilon}_{vp}\} = \gamma\langle\varphi(F)\rangle \frac{\partial F}{\partial\{\sigma\}} \tag{3}$$

in which γ is a flow parameter controlling the plastic flow rate, F is a yield function. The most common version of function $\varphi(F)$ is

$$\varphi(F) = \left(\frac{F - F_0}{F_0}\right)^N \tag{4}$$

where the exponent N is a prescribed constant, F_0 denotes any convenient reference value of F.

To ensure no visco-plastic flow below the yield limit we write

$$\begin{aligned} \langle\varphi(F)\rangle &= 0 && \text{if } F < 0 \\ \langle\varphi(F)\rangle &= \varphi(F) && \text{if } F \geqslant 0 \end{aligned} \tag{5}$$

From the evolution equation of the viscoplastic constitutive relation, it can be found that the flow parameter γ is inversely proportional to the viscosity μ, that is

$$\gamma \sim \frac{1}{\mu} \tag{6}$$

For TNT explosive the viscosity μ is considered to be depedent on the temperature and pressure[11]

$$\begin{aligned} \mu &= \mu_0 && T < T_0 \\ \mu &= \mu_0 \exp\left(\frac{P}{P_0}\right)\exp\left(\frac{E_0}{T} - \frac{E_0}{T_0}\right) && T \geqslant T_0 \end{aligned} \tag{7}$$

where $\mu_0 = 1000$poise, $P_0 = 165$MPa, $E_0 = 3880$K and $T_0 = 295$K for TNT.

Based on the experimental results for TNT[10], a concrete formula expressing the tendency of the elastic modulus with changing temperature can be obtained

$$E(T) = 48.41(T_m - T) \tag{8}$$

In light of the law of energy conservation, we have

$$\rho c \Delta T = \beta \int \sigma d\varepsilon \tag{9}$$

where ρ is the mass density, c is the specific heat at constant pressure, and β is a constant, roughly 0.85~0.95 at adiabatic condition. For simplicity, β is taken to be unity, so the temperature rise is given by

$$\Delta T = \frac{\int \sigma d\varepsilon}{\rho c} \tag{10}$$

3. NUMERICAL RESULTS AND DISCUSSIONS

The constitutive model is incorporated in the program package DYNPAK[12], and an explicit transient dynamic finite element code is developed for the analysis of dynamic deformation of explosive column. DYNPAK is further modified to calculate temperature field. The fluidity and elasticity are thought to be temperature dependent.

The explosive column are 19.1mm in diameter and 38.2mm high. Material properties for TNT used in calculation are listed in Table 1. The loading illustration is shown in Fig. 1.

Fig. 2 shows the dynamic response of explosive column at the node of the upper surface. The effect of temperature has not been considered in the first computer curve, so there is obvious deviation between the calculated values and the experimental results. After the effect of temperature is considered, the second computer curve shows a fairly good agreement.

Table 1. Material properties of TNT column

material constants	values
ρ (Kg/m^3)	1616.0
c (J/Kg • K)	1290.0
μ_0 (Pa • s)	100.0
T_0 (K)	295.0
P_0 (MPa)	165.0
γ (MPa)	38.5
T_m (K)	355.5
E (MPa)	3050.0
E_0 (MPa)	3880.0

In order to model the hot spot formation in explosive due to impact, a cylindrical void at the center of the explosive column is introduced. The void is 1.2mm in diameter and 1.2mm high. The quarter finite element mesh, with 1449 nodes and 460 elements, is shown in Fig. 3(a), and the deformed mesh shown in Fig. 3(b). Fig. 4 shows the local deformed mesh.

The distribution and contour plot of temperature in the deformed column, shown in Figs 5 and 6, indicate the local elevated temperature near the corner of the void. The numerical results also show the concentration of shear strain and a large velocity gradient near the void. So it can be hypothesized that the localized hot region is mainly due to the adiabatic shear mechanism for the explosive column containing cylindrical voids.

The effects of the shape and size of voids on local high temperature forming are shown in Figs 7 to 10. Fig. 7 shows the temperature contours in the region near the spherical void. It indicates that local high temperature is concentrated in a thin layer near the void, and there are little changes for temperature in the region away from the spherical void. The results of calculation for the explosive column containing a ellipsoid void, shown in Figs 8 and 9, indicate the formation of elevated temperature in the region where the curvature of ellipsoid changes very large. Fig. 10 shows a contour plot of temperature for the larger cylindrical void. It can be seen that it is easier to form local high temperature for larger voids comparing to the case in Fig. 6.

Based on the numerical results, it can be thought that the explosive column containing different voids under impact can produce local high temperature. For the cylindrical void, the local elevated temperature is concentrated in the region near the corner of the void, in which the shear strain is highly concentrated and a large velocity gradient emerges, and in this case the formation of local hot region is mainly controlled by the adiabatic shear mechanism. For the spherical or ellipsoid voids, the local high temperature is concentrated in a thin layer near the void, and there is little temperature rise in the region away from the void. So it is obvious that the dominant mechanism may be of cavity collapse or viscoplastic heating, but adiabatic shear for the spherical or ellipsoid voids .

4. CONCLUSIONS

(1) The numerical results show that the explosive column containing different voids under impact can produce local high temperature.

(2) The shape of voids has strong effects on hot spot forming mechanism. For the cylindrical void, the local elevated temperature is concentrated in the region near the corner of the void, which is mainly controlled by the adiabatic shear mechanism. For the spherical or ellipsoid voids, the local high temperature is concentrated in a thin layer near the void, which may be attributed to the mechanism of cavity collapse or viscoplastic heating.

(3) The size of voids has also effects on local elevated temperature. The results of calculation indicated that it is easier to form local high temperature for larger voids comparing to the smaller ones.

References

[1] John Starkenberg, Proc. 7th Symp. Detonation, 1981

[2] E. K. Walsh, Proc. 8th Symp. Detonation, 1985

[3] P. K. Tang et al. , Proc. 8th Symp. Detonation, 1985

[4] J. Kang et al. , Combustion and Flame, Vol. 89, 117, 1992

[5] P. P. Bowden & A. D. Yaffe, Initiation and Growth of Explosion in Liquids and solids, Cambridge University Press, 1952

[6] R. B. Frey, Proc. 9th Symp. Detonation, 1989

[7] J. E. Field et al. , Proc. R. Soc. Lond, Vol. A382, 231, 1982

[8] Winter & Field, Proc. R. Soc. Lond, Vol. A343, 399, 1975

[9] P. C. Chou et al. , Inter. Confer. on Shock-Wave and High Strain Rate Phenomena in Materials, San Diego, 1990

[10] X. P. Han et al. , Explosion and Shock Waves, Vol. 15, No. 1, 20, 1995

[11] R. B. Frey, Proc. 7th Symp. on Detonation, 1981

[12] D. R. J. Owen & E. Hinton, Finite Elements in Plasticity—Theory and Practice, Pinerige Press Limited, 1980

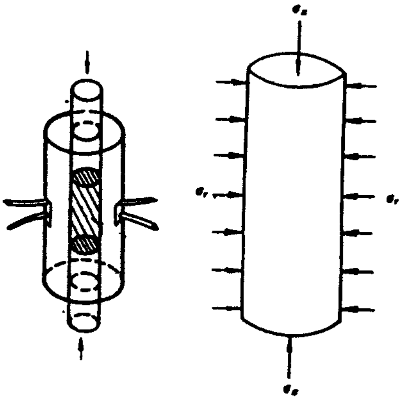

Fig. 1 Loading illustration

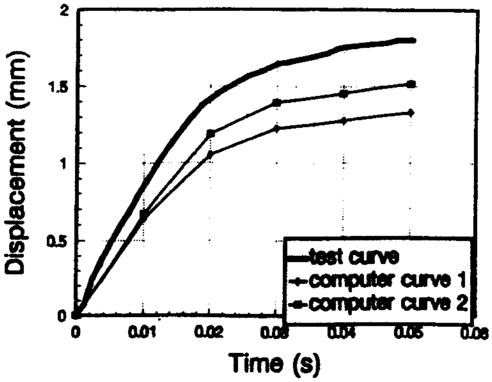

Fig. 2 Comparison between experimental results and numerical simulation

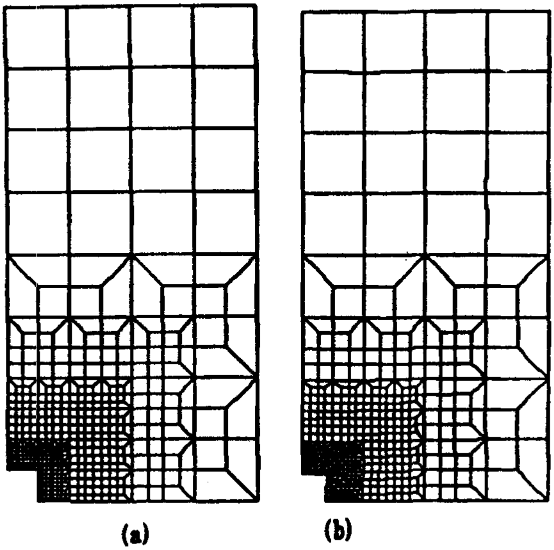

Fig. 3 (a) Finite element mesh
(b) Deformed mesh

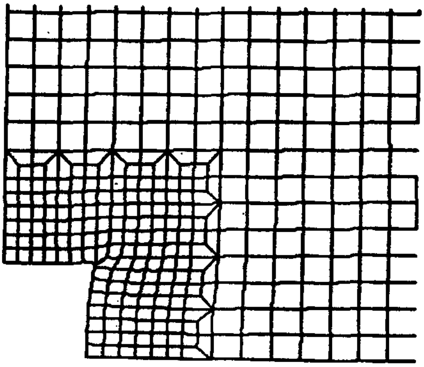

Fig. 4 Local deformed mesh

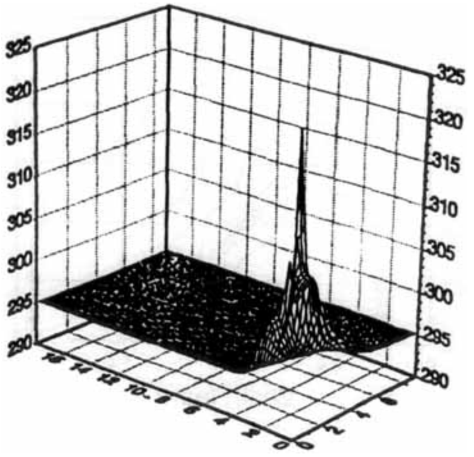

Fig. 5 Curved surface of temperature

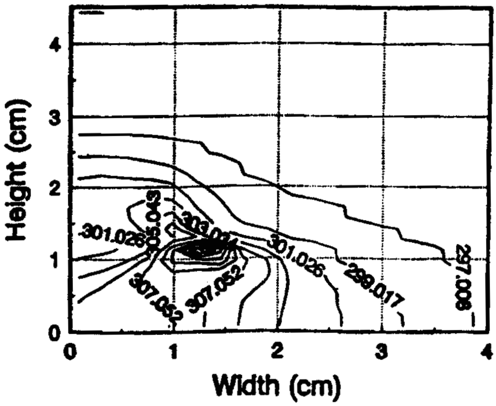

Fig. 6 Temperature contour plots
of column($r = z = 1.2$mm)

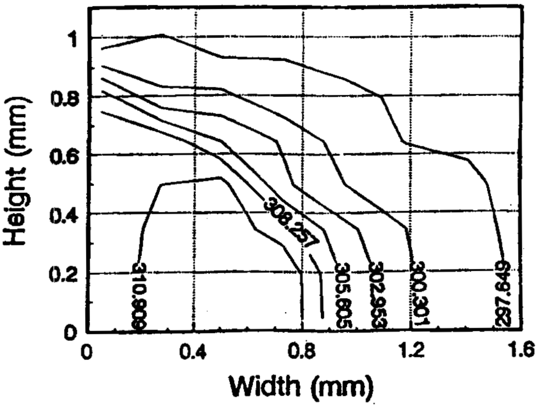

Fig. 7 Temperature contour plots of column ($r = 0.6$mm)

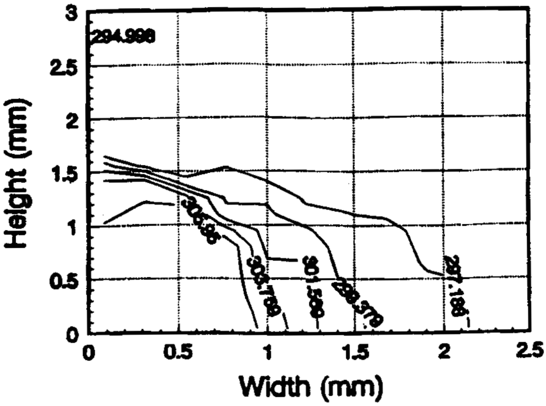

Fig. 8 Temperature contour plots of column ($a = 0.6$mm, $b = 1.2$mm)

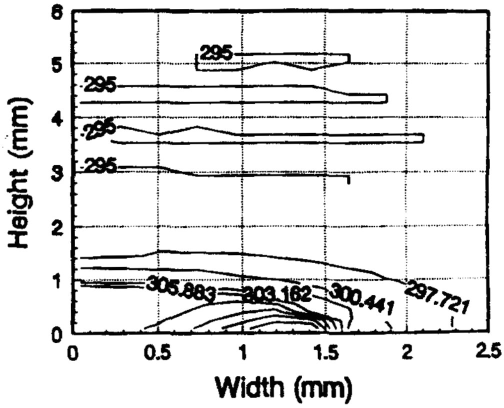

Fig. 9 Temperature contour plots of column
(*a* =1. 2mm, *b* =0. 6mm)

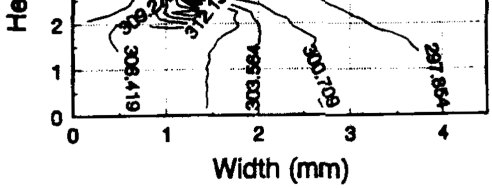

Fig. 10 Temperature contour plots of column
(*r* =1. 2mm, *z* =2. 4mm)