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Study on the Improvement of Mining Explosives by Nanotechnology

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Abstract: Nanotechnology techniques may be used to influence, or establish, certain properties of materials such as the oxide coating on aluminum particles. It is shown how control of the melting of the coating on aluminum particles in a mining explosive helps control the split of the total energy released into shock energy, that supports the detonating shock wave and heave energy, that heaves the overburden off the ore body. By appropriately choosing the thermal characteristics of the coating on the aluminum particles the total energy may be split into the most advantageous proportions.

Key words: explosion mechanics; mining explosive; AN emulsion explosive; shock energy; heave energy; nanotechnology

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1 Introduction

Energetic materials communities' understanding of explosives and modeling tools are also biased toward the near-ideal explosives found in military munitions. These explosives work well in their application because they release their energy quickly into the creation of the shock wave. On the other hand, commercial mining explosives, especially those intended for use in open pit mines, need to release their total energy more slowly. Some of this energy must be released into the shock wave that breaks up the rock and sustains the detonation. However, the ability of the explosive to heave the overburden off the ore body rests heavily upon the portion of the energy that does not support the initiating shock wave.

At this point in time China is making changes to their mining explosives and seem to be concentrating on ammonium nitrate emulsion explosives. One of the changes is to remove the TNT that has been in use for sensitizing the explosive. By changing from such an energetic sensitizer as TNT to an inert, or less energetic agent, for sensitization, one significantly changes the energy release characteristics of the explosive. This provides an excellent opportunity to understand, and adjust, the formulation to maximize the efficiency of the explosive for use in open pit mines.

2 Background

All theoretical studies of the reactive hydrodynamics begin with the time dependent conservation statements of mass, momentum, energy, equation of state, a reaction rate law and the CJ condition. Historically, the first efforts to determine a solution to the steady state problem involved a simplification to one-dimensional geometry and the assumption of instantaneous reaction[1,2]. This is a solution containing six unknowns.

However, real explosives used in drilled boreholes in open pit mines are two-dimensional and do not release their energy instantaneously. In order to understand the influence upon the effort required to obtain a solution to the expanded equations meeting these realities, one must first expand to two dimensions and then add realistic reaction rates. This expansion will also allow a better understanding of the characteristics of the explosive that determines how the energy released is divided into shock energy and heave energy.

In two-dimensional modeling of detonations the time rate of change of the pressure becomes an important equation in that it sets up the determination of the sixth relationship instead of the CJ condition that establishes a steady detonation solution. This equation is also referred to as the master equation because of its ability to establish the steady solution[3]. The time dependent equations above produce the time rate of change of the detonation as

$$\frac{\mathrm{d}p}{\mathrm{d}t} = -\frac{\rho(D-u)^2\sigma R}{\Psi} \tag{1}$$

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with the associated definitions of the thermicity $\sigma \equiv \frac{1}{\rho c^2}\left(\frac{\partial p}{\partial \lambda}\right)_{E,\rho}$, and the sonic parameter $\Psi \equiv 1 - \frac{(D-u)^2}{c^2}$ At the sonic point the local sound speed, c, equals the flow velocity $D-u$. This condition means the denominator of Equation (1) vanishes and in order for the time rate of change in the pressure to remain finite the numerator must also vanish. It does so when a single reaction is completed and $R=0$.

Adopt the Wood and Kirkwood (W&K) two-dimensional model[4] that assumed cylindrical symmetry and that the initiating shock front was curved as a section of a sphere where the sphere's radius, a, is larger than the diameter of the cylinder. The system of equations derived through the use of these assumptions, plus the assumption of considering the equations only on the axis of the cylinder, is found to be;

$$\left\{\frac{\partial[\rho(D-u)]}{\partial x}\right\}_{r=0} + \rho\left[2\frac{\partial \omega}{\partial r}\right] = 0, \tag{2}$$

$$\rho(D-u)\left(\frac{\partial u}{\partial x}\right)_{r=0} = \left(\frac{\partial p}{\partial x}\right)_{r=0}, \tag{3}$$

$$\left(\frac{\partial \omega}{\partial x}\right)_{r=0} = 0, \tag{4}$$

and, finally, the master equation in the W&K model is

$$\left(\frac{\partial p}{\partial t}\right)_{r=0} = \frac{-\rho(D-u)^2\left(\sigma R - 2\frac{\partial \omega}{\partial r}\right)}{\Psi} \tag{5}$$

The $r=0$ subscripts in Equations (2) through serve as reminders that these equations are specialized to the axis of the cylinder.

By comparing Equation (5) with Equation (1) the two-dimensional master equation gains an additional term in the numerator. This term, in essence, contains the loss of energy out the sides of the cylinder and this energy does not sustain the initiating shock. This loss of energy requires the detonation velocity to drop and this requirement shows up in the fact that in the W&K model the sonic condition of the denominator vanishing may now be matched by a vanishing numerator before the reaction has been completed. Though the energy lost in the flow of material in the radial direction does not support the initiating shock wave, it will still be very useful for heaving overburden off the ore body in an open pit mine.

3 Nanotechnology influence

Aluminum particles have been added to explosives, both military and commercial, for some time. Primarily, the addition of aluminum increases the total energy released in a detonation. However, for the open pit mining explosive the addition of aluminum has additional beneficial effects. Rather, here we would like to concentrate upon the effect of the additional chemical reactions upon the split of the total energy released into shock energy, the energy that sustains the initiating shock wave, and heavy energy, that part of the total energy that is released after the sonic surface has been reached.

When aluminum particles are introduced into an explosive, such as an ammonium nitrate (AN) emulsion explosive, at least three reactions must be considered. First, there is the exothermic reaction of the AN as its energy is released. Secondly, there is an endothermic reaction wherein some energy from the exothermic release of energy from the reaction of the AN is absorbed in the process of melting and/or cracking the oxide coating on the aluminum particles. The third reaction would be the exothermic reaction of the, now released, aluminum with some of the oxygen in the reaction products or the entrained air. The influence of nanotechnology may be seen without the added complexity of introducing all three of these reactions. Therefore, only a single exothermic reaction followed a single endothermic reaction will be considered.

The first exothermic reaction will be considered to be a simple burn rate as

$$\frac{d\lambda_1}{dt} = (1-\lambda_1) = R_1 \tag{6}$$

and the second reaction will be taken to be given by

$$\frac{d\lambda_2}{dt} = (\lambda_1 - \lambda_2) = R_2 \tag{7}$$

The total thermicity is now given by

$$\sigma \cdot R = \sigma_1 \cdot R_1 + \sigma_2 \cdot R_2 \tag{8}$$

In a one-dimensional detonation the sonic condition, of Equation (1) requires the thermicity to vanish at the sonic point.

If the first reaction is an exothermic reaction with an energy release of $\sigma_1 = 100RT$ while the second reaction is an endothermic reaction with total energy absorption of $\sigma_2 = -75RT$, then the family of partially reacted Hugoniots are still a one-parameter family. The ratio of the rate laws provide

$$\frac{(d\lambda_2/dt)}{(d\lambda_1/dt)} = \frac{d\lambda_2}{d\lambda_1} = \frac{(1-\lambda_1)}{(\lambda_1-\lambda_2)} \tag{9}$$

By integrating Equation(9) we find

$$\lambda_2 = \lambda_1 + (1 - \lambda_1)\ln(1 - \lambda_1) \qquad (10)$$

But the energy release is given by $Q = q_1\lambda_1 + q_2\lambda_2$ and by differentiating

$$\frac{d\lambda_2}{d\lambda_1} = \frac{(-q_1)}{(q_2)} \qquad (11)$$

which is the slope of the energy release line in the plane of the reaction extents, λ_1 *vs.* λ_2. By equating the two slopes in the reaction extent plane (Fig. 1), we find $\lambda_2 = \lambda_1 + \frac{q_1}{q_2}(1 - \lambda_1)$.

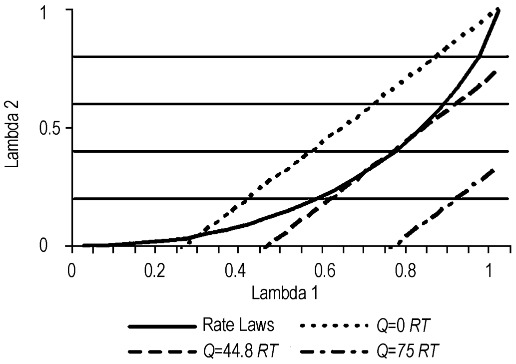

Fig. 1 Reaction extent plane

Comparing this to Equation(10) we find

$$\lambda_1 = 1 - e^{q_1/q_2} \qquad (12)$$

For our assumed heat of reactions, the sonic point is reached when the reaction extent of the first reaction has reached $\lambda_{1s} = 0.7364$, the second reaction extent at the sonic point is $\lambda_{2s} = 0.3849$. The total energy released at the sonic point is given by $Q_s = 44.8RT$.

4 Conclusions

The solution shown, wherein an endothermic reaction follows an exothermic reaction, argues that the endothermic reaction has a strong influence in establishing the split of the total energy into shock energy and heave energy. Given the strength of the influence of the endothermic reaction upon the split of energy, then the importance of the thermal properties of the coating on the aluminum particles may be seen. The thermal properties of the coating, that is the thermal conductivity and, more importantly, the specific heat, allows room for nanotechnology to enter into the engineering approach to the control of the split of energy from a mining explosive.

If nanotechnology can be used to set the thermal properties of the coating on the aluminum particles added to an explosive, then nanotechnology may be used to tailor the split of energy of a mining explosive for the optimal ratio of shock/heave energy for the specific properties of the overburden at any given open pit mine.

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纳米技术在矿用炸药中的应用可能性研究

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摘要: 从爆轰理论的基本方程分析了二维爆轰中随径向距离变化的压力对能量分配的影响。并在此基础上,对含铝矿用硝胺乳化炸药中的铝粉反应过程进行了理论分析,认为铝粉的吸热和放热反应过程对总能量分配为冲击波能(用于支持爆轰波以及破坏岩层)以及抛掷能(用于抛掷)的比例影响明显。由于该过程取决于铝粒子包覆材料的热性能,如热传导、比热等,故可通过纳米技术影响或改变包覆铝粒子氧化材料的性质、控制包覆材料的熔化,以及选择其热性能,以最优比例分配使用总能量,达到最佳的爆破效果。

关键词: 爆炸力学; 矿用炸药; 硝胺乳化炸药; 冲击波能; 抛掷能; 纳米技术

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