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INVITED DISCUSSION OF SHOCK INITIATION MECHANISM

The papers we have heard contribute very useful data to help us describe the explosive sensitivity to shock. Perhaps the experimental studies of Titov will be extended to furnish us Pop plot data for TNT at different initial temperatures in addition to the gap data. Pop plot data (distance of run as a function of plane wave initiation pressure) is the most useful type of data for shock initiation studies as it is essential for engineering or modeling studies.

The embedded Manganin gauge measurements of Wackerle exhibit curious maxima in the pressure histories which, if real for PETN or 9404, are poorly understood. We need to know more about this experimental technique under these conditions.

The mechanism of shock initiation of heterogeneous explosives is one of debate as evidenced by Howe's assumption of grain burning with heat conduction, Wackerle's assumption of the plastic work model, and by Titov and Nunziato's hydrodynamic flow modeling.

How important are transport mechanisms such as heat conduction, viscosity, elastic-plastic flow compared to the hydrodynamic flow? Are there pressure ranges where one transport mechanism may dominate and others where it is not important? Can the mechanism of adiabatic compression of the air in holes be important?

When heat conduction has been included into hydrodynamic calculations of hot spot propagation[1] or hot spot formation and propagation[2], it has been found to be negligible. The energy transfer accomplished by shocks and rarefactions is several orders of magnitude faster than energy transfer accomplished by heat conduction. If shocks are present and the time scale of interest is of the order of microseconds, then heat conduction is not an important energy transfer mechanism. A grain burning model using heat conduction for its energy transfer mechanism is therefore of little interest for describing shock initiation phenomenon.

The adiabatic compression of gas bubbles to high temperatures and the transfer of the heat to the explosive by heat conduction has been investigated both experimentally and theoretically as a mechanism of explosive shock initiation. The classical experimental studies of Seely and Seay[3] showed that changing the gas in the voids of PETN from one that would give low temperatures to one that would give an order of magnitude higher temperatures had no effect on the shock initiation properties. Several other experimental studies have confirmed this observation. Since the last Detonation Symposium the Joint Services Explosive Program sponsored some useful studies of this problem. Experimental studies of Craig[4] of the shock compression of various layers of gases in contact with explosives showed that the nature of the gas did not matter. Detailed numerical modeling[5] of the experiment showed that plane surface heat conduction across the compressed gas-explosive interface could not give a high enough temperature for a sufficient amount of time to result in any significant amount of explosive decomposition for systems experimentally observed to decompose. The gap initiation problem is still unsolved and apparently some other source of initiation energy is required such as shock interactions with surface irregularities or with internal voids is required to explain the experimental observations. It is surprising that the mechanism of initiation that is probably important in the accidental premature initiation of explosives in shells is unknown. We do know that some phenomenon other than plane surface heat conduction and adiabatic gas compression is dominating the initiation process.

The heating that results from viscous and elastic-plastic flow has been suggested[6] as a source of energy for initiating explosives at low shock pressures (~1 kbar) and long times (~milliseconds). If realistic viscous or yield coefficients are used, the amount of heating has been found to be insufficient to produce initiation. However, the notion that hotspots result from plastic work at void peripheries is being studied by groups led by John Taylor and by Jerry Wackerle at LASL.

While it is a great hand waving model, it has so far required what are probably unrealistic material properties to result in sufficient heating to be of interest in explosive initiation. However at this stage of our understanding of very low pressure shock initiation mechanisms it is unwise to ignore the possibility that viscous and elastic-plastic heating may be important for some applications.

For higher pressure (10 kbar) shock initiation of heterogeneous explosives we have found the heating from shock interactions at density discontinuities to be more than sufficient to result in initiation. The "Hydrodynamic Hot Spot" concept includes all the effects that can occur when shocks interact with discontinuities or with each other such as jetting, void collapse, shock separation and collision, mach and regular shock reflection and anything else one might observe in a reactive fluid dynamical numerical simulation of the flow. The development of this concept may be followed by studing the papers in previous Detonation Symposiums. Perhaps the most convincing experimental and theoretical demonstration of the hydrodynamic flow mechanism was the observed agreement between the computed[8] and experimental induction times[9] resulting from the shock interactions formed in nitromethane by corners of Plexiglas, gold and aluminum. An important consequence[2] of the hydrodynamic hot spot model is that the hot spot continues to decompose after the initial shock wave passage thus reproducing the experimentally observed decomposition behind the shock wave such as Dremin burn in addition to the shock front build-up.

The major mechanism of hot spot formation and energy transport in the shock initiation of heterogeneous explosives is hydrodynamic flow. The correlation of initiation properties with surface area, particle size, density and other physical properties can be interperted as the necessary consequence of a hydrodynamic mechanism and one does not need to invoke transport mechanisms.

As we have previously mentioned, the details of the hydrodynamic flow for many problems of practical interest are still unknown. Those attempting to investigate a shock initiation problem should concentrate first on the hydrodynamics of the problem and then add transport or material properties as needed.

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