DETONATION WAVE STRUCTURE IN LIQUID HOMOGENEOUS, SOLID HETEROGENEOUS AND AGATIZED HE.

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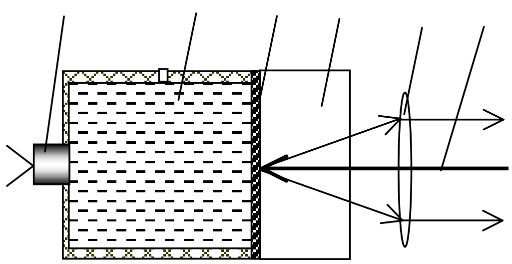
Heterogeneous HE decomposition mechanism in hot spots in detonation wave front is considered. Study of detonation wave structure of HE (HMX, RDX, PETN, etc.) with various porosity values (1-10%) is performed. Different structures of detonation wave with both pressure sharply raising and pressure smoothly growing for several tens of nanoseconds are recorded in liquid HE (nitromethane, tetranitromethane and fuel/oxidizer-type mixtures based on them). Results of the experiments for liquid homogeneous and solid agatized HE are under discussion.

EXPERIMENTAL SETUP.

Structure of detonation wave was recorded by Fabry-Perot laser velocimeter with nanosecond time resolution. The experimental setup is depicted in Fig. 1. U(t) profile was recorded at the HE-(LiF) window interface, where between HE and the window a thin foil or a layer (~1 μm) sprayed on LiF was placed which reflected laser beam [1, 2, 10].



1 - detonator; 2 - liquid HE in cylindrical cell or sample of solid HE; 3 - Al covering (~1 μm) or Al foil (5-10 μm); 4 - crystal of LiF; 5 -laser beam (λ=694.3 nm); 6 - focusing lens.

FIGURE 1. THE EXPERIMENTAL SETUP.

HE was initiated by electric detonator. Diverging detonation wave was propagating from the electric detonator. Pressure in Al cap of the detonator was 22 GPa. Size of laser spot at the HE-LiF interface was ≈ 100 μм.

SOLID HETEROGENEOUS HE.

Two types of particle velocity profiles, namely, smooth decreasing profiles and profiles with attenuated oscillations were recorded in solid heterogeneous HE. These profiles are depicted in Fig.2

Let us to consider smooth profiles first. Earlier we recorded experimentally the Neumann spike equal to P=49±2 GPa [1, 2] for four high-density HMX-based compositions (of the PBX-9404 type). Similar profiles were recorded for some other high-density (98-99 % TMD) HE (TNT/RDX 50/50, plastified PETN, etc.)

To explain the profiles with oscillations, experiments were performed, where HEs with differend densities were used. It is recorded in a number of experiments that just before detonation wave arrival HE-window interface starts smoothly accelerating during 5-7 ns up to velocity of U≈100 m/s. Then recording is broken. The reason of such acceleration can be microjets that overtake detonation front, accelerate LiF surface, and destroy Al-covering (recording break). The jets occur due to HE voids collapse.

In a number of model experiments, conical cavities were formed in plastified PETN with depth of 0.3-4 mm and vertex angle of 30-60 degrees. HE in these tests came in contact with thick (20…50 mm) aluminum plate. The size of the cavity, that was formed in the Al plate due to the impact of jets is approximately equal to the size of conical cavity in HE. In case when not an aluminum plate but HE is opposite the jets, the latter will effect on the front HE layers, i.e. the jets make an impact on unreacted HE.

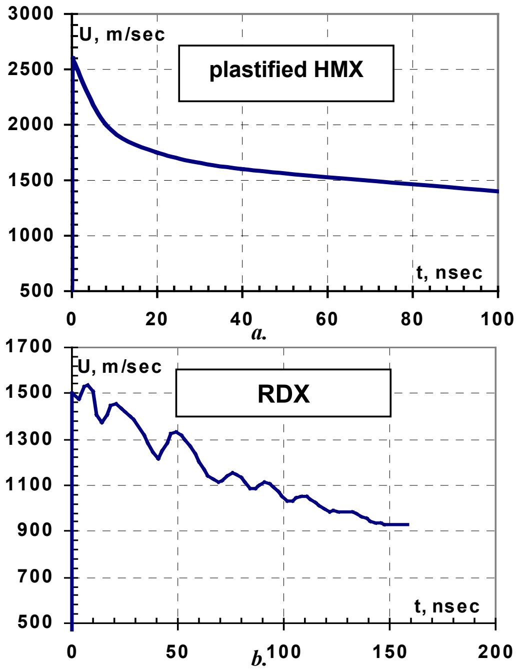


FIGURE 2. PARTICLE VELOCITY PROFILES FOR: (a) PLASTIFIED (98,5% TMD) HMX AND (b) RDX (93% TMD).

Velocity of jets in these conical cavities was measured. The jet head part velocity was 9-12 km/s, which is higher than detonation velocity (7.8 km/s).

We suppose that if the jet is decelerated in the layer of high-density HE, and the window is situated just behind the HE layer, then the jet influences HE, and in the falling profile U(t) at the boundary HE-window we record velocity oscillation up to ±100 m/s and with duration up to 20 ns. In our U(t) recordings together with smooth profiles there are profiles with damping oscillations. In cases when HE has high porosity and cavities size is large the jet can induce very large perturbations in U(t) profile. In [11], for HMX with porosity of 35% and average particle size =10 μm, velocity oscillations reach 300…400 m/s, at particle size of 120 μm they are up to 800-1000 m/s.

It is known that a large number of micro cracks and gaps is in heterogeneous HE. If a crack is perpendicular to detonation front then at the initial moment of detonation wave arrival the crack plane turning occurs for angle $\alpha \approx 5°$ [12], i.e. at crack collapse at angle $2\alpha \approx 10°$, jet can also be realized. Experiments were performed, where cracks with widths of 10-100 μm were artificially caused in HE. In the case, when HE contacted Al plate, a groove was formed in the plate under crack after explosion. Depth and width of the groove was 3-4 times thicker than the crack inside HE. It shows powerful effect of jets occurred in HE cracks on HE layers located ahead or metal plates.

Besides, the beginning of jets formation occurs not at Chapman-Jouguet (C-J) pressure, but at Neumann spike pressure, the value of which is 30% more than the C-J pressure [2, 10], jet parameters and its influence on unreacted HE will be significantly higher.

Most HEs cavities have the forms not of spherical volumes, but of long polyhedrons, cracks, gaps which produce many microjets and introduce turbulence into detonation front.

It follows from estimations that in heterogeneous HEs even of very high density (99% TMD) in 1 mm3 (109 μm3) HE contains 107 μm3 air and 107 voids at void size of 1 μm3, and 10000 voids at voids size of 10 μm (1000 μm3). These voids are the main reason of quick decomposition of HE in detonation wave front. It is shown in [13, 14] that collapse of voids is also one of basic reasons of hot spots formations where pressure is much lower (several tens of kilobar).

So, it is shown that the reason of occurrence of local heated areas (hot spots) in detonation wave front is, probably, microjets, which leave behind the detonation front, penetrate into unreacted HE, turbulize the front, and increase velocity of HE decomposition in detonation front.

LIQUID HOMOGENEOUS HE.

Both a stable front (in accordance with ZND model) mirror reflecting light (tetranitromethane, nitroglycerine) and unstable front with pulsing detonation can exist in liquid homogeneous HEs of monolithic initial density [6].

Earlier we performed study and revealed that different profiles of particle velocity U(t) are recorded at initiation of liquid HE according to the scheme presented in Fig.1. Smoothly decreasing profiles (see Fig.2-a), where value of the Neumann spike was respectively equal to 21.6 GPa and 24.2 GPa, were recorded in accordance with ZND model at initiation of tetranitromethane (TNM) and its mixture with nitromethane (NM) – TNM/NM-46/54 [2].

Two types of U(t) profiles were recorded at initiation of mixture composition consisting of TNM and nitrobenzene (NB) TNM/NB-74/26. When changing HE thickness from 2 mm to 30 mm, it is possible to record accidentally either a shock wave with amplitude of 17 GPa, or a complicated structure of detonation wave, where velocity is growing for 20-25 ns, and then recording is broken. The maximum recorded value was 41.6 GPa that was 2.5 times higher than pressure of shock wave (17 GPa).

A. Dremin explained it by the failure of chemical reaction [4, 5, 9]. In the front of detonation wave the same as in theory of thermal explosion, first comes the induction period and after this self ignition. For HE with slow energy release kinetics, the induction period is the basic part of explosion time and self ignition in Neumann spike can not exist (failure of chemical reaction). Detonation occurs later and passed along compressed HE catching up with the front, in this way occurs three-shock wave configurations (pulsing, unstable detonation front) [4, 5, 9]. Apparently, adding NB into TNM raises its energy and sensitivity, but makes energy release kinetics slow and detonation front pulsing.

In TNM the shock front has the view of a mirror [6]. We reflected light from metal samples of different roughness and observed that already at roughness ≤ 0.1 μm (100 nm and less) the samples reflected the light mirror. Taking for evaluations detonation velocity D=10 km/s=10 nm/ps we see that the duration of shock discontinuity zone l/D=10 ps and less can produce mirror reflection. Considering a molecule size to be $\approx$1 nm for width of shock jump of 100 nm and less, we see that increase of parameters in shock jump up to maximum values can occur on a chain consisting of $\approx$100 molecules and less. The other authors [9] suppose that duration of shock jump is $\approx$ 1 ps (10 nm). In this case, parameter increase will occur in a chain of $\approx$10 molecules.

AGATIZED HE.

A series of experiments was performed for recording structure of detonation wave in HMX (99% TMD) agatized (i.e. pressed with dissolvent presence). A concave profile U(t) falling down after the Neumann spike was recorded in all experiments. The Neumann spike value was P=49.4 GPa that was similar to the spike values for the other HMX-based compositions (98-99% TMD), namely, P=49±2 GPa [1]. It was thought earlier by some scientists [15,16] that there is no chemical spike in agatized HE. Our studies confirm presence of chemical spike in agatized HMX. Absence of chemical spike in work [15] was caused by use of thick foils (100-400 μm) (where chemical spike was damped) and by use of low-dense HE (80-93% TMD), where profiles with oscillations occurred, which resulted in recording of underestimated values of the Neumann spike. Absence of chemical spike in work [16] was caused by low resolution capability of the method.

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