DETONATIONS OF A THIN HE LAYER IN TUBES WITH A DIFFERENT GAS FILLING

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Shock wave and detonation propagation in a tube with a powder layer on the wall was studied in a number of preceding works. In presented paper some new results concerned with an air pressure reduction and an other gases filling influence is obtained. A part of the results was published recently in our work [1].

Detonation modes of thin explosive layer on the walls of glass and plastic tubes of 0.6-3 mm in diameter were studied. The used high explosives are lead azide (a primary HE) and PETN, RDX, and HMX (secondary ones). They were polydispersible powders with a minimal particle size about 1 μ and maximal sizes about 30 μ, 80 μ, 200 μ , and 30 μ respectively. An amount of explosive per the unit of tube volume was changed in the range 5 - 20 mg/cm^3 for lead azide and 5 - 60 mg/cm^3 for the secondary HE. In all cases the layer thickness was less than critical one excluding a self-sustaining detonation propagation in the layer on an analogous wall outside tube. The free space of tube was filled air or a combustible gaseous mixture. Initial gas pressure P_0 varied from 10^5 to about 20 Pa. The detonation was initiated by a high-voltage electric spark with energy ~1 J at a closed tube end. Also an additional charge of lead azide of weight about 5 mg was used in some experiments for the initiation. The development of the explosion process in the tubes was registered by the streak-photographs method.

As for the primary so for secondary explosives, independent on initial air pressure P_0, the self-sustaining detonation wave (DW) was registered in the tubes. After a transitional part of DW way its velocity D stabilised as approximately constant. A luminescence of stable DW in plastic and glass tubes of 2-3 mm in diameter had always a strip-like structure on the streak-photographs, that is characteristic for spin detonation mode with a rotating transversal wave (TW). The photographs allows determining the spin pitch L along the tube and velocity D. Ratio of spin pitch to tube circle length turned to be near to 1, that is almost the same as at spin detonation in gases. The spin absence was fixed only on unsteady way parts of detonation acceleration at $D < 1200$ m/sec and also in some experiment close to detonation limit. DW was not quite stable in last case, it had velocity D = 1000-1200 m/s. At the same time, the stable detonation propagated without any spin manifestations in plastic tube of 0.6 mm in diameter, where HMX with 5 % Al was used as an explosive.

Different modes of hybrid detonation, as one-frontal and two-frontal, high-speed and low-speed ones, were observed when the tubes with the secondary HE on walls were filled by an explosive gas mixture under a varying initial pressure. The value D of the modes were in range from D_0 to $D_0/2$ where D_0 is the detonation velocity of the gas mixture. It is should be emphasized that the lower D were less than the detonation velocity in the same tube with air or with no gas inside the tube.

The experimental D values obtained in tubes with HE and air are compared with Chapman - Jouguet detonation velocities D_{CJ} calculated for the same systems but with uniform distribution of substances over the tube cross-section. We obtained $D \le D_{CJ}$ for the secondary HE in all experiments. This can be explained by the DW momentum losses owing to friction and wall broadening at long reaction zone. The situation is different for lead azide, for which $D \le D_{CJ}$ only nearby the detonation limit, and $D > D_{CJ}$ at increase the explosive amount even in non-hard polyethylene tube. Moreover, the detonation velocity surpasses sufficiently, by 25 % and more, the "ideal" value D_{CJ}, despite the certain presence of losses on walls in this case also. Changing P_0 practically does not influence on detonation velocity in all the cases.

But initial pressure influence proves to be essential for a detonation front structure. At atmospheric one a luminescence front line was sharp and bright. It coincided with chemical reaction start line practically. With decreasing P_0 an air luminescence drops immediately behind a leading shock wave (SW), and the shock separates from reaction zone. At P_0 ~100 Pa a distance between they is in order of 10 tube diameters. And SW becomes invisible besides, its place is defined by its reflection registration when the luminescence grows multiply. In the way from SW to the reaction zone and further to a reaction product area, the luminescence grows and than decreases gradually if the tube contains a secondary HE. The reaction zone length defined as a highest luminescence zone is equal a few tens of the tube diameters in this case.

The forwarded placement of SW in front of the invisible zone can be sustained only by the expanded products of explosive decomposition. Besides TW exists on all the length of the invisible zone: a strip-like

luminescence structure behind the reflected wave is the evidence of this. The front part of TW (before the reaction zone) can be named the "frontal tail" as differentiated from the common back "tail" which is the transversal acoustic wave in products going back and created by the self-oscillating process in the reaction zone. The nature of frontal and back tails is equal. But frontal tail arises at spin detonation of vacuumed heterogeneous systems only, it is absent in all the previously investigated detonation waves. Decline of frontal tail is usually opposed to the back tail decline.

The difference between the primary and secondary HE reveals in some special features of flow in the reaction zone, which are registered on the streak-photographs. For tubes with secondary HE the luminescence and TW decline angle change along the axis coordinate smoothly. TW has no special selecting segment which can be recognised as the reaction zone and, moreover, as the transversal detonation wave (TDW). For tubes with lead azide the streak-photograph view is the same only nearby the detonation limit with respect to the explosive amount. At removing from the detonation limit the picture qualitatively changes. Firstly, under low initial pressures in the detonation front a light zone appears, it has quite a definite back boundary line separating it from the area of further flow. Secondly, TW has a break on the boundary line. And in the break vicinity the TW structure has some special features reminding sometimes TDW at spin gas detonation . At a subsequent increasing P_0 in a series of experiments the distance X between SW and the back boundary line of the light zone decreases.

Detonation mechanism in vacuumed system considering the present mathematical model for vacuum-suspension [2] is seen as the next. At the stage of DW formation in its frontal part a hot gas precursor arises with smoothly decreasing along the axial coordinate Z pressure and density, up to a small value of this quantities behind the leading shock front. SW in residual air practically does not influence. Gas flow in the precursor breaks off explosive particles from the wall forming increasing boundary layer of suspension with not equal velocities of gas and particles. With motion of particles or their vapors into depth of precursor (with possible intermediate melting, break up of liquid fragments, and vaporization, as dependent on explosive characteristics), they are heated up to ignition. Transversal wave prolonged forward from reaction zone until SW intensifies these processes and also the process of further combustion. In the case of secondary explosives before the end of the chemical reaction zone being prolonged enough, the complete intermixing the products in the tube cross-section happens, therefore the detonation velocity as determined by the common Chapman-Jouget rule considering losses on walls. It is equal or less than D_{CJ}, as in computations for the model [2]. In the case of high-sensitive primary explosive (lead azide) the chemical reaction goes substantially more quickly and is finished in the near-wall area of the suspension before its spreading for whole the cross-section. Reaction products extending into the axial area form frontal and back jets. The frontal one compensates gas losses from the precursor by a wall boundary layer. Velocity of the precursor supported in such way determines DW velocity. And it turns out to be more than one calculated according to the Chapman-Jouget rule which does not relate to this case. Thus it can be concluded, that in the vacuumed tubes with a thin layer of explosive on the walls the initiation transfer is realised by a flow of reaction products moving in the front part of detonation wave, i.e. a convective mechanism of detonation propagation is valid there.

As in all previously investigated systems, here the detonation spin is the self-oscillating process under conditions of instability of more simple axially symmetric flow in DW. The absence of spin appearances at the detonation of HMX/Al in tube of 0.6 mm in diameter is stipulated, probably, in too small diameter of a channel leading to disproportion of characteristic chemical reaction time and period of own transversal oscillations of reacting flow.

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