

Deflagration to detonation transition in mechanoactivated mixtures of ammonium perchlorate with aluminum

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Abstract. Deflagration-to-detonation transition (DDT) in aluminum–ammonium perchlorate (Al/AP) loose-packed charges (80% porosity) has been studied. The charges were manufactured from preliminary mechanoactivated mixtures. The mixtures placed in steel tubes 10 mm in diameter were ignited by Nichrome wire. It was found that it is possible to distinguish three parts corresponding to different stages of DDT process development. Steady-state detonation velocity reached the level of 2500 m/s at the distance of 90 mm from the ignition point.

1. Introduction

Since 2002 in ICP RAS, the research in the field of mechanoactivated composites based on different solid fuel-oxidizer mixtures have been conducted (see review [1]). Previously, optimal regimes of mechanoactivation of energetic composite (MAEC) aluminum–ammonium perchlorate (Al/AP) have been found [2]. This work is devoted to the study of deflagration-to-detonation transition (DDT) in loose-packed charges of Al/AP mixtures (20/80 wt%). The characteristic lengths of DDT and the velocity of steady-state detonation under specified conditions have been measured.

2. Materials

The mixture components, AP 50–100 microns in size and Al powders of two types: nanoscale Al(8) (the powder with specific surface area of 8 m²/g, consisting of two fractions 3–5 μm and 100–300 nm, see figure 1a), and pyrotechnic powder PP-2 (50–200 μm × 2–5 μm) were activated in the planetary mill “Activator–2SL”. The mechanical treatment of AP-based mixture was carried out in hexane with each cycle equal to 60 s of duration. The activation time was $t_{\text{act}} = 10$ min. The weight ratio of components Al/AP was 20/80. Characteristic SEM-picture of mechanically activated mixture is shown in figure 1b.



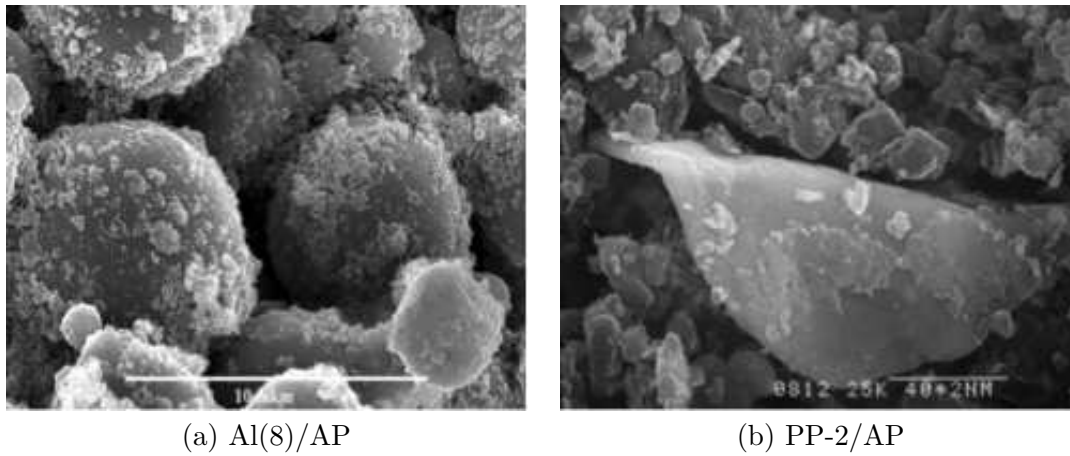


Figure 1. SEM-images of mechanoactivated mixtures.

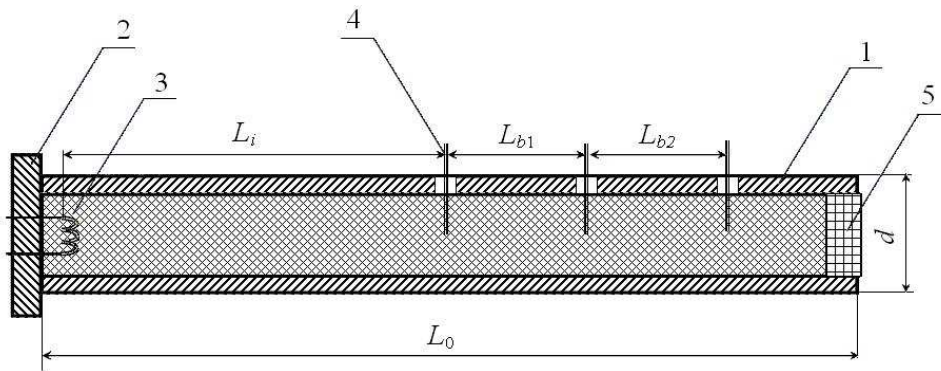


Figure 2. Scheme of charge: 1—steel tube; 2—steel bolt; 3—nichrome wire; 4—light fibers; 5—plug.

3. Experimental set-up

Both combustion velocities and detonation ones of MAECs were measured in steel tubes with inner diameter $d = 10$ mm and length $L_0 = 120$ mm at a porosity of mixtures $\approx 80\%$. Experiment set-up is shown in figure 2. Initial mixture was sieved and poured into the tube and hand pressed to the same charge density. The loose-packed mixture was initiated by the heated Nichrome wire ($R = 4-6 \Omega$) placed nearby the closed end of the tube. The rate of the process along the tube was measured using optical fibers inserted into the tube on a half of its diameter in order to prevent possible influence of flame passage along the tube wall. The fibers transmitted the light emitted by products to photodiodes. The electrical signals were recorded by digital oscilloscopes. In the most tests, the bases of measurements L_b were equal to 20 mm while the distance from the ignition point to the first optical fiber (L_i) was varied from 9 to 70 mm. Characteristic time of wire heating-up was measured as 40–50 ms. The instant at which Nichrome wire was broken out was chosen as the onset of the reaction spreading over the mixture.

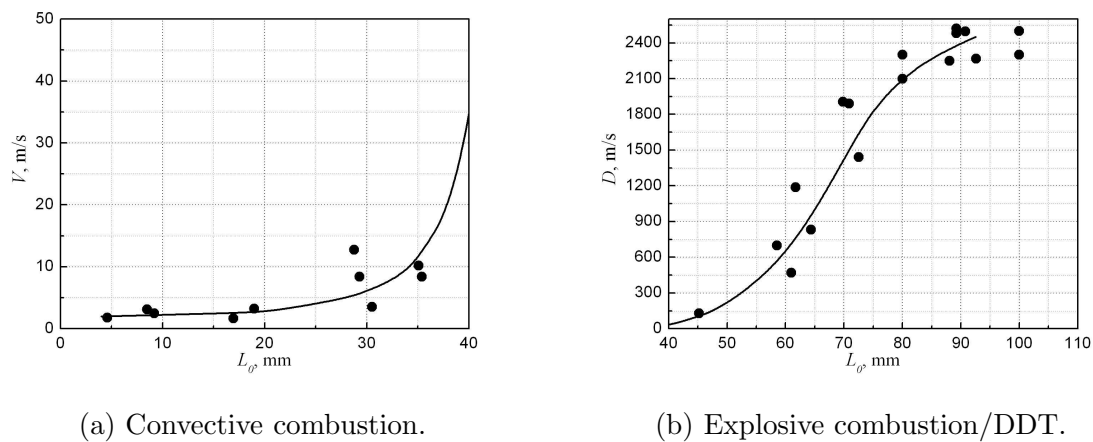


Figure 3. Dependence of combustion and detonation velocities on the distance from the ignition point.

4. Results and discussion

The averaged velocities were ascribed to the middles of the measuring bases L_b . The velocity of the process varied from several meters per second (at 10 to 15 mm from the ignition point) to 2.5 kilometers per second to steady-state detonation. In order to present the results clearer seen, the obtained D -values versus the distance from the ignition point (L) were plotted in two parts, see figure 3.

DDT-process in such mixtures is rather complicated one, so a small difference in the initial test conditions, such as electrical resistance of Nichrome wire or slight density perturbation over the tube length, could noticeably influence the measured velocity and the length at which DDT process took place. For example, lesser resistance of the wire resulted to the faster DDT over the length. Therefore, there could be some variation in the average velocities measured at the same base situated at the same distance from the ignition point.

However, one can identify three areas characterized by different velocities of the process. At the first area $L < 30\text{--}35$ mm, the process proceeds with velocities equal to several meters per second with slight self-acceleration. At the distance of $L \approx 5\text{--}60$ mm, the velocity increases quite rapidly from tens to more than hundreds of meters per second. In the area of 60–70 mm, we observe the formation of the detonation process.

According to the obtained results, one can assume the following picture of DDT process. Convective burning of fine AP fraction (seen in figure 1b) occurs nearby the Nichrome wire. The combustion zone propagates through the tube with average velocities $V \approx 10$ m/s in the form of jets, filling the pore space by the heated products of combustion. Consequently, coarse fraction of AP particles is ignited and melt Al is involved in reaction with AP combustion products. Thus, one can suppose the formation of more powerful jets of reaction products consisted of Al with AP which have higher temperature. At the distance of $L = 30\text{--}35$ mm from the initiating wire, the jets start to lead the reaction in the mixture. Such combustion process which propagates in form of high speed jets at velocities of hundreds meters per second was called as an explosive combustion by Apin [3]. Explosive combustion occurs at the distance of 30–60 mm, at larger distance from the ignition point (in the region of 60–70 mm), zone of explosive combustion is transformed into a detonation wave.

These assumptions are qualitatively confirmed by the appearance of the post-test steel tube (figure 4). Three area of destruction are seen in the photograph, the undestroyed part of the wall is that at which the tube was placed to the steel corner. The area I (0–60 mm) corresponds to

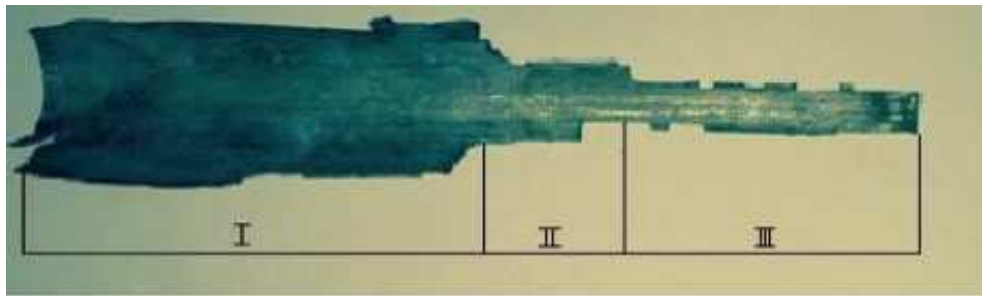


Figure 4. The appearance of the post-test steel tube, shot No. 1634, $D = 2400$ m/s.

the first two zones mentioned above as the zones of convective burning and explosive combustion (with velocities about tens of meters per second and that of more than 100 m/s consequently). The area noted as the second one (60–78 mm) corresponds to the formation of detonation which spreads with the velocities less than 2000 m/s. Steady-state detonation with $D = 2200$ –2500 m/s is observed in the third area (> 78 mm).

Equal disclosure of the tube at the first 60 mm of length (zone I) confirms the hypothesis of convective burning of fine AP (which does not cover the entire volume of the mixture) and its consequent transition into explosive combustion with jet mechanism.

5. Conclusion

There are three stages along the length of DDT, each of which can be ascribed the leading mechanism of propagation with the characteristic velocity (convective burning, explosive burning and detonation formation). Steady-state detonation velocity reached the level of 2500 m/s.

Al/AP mixtures could be considered as possible components of new initiating and incendiary compositions. Mechanochemical activation is a way to control burning rates and transition to the explosion.

Acknowledgments

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