第7卷　第1期　　　含　能　材　料　　　Vol.7, No.1
1999年3月　　　ENERGETIC MATERIALS　　　March,1999

文章编号：1006-9941(1999)01-0034-04

Measurement of Shock Wave Velocity in Plexiglass for Detection of Energy Release in Aluminized Nonideal Explosives

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Abstract: A method was worked out for the detection of the additional energy release behind the detonation wave on the basis of the measurement of the shock wave velocity in a plexiglass block. Explosives tested were NH_4NO_3/TNT 80/20, NH_4NO_3/TNT/Al 80/10/10, NH_4NO_3/TNT/LiF 80/10/10 and NH_4NO_3/Al 90/10. It was established that a decrease of the shock wave velocity with increasing distance from the explosive charge. It can be slowed down by using aluminized explosives and the higher dispersity of Al, the slower decay of the shock wave velocity is. These effects are caused by an increase in pressure of explosion gases acting on the plexiglass boundary as a result of releasing the additional chemical energy from aluminium oxidation.

Key words: energy release; nonideal explosives; shock wave velocity

1　Introduction

Nonideal explosives are characterized by incomplete releasing chemical energy in the reaction zone of detonation wave. It means that experimental values of detonation parameters are significantly lower than the calculated ideal parameters obtained with an assumption of thermochemical equilibrium in detonation products. The difference depends among other things as on diameter of the charge and physical and chemical properties of explosive mixtures, for example, component dispersity, density, and so on[1~4]. The kinetics of energy release in nonideal explosive mixtures can be investigated by recording the process of driving of acopper tube[5~9] or by measurement of the amplitude and shape of the pressure pulse at different distances from the explosive charge in varied media, for example in air[1], in water[10~11], in paraffin[12]. An appearance of secondary exothermic reactions in detonation products and releasing an additional energy manifests by an increase in the length of time of the pressure pulse. All the methods require complicated devices and sometimes sophisticated models to analyze experimental results. But in this study we tried to employ a simple method of measurement of shock wave velocity in plexiglass to detect the energy release in aluminized nonideal explosives.

2　Experimental approach and results

Crystalline ammonium nitrate (size of grains < 0.8 mm), fine-grained TNT (size < 0.8mm), flaked TNT (2.5 mm mean size), flaked aluminium (0.7mm mean size) and aluminium powder (0.15mm mean size) were used to prepare explosive mixtures. Powder of lithium fluoride (0.05mm mean size) was also used as an inert addition instead of flaked aluminium.

Before the main experiments, the density of the mixtures were characterized by a pycnowmetric method and the detonation velocity was determined under the same conditions as during the experiments. The detonation velocity was measured by electrical pins located in the 80mm diameter charge. In order to exclude any influence of the initiation pulse on the detonation velocity the measurements were located at 160 mm from the loaded boundary of the charge. The composition of the explosive mixtures tested and the results of preliminary measurements are presented in Table 1.

The mean shock wave velocity in the plexiglass block consisted of six 10mm layers was measured by electrical pins; the set-up is shown in Fig. 1.

The working part of the electrical pins are placed in a cavity (0.3mm in depth) in the layer and it is a charged electrical probe consisting of two insulated copper wires

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收稿日期：1998-03-23

(0.2mm in diameter) covered by an aluminium foil (0.05mm). The first probe is fixed at 10mm distance from the end of the charge and the following probes are located between succeeding plexiglass layers, so each measurement distance is 10mm in length.

Three tests were performed for all systems and the mean values of velocity were calculated. The results of measuring are shown in Fig. 2.

Table 1 Composition and properties of the explosive mixtures

	Explosive mixtures						
	AN/TNT 1	AN/TNT 2	AN/TNT/Al 1	AN/TNT/Al 2	AN/Al 1	AN/Al 2	AN/TNT/LiF
Component/wt. %							
Ammonium nitrate	80	80	80	80	90	90	80
Fine - grained TNT	20	–	10	10	–	–	10
Flaked TNT	–	20	–	–	–	–	–
Flaked aluminium	–	–	10	–	10	–	–
Aluminium powder	–	–	–	10	–	10	–
Lithium fluoride	–	–	–	–	–	–	10
Parameter							
Density/($kg \cdot m^{-3}$)	980	970	980	980	950	930	980
Detonation velocity/m^{-1})	4510	4080	4170	4140	3550	3550	no detonation

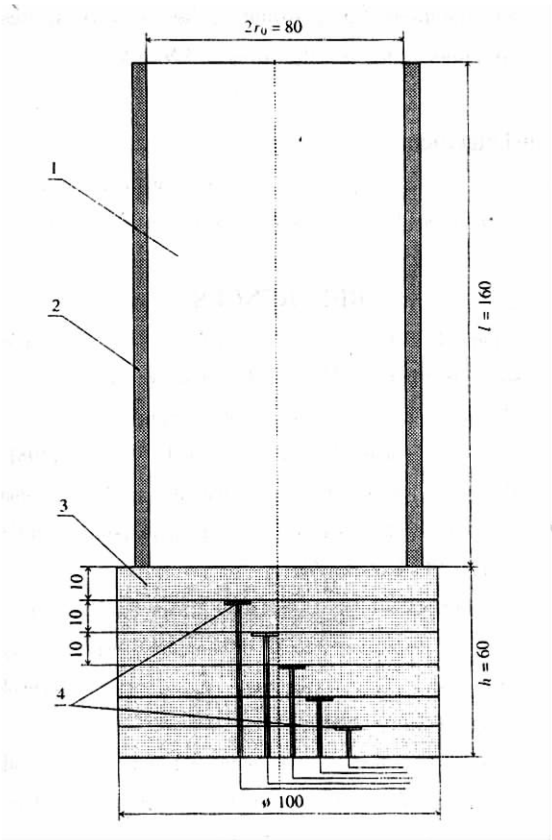

Fig. 1 Diagram of the system for measuring the shock wave velocity at different depths in plexiglass block
1——charge of explosive tested; 2——PVC tube; 3——plexiglass layer; 4——electrical pins.

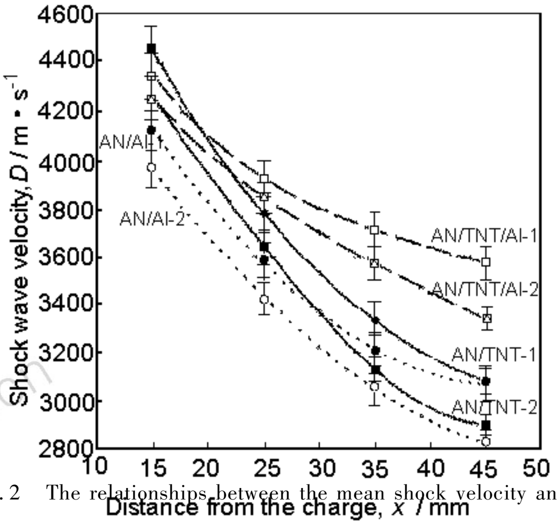

Fig. 2 The relationships between the mean shock velocity and the distance from thte end of the charge for explosives tested.

The curves (in Fig. 2) illustrate changes of the mean shock wave velocity as a function of distance from the loaded surface of the plexiglass block.

3 Discussion

From the analysis of curves shown in Fig. 2, it follows that the mean shock wave velocity decreases monotonously with increasing distance from the loaded surface of the plexiglass block. The downfall dynamics depends on homogeneity of the explosive mixture and it characterizes the property of explosives tested. The partial replacement of fine-grained TNT in AN/TNT-1 by flaked aluminium causes a decrease of detonation velocity (Table 1) but simultaneously generates a shock wave which has the highest velocity after the distance of about 20mm. Only 4/5μs is needed to cover the distance by the shock wave, so it can be said that this time is long enough to enter aluminium into chemical reactions occurring in detonation zone. This result is in good agreement with published values of induction time of aluminium oxidation in detonation wave, for example 4μs in [5], 1/10μs in [6]. It must also be noted that exothermic reactions between aluminium particles and products of AN/TNT decomposition start just inside the reaction zone. That is why the detonation process in AN/TNT/LiF mixture failed, though the physical properties of LiF are similar to the aluminium properties[5]. The amount of reacted aluminium in the reaction zone and not far from it depends significantly on Al dispersity and detonation parameters of the explosive in which the aluminium is present. If these parameters are higher the more aluminium reacts and consequently more energy is released. For these reasons, the shock wave generated by detonation of AN/TNT/Al-1 charge attains the highest value at relatively short distance from the charge (Fig. 2). In case of AN/Al mixtures, nearly the same value of shock wave velocity as that of AN/TNT explosives is reached in section situated 30/35mm from the loaded surface of the plexiglass block. Thus it is found that both large-sized and small-sized particles of aluminium can react effectively with the detonation products after about 10-μs-time lapse from the moment of loading the block by the detonation wave.

From the point of view of maximization of the shock wave velocity in the neighbourhood of the explosive-inert medium boundary, the addition of small-sized aluminium particles into AN/TNT explosives seems to be especially profitable. On further distances the same shock wave parameters as for AN/TNT mixtures can also be reached by using explosives containing 90% of ammonium nitrate and 10% of aluminium. These effects are probably caused by an increase in time of loading and in pressure of explosion gases acting on the plexiglass boundary in consequence of releasing the additional chemical energy from oxidation of aluminium.

4 Conclusions

Analysis of the results obtained in this work leads to the following inferences:

(1) Measurement technique employed in this study enables us to observe effects of the additional energy released in aluminized nonideal explosives.

(2) The combustion process of aluminium particles and releasing the supplementary energy begin just inside the reaction zone of detonation wave in the AN/TNT/Al mixtures.

(3) The rate of heat production from aluminium oxidation in detonation wave depends significantly on the dispersity of Al particles and detonation parameters of explosives.

(4) Replacing some amount of TNT in the AN/TNT mixture by Al almost does not lower the initial value and causes smaller decrease in the shock wave velocity in plexiglass.

(5) Complete replacement of TNT in the AN/TNT mixture by Al reduces the initial velocity of the shock wave but on further distances ($x > 40$mm) the velocity values are nearly the same as for no aluminized AN/TNT.

Acknowledgement

This work was accomplished within the framework of the project 9T12A 04109 financed by the Scientific Research Committee.

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冲击波测量法检验含铝非理想炸药的能量释放

摘要：将有机玻璃紧贴于炸药柱，当爆轰波沿药柱传播至界面时即在有机玻璃中引起一个强烈的冲击波。利用一特定装置分别测定在 NH_4NO_3/TNT 80/20，NH_4NO_3/TNT/Al 80/10/10，NH_4NO_3/TNT/LiF 80/10/10 和 NH_4NO_3/Al 90/10 等炸药爆轰作用下有机玻璃中冲击波的传播速度，以检验含铝非理想炸药的能量释放。结果表明，冲击波速度随着传播距离的增加而降低；铝粉颗粒越细，冲击波衰减速度越慢，这是由于铝的氧化反应热所致。

关键词：冲击波速；非理想炸药；能量释放

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