

Shape of Detonation Wave in Different Energetic Materials Based on Nitrocellulose and Nitroglycerine

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The experimental research on shape of detonation wave was done for cylindrical explosive charges with 5 different energetic materials with nitrocellulose and nitroglycerine. Energetic materials were manufactured with the technology for production of ball propellants. Shape of detonation wave was determined using the method of measurement of detonation wave arrival time to a certain point in the charge. Measurement system was developed in the Military Technical Institute (VTI) in Belgrade and had 16 fibre optic cables, multi-channel optical signal detector and oscilloscope. Curvature of detonation wave was determined at two different distances from initiation point. Average radii of detonation waves were determined using the regression analysis of experimental data. Also, the change in detonation wave curvature was observed at different distances from the detonator.

Key words: detonation wave, energetic materials, nitrocellulose, nitroglycerine.

List of abbreviations and acronyms

AGD – average grain dimension;
AN – ammonium nitrate;
ANFO – ammonium nitrate with fuel oil;
BC – booster charge;
C(s) – solid carbon;
DBP – dibutylphthalate;
DPA – diphenylamine;
DW – detonation wave;
EDC – electric detonating cap;
EM – energetic material;
hum – humidity;
MP – measuring point;
NC – nitrocellulose;
NG – nitroglycerine;
FOH – fiber optic holder;
PETN – pentaerythritol tetranitrate, penthrite;
solv – solvent;
TNT – trinitrotoluene.

Introduction

DETONATION can be considered as a stationary process where balance between parameters of process and external conditions is achieved. When process is disturbed, the changes of those values occur and new balance is achieved. The knowledge on detonation parameters can help to determine nature and characteristics of the process itself. In theoretical considerations there can be two distinctive behaviours of the detonation: ideal and non-ideal. Ideal detonation is considered when detonation parameters have

values that correspond to Chapman-Jouguet condition of the system and can be explained using Zel'dovich-von Neumann-Döring detonation model [1-2]. Non-ideal detonation can also be stable. The research on detonation in liquid energetic materials (EM) showed that process is self-sustained even during significant non-ideal behaviour [2]. Other research showed that detonation wave front can also have pulsating propagation [3].

Non-ideal detonation is found in heterogeneous charges with significant amount of inert or slow-reacting components [4-5]. Such EM are insensitive explosives, ANFO explosives, explosives with metal powders, etc. There were developed many models of non-ideal detonation [5-6].

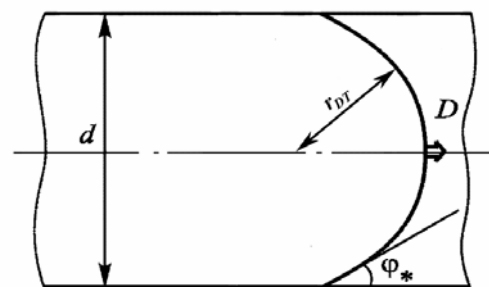


Figure 1. Schematic representation of curved detonation wave [1]

Theories on ideal detonation assume plain DW front. Curvature of detonation wave (DW) front is considered to be a consequence of non-ideal detonation. DW is planar when explosive charge diameter is many times larger than critical diameter of the EM inside it. Most models of non-ideal detonation are based on the Wood-Kirkwood theory on

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curvature of DW in cylindrical charges [7]. Curved DW which is propagating with detonation velocity D inside explosive charge with diameter d is represented in Fig.1 [1]. In reality, DW has a complex shape, but can be approximated with a part of a circle with radius r_{DT} .

Value r_{DT} is an average radius of DW and is appropriate for determination of changes in DW curvature.

Experiments

Experimental measurements of DW curvature were done for explosive charges with five different energetic materials with nitrocellulose (NC) and nitroglycerine (NG), which can be used as propellants in small-arms or artillery ammunition. Considered propellants were produced in Chemical industry "Milan Blagojević", Lučani, Republic of Serbia (MBL). Compositions are listed in Table 1 [8].

Two propellants (SB-520 and SB-412) are used in ammunition for 7.62 mm assault rifles and 9 mm pistols and submachine guns, respectively. Other three propellants (DSB-20, DSB-15 and DSB-10) were mixtures of single base and double-base propellants, produced using ball (spherical) propellant technology. Grains of these propellants were not flattened and have approximately spherical shape. Characteristics of propellants are listed in Tables 1 and 2.

Propellants were filled inside cylindrical explosive charges with 0.3 mm thick paper casings, bonded with 0.07 mm adhesive tape. Diameter of all charges d_{EP} was 50 mm. There were two different charge lengths l_{EP} , 100 and 185 mm.

Table 1. Compositions of propellants

Energetic material	Content, mas. %								
	nitrogen in NC, ω_N	ω_{NC}	ω_{NG}	ω_{DPA}	ω_{DEP}	ω_{KNO_3}	$\omega_{C(s)}$	ω_{solv}	ω_{H_2O}
SB-520	13.20	81.08	10.36	1.11	5.49	0.10	0.21	0.46	1.19
SB-412		79.58	18.70	1.02			0.17		0.53
DSB-20		77.44	20.09	1.09			0.10	0.25	1.03
DSB-15		82.45	15.07	1.12			0.10	0.23	1.03
DSB-10		87.46	10.05	1.14			0.10	0.21	1.04

Table 2. Main characteristics of energetic materials [8]

Energetic material	Grain shape	Molar mass	Heat potential	Average grain dimension
		M , g·mol ⁻¹	Q , kJ·kg ⁻¹	AGD , mm
SB-520	flattened sphere	213.02	3651	0.4953÷0.5716
SB-412	flattened sphere	241.79	4350	0.3429÷0.4191
DSB-20	sphere	221.77	4668	0.4953÷0.5715
DSB-15	sphere	224.68	4505	0.4953÷0.5715
DSB-10	sphere	227.36	4342	0.4953÷0.5715

Charges were initiated using electric detonation caps (EDC) "EK-40-69" and spherical booster charges (BC) with 8 g of explosive consisted of 85% PETN and 15% polymer binder. Lower end of EDC were positioned in the centre of boosters. The boosters had 22 mm diameter and were placed to 10 mm depth into charges. Shape and dimensions of explosive charges are shown in Fig.2. Characteristics of explosive charges are listed in Table 3.

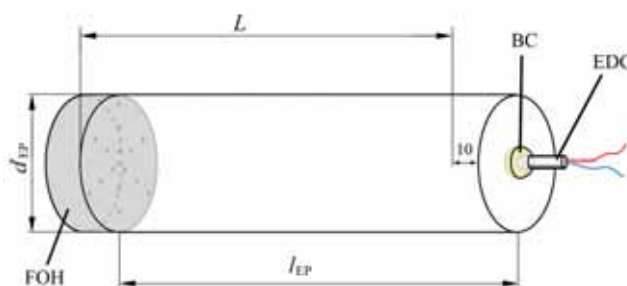


Figure 2. Experimental setup with charge dimensions

Shape of DW was experimentally determined by time of DW arrival to a certain point in the explosive charge. These moments can be recorded because of the intense light emission from the DW. Optic cables have the ability to transmit that light effect to optical transducers where they are transformed to electrical signals which could be recorded. Insulated single core fibre optic cables were used in this research (cable diameter 2.2 mm, core diameter 1 mm).

Measurement system used in this research was developed in the Military Technical Institute (VTI) in Belgrade. There were 16 fibre optic cables used inside an appropriate cylindrical fibre optic holder (FOH) positioned on the surface opposite to the point of initiation, which is shown in Fig.2.

Table 3. Characteristics of explosive charges

Charge No	Energetic material	Mass of propellant	Charge length	Charge volume	Charge density
		m_{SB} , kg	l_{EP} , mm	V_{EP} [dm ³]	ρ_0 [kg·dm ⁻³]
1	SB-520	0.202	100	0.196	1.029
2	SB-412	0.100			0.509
3	DSB-20	0.198			1.008
4	DSB-15	0.197			1.003
5	DSB-10	0.198			1.008
6	SB-520	0.367	185	0.363	1.009
7	SB-412	0.176			0.486
8	DSB-20	0.359			0.989
9	DSB-15	0.359			0.989
10	DSB-10	0.359			0.989

FOH was made of low-density polyethylene. FOH has one central position and 15 symmetrical positions for fibre optic cables at 5 different distances from the FOH centre (Fig.3). Since FOH in this research had same 50 mm diameter as explosive charges, fibre optic positions y were 4.5, 9.0, 13.5, 18.0 and 22.5 mm from the central position. All distances were measured with 0.1 mm precision. Fibre optic cable ends were equally longitudinally positioned inside FOH and covered with thin aluminium foil to prevent premature transmission of light.

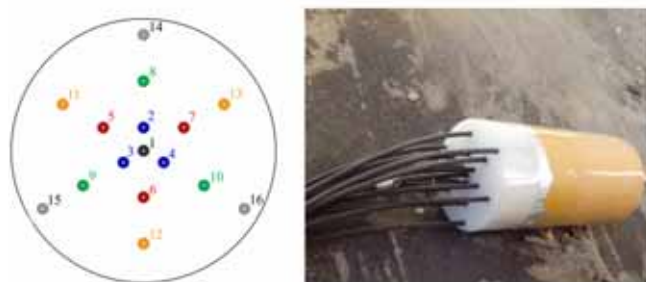


Figure 3. Positions of measuring points inside fibre optic holder

Such arrangement of measuring points (MP) in FOH provides three records per same distance from the central position (MP 1).

Opposite ends of fibre optic cables were connected to the multi-channel fibre optic signal detector, connected to the Tektronix Mixed Signal Oscilloscope MSO 2022B, which served as a time counter. Oscilloscope has 200 MHz bandwidth, 1 GS/s sampling and main maximum sample rate up to 2 ns in all 16 digital channels, so the device can measure time with 5 ns precision [9]. When DW arrives to a MP, light is transmitted through fibre optic cable to an optical detector, where it is transformed into electrical signal and then detected by the oscilloscope.

When properly protected, damage of fibre optic cables after each experiment was acceptably small. In each experiment, the cables were damaged up to 20 cm in length, and were reused in following experiments after proper inspection and equal shortening, in order to obtain same length of all cables and to minimize measuring errors.

Analysis and discussion

Experimental recordings were used to determine positions of points that correspond to DW front. It was necessary to reset all recordings according to the initial moment of time, when DW arrived at FOH. Initial moments were calculated as an average value of recordings at MP 1-4, in order to minimize errors due to non-ideal positioning of FOH and EDC and other experimental errors. Differences between recordings at MP 1-16 and initial moment represent time intervals t_1-t_{16} . After that, average values of time intervals t_{sr} were calculated for three MPs at same distances from MP 1. Average values t_{sr} were used to calculate the positions x_{sr} of DW at y distances from MP 1:

$$x_{sr} = D_L \cdot t_{sr} \quad (1)$$

D_L is detonation velocity for EM at distance L from the initiation point. Those values were previously experimentally determined [10]. It was also shown that D_L values are nearly constant at considered distances from initiation point. Nearly ideal constant values were observed at distances larger than 150 mm.

Shape of DW can be approximated as spherical with radius r_{DT} .

$$r_{DT} = \sqrt{x^2 + y^2} \quad (2)$$

Regression analysis was used to determine radii of DW according to calculated positions of points (Eq.2), for maximum R^2 criterion. The results are listed in Table 4.

Determined x_{sr} values are not significantly distant from their presumed position. For example, for all charges at measuring points 2-4 values x_{sr} of approximately 0.1 mm are expected (nearly planar DW). But, determined values are slightly different, up to 0.3 mm. Similar is observed for other measuring points. This can be the consequence of experimental errors and can be considered acceptable.

Correlation of determined results is acceptable, where charges 2 and 8 have correlation lower than 0.90. Shape of DW for charges 2 and 7, filled with SB-412 is graphically represented in Fig.4.

Table 4. Results of experimental data analysis

Charge No.	Distance between FOH and BC	Detonation velocity at distance L	Average position of DW						Calculated DW radius	R^2
			MP 1	MP 2-4	MP 5-7	MP 8-10	MP 11-13	MP 14-16		
			L , mm	D_L , ms ⁻¹	x_{sr} , mm					
1	90	5032	0.0	0.0	0.2	0.8	1.6	2.8	95.5	0.9916
2		3262	0.3	-0.1	0.8	0.4	1.4	2.1	94.5	0.8824
3		5183	0.1	0.0	0.5	1.0	1.8	3.2	84.2	0.9909
4		4929	0.0	0.0	0.4	0.9	1.9	3.0	85.1	0.9965
5		4856	0.1	0.0	0.3	0.8	1.5	2.6	93.8	0.9940
6	175	5203	-0.1	0.0	0.4	1.5	1.5	4.8	63.8	0.9100
7		3459	-0.1	0.0	0.4	1.2	2.2	3.8	71.0	0.9982
8		5185	0.0	0.0	-0.1	0.7	0.9	5.0	69.2	0.8126
9		5169	0.1	0.0	0.1	0.4	0.0	1.9	122.3	0.9335
10		4952	0.0	0.0	0.2	0.8	1.5	2.6	86.2	0.9901

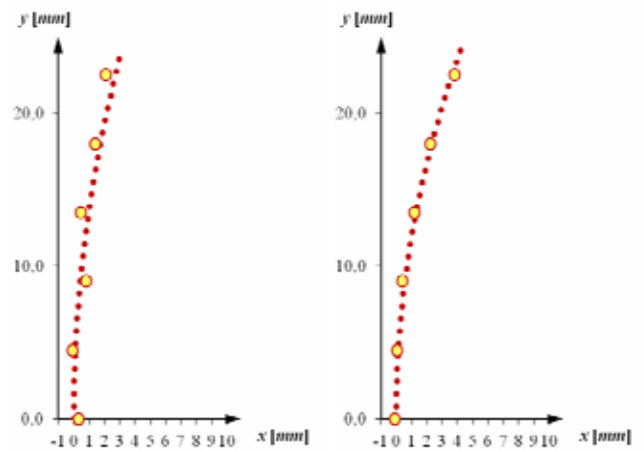


Figure 4. Shape of DW for charges number 2 and 7, filled with SB-412

Conclusions

Results show that DW curvature is in 84.2-95.5 mm range for all charges at 90 mm from initiation point. It can be concluded that radial propagation of DW is dominant. But, results show that change in DW curvature is occurring in all charges.

At 175 mm distance from initiation point, DW radii are in 63.8-86.2 mm range for all charges except DSB-15 (122.3 mm). It can be concluded that these values of r_{DT} represent DW curvature in a stationary state of the system.

Assumption of spherical DW shape was considered because of its simplicity and it can be considered acceptable. Other curves could provide better correlation with experimental results.

Results of DW curvature are similar with results [11] for similar EM, but ultra high-speed camera was used. Method and measuring system used in this research are considerably more cost-effective compared to methods with ultra high-speed cameras. Charge preparation is moderately demanding in this method.

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Oblik detonacionog talasa u različitim eksplozivnim materijama sa nitrocelulozom i nitroglicerinom

Izvršeno je eksperimentalno istraživanje oblika detonacionog talasa u cilindričnim eksplozivnim punjenjima sa 5 različitim eksplozivnih materija, u čijem sastavu su nitroceluloza i nitroglicerina. Razmatrane eksplozivne materije izradene su tehnologijom proizvodnje sferičnih baruta. Oblik detonacionog talasa određen je metodom merenja vremena nailaska detonacionog talasa u određenu tačku u punjenju. Korišćen je merni sistem razvijen u Vojnotehničkom institutu u Beogradu sa 16 optičkih kablova, višekanalnim detektorom optičkog signala i osciloskopom. Zakrivljenost detonacionog talasa merena je na dva različita odstojanja od mesta iniciranja. Prosečne vrednosti poluprečnika detonacionog talasa određene su regresionom analizom eksperimentalno dobijenih podataka. Uočena je promena u zakrivljenosti detonacionog talasa na različitim odstojanjima od mesta iniciranja.

Ključne reči: detonacioni talas, eksplozivna materija, nitroceluloza, nitroglicerina.