Federal State Unitary Enterprise «FCDT "Soyuz"

Dependency of detonation velocity of mixed aluminized explosive composition on the content and type components and the diameter of the charge

Yu.M. Milekhin, V.N. Kulikov, A.A. Matveev, A.N. Osavchuk, N.I. Shishov

The detonation velocity (*D*) of explosive compositions (EC) is one of the main explosive characteristics, witch determines the efficiency of its use in various sector economy, as well as level of danger of its production.

Due to the fact that intensive work is currently being carried out to create new more powerful explosive compositions, the study of detonation processes in them is an urgent task both scientifically and practically. It is known, that detonation process in such systems is not perfect – it is characterized by the presence of a larger, in comparison with single-component explosive, reaction zone and components afterburning outside of it. .

Despite extensive and long-term studies of metallized explosives (and EC), there are no reliable data on the role of metal in the process - mechanism and kinetics of its response to this work. The most common assumptions are:

- the optimal content of metallic fuel (Al) in the mixed composition is 15…20%,

- in the zone of chemical reaction of the detonation process is the oxidation of *Al*, which, depending on the particle size is 5...10% of the total, and most of the energy is released in the further zone.

- the use of ultra and nano-dispersed Al powder in the formulation of EC does not increase the detonation velocity, but rather reduce.

Insufficiently studied the question of the influence on the detonation parameters of dispersion of the components in EC - explosives and oxidizer.

The paper presents the results of experimental and calculated the study where the effect of various formulations parameters, as well as the diameter of the charge on the values of detonation velocities of EC model samples is determined:

- type of the component (explosive, polymer binder),
- the content of the components (explosive, *Al*, oxidizer- AP) and their particle size,
- diameter of charge EC.

EC detonation velocity ($D_{exp.}$) in the experiment was registered with the help of continuous photography of the process on the cured charge with a diameter (*d*) of 40 mm at the sector 2.5…7 *d* (Fig. 1). Calculations of detonation velocities ($D_{C\text{-}J}$) of the given samples EC for an ideal process variant were performed

(a) (b)

Fig. 1. Photo registration of the detonation process velocity in EC:

a) 6% AP, 20%Al; D_{exp} = 8010 m/s;

b) 30% AP, 30% Al; D_{exp} = 6720 m/s

1. Effect of the Component Type (Explosive, Binder) and Explosive Content

There are studied the experimental samples EC, contenting of various type of explosives – HMX or Cl-20, and binder – inert or active (detonation ability), as well as studied the effect content of explosive (HMX) in EC, the results are shown in Table 1 .

Table 1. Detonation velocity of a number samples EC

Parameter EC	EC, №					
	1	2	3*)	4	5	6
Density, g/cm³	1,85	1,93	1,71	1,75	1,93	1,93
Detonation velocity, m/s - D_{exp} - $D_{C\text{-}J.}$	*7860 (ρ=1,77)* *8010*	*8600 (ρ=1,92)* *8523*	*8040* *7750*	*8280* *8113*	*7160* *7969*	*7500* *7969*

*) -- *composition based on an inert binder*

The analysis of the results in Table 1 shows that the studied EC samples, in comparison with the approved explosives, have sufficiently high values of detonation velocities.

EC sample (#2), containing the most powerful explosive - CL-20, has the highest detonation velocity. Its counterpart for other components (# 1), but with HMX, has substantially lower experimental and calculated detonation velocities.

Compositions (# 3) based on the inert binder have lower experimental detonation velocity and especially calculated ones.

EC samples # 5 and 6 differ by the type of the active binder, this fact manifests itself in experimental detonation velocity values. In general, $D_{exp.}$ slightly increase with increasing the content of HMX from 60 to 80%.

2. Effect of Aluminum Powder Content

The effect of aluminum powder content (0…40%) with particle size 3…5 *μm* on the detonation velocity of EC is studied at two amounts (6 and 30%) of the oxidizer - (AP). The results are shown in Table 2, and the dependency of experimental and calculated detonation on EC velocity to the components content - in Fig. 2. All *Al* and AP content changes in the formulation are made at explosive.

Table 2. Detonation velocities of a number of EC with different aluminum powder content (for 6 and 30% AP).)

Parameter EC	Oxidizer content, % (wt.)								
	6					30			
Al content, % (wt.)	0	10	20	30	40	10	20	30	40
Detonation velocity, m/s - $D_{exp.}$ - D_{C-J}	8180 8820	8000 8439	8010 7989	7850 7246	7820 6400	7370 8321	7280 7903	6720 7379	6560 6635

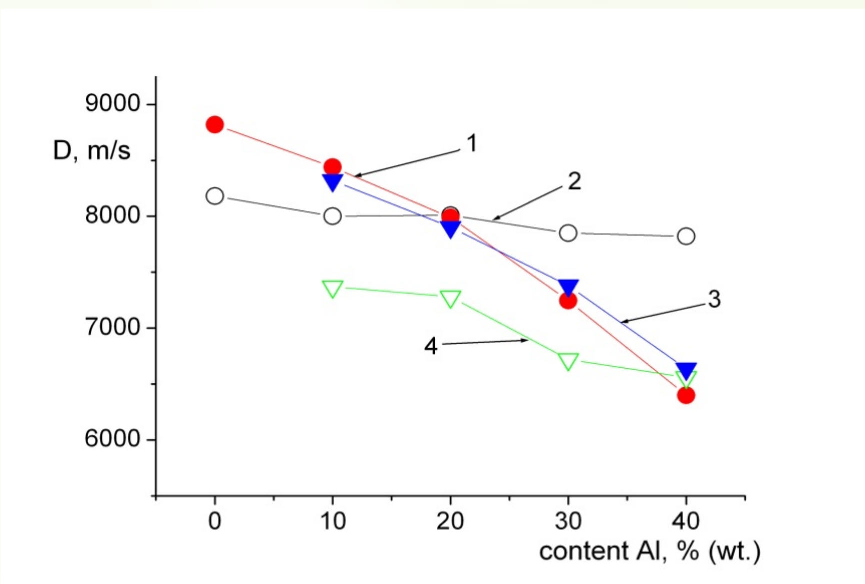


Fig. 2. Dependency of EC D_{exp} and D_{C-J} on the Al content at 6 and (or) 30% AP
1, 2 – calculation and experiment, respectively, at 6% ;
3, 4 – calculation and experiment, respectively, at 30% .

Results given in Table 2 and Fig. 2 show that with the increase of metallic fuel weight content from 0 to 20% in EC formulation (at 6% AP) the density increases too, and detonation velocity slightly decreases. Further increase of *Al* content to 40% decreases the obtained EC characteristics, except for ρ. The increase of oxidizer content in EC from 6 to 30% leads to significant decrease of its D_{exp}. The quantity of Al powder of ≈ 20% can be considered optimal in term of energy release and detonation parameters which is confirmed by other researchers.

It should be noted that in contrast to the experimental dependences of the detonation velocity on the mass content of *Al*, the calculated ones for both amounts of the oxidant are close both in terms of values and in form - a gradual decrease.

The most correct match $D_{exp.}$ And D_{C-J} at 6% of the oxidant is observed at 20% *Al*, and 30% - 40% of metal. These points can be useful in improving the thermodynamic model used for calculating detonation parameters in multicomponent compositions, taking into account the kinetics of decomposition of metal and oxidizer, and later the binder.

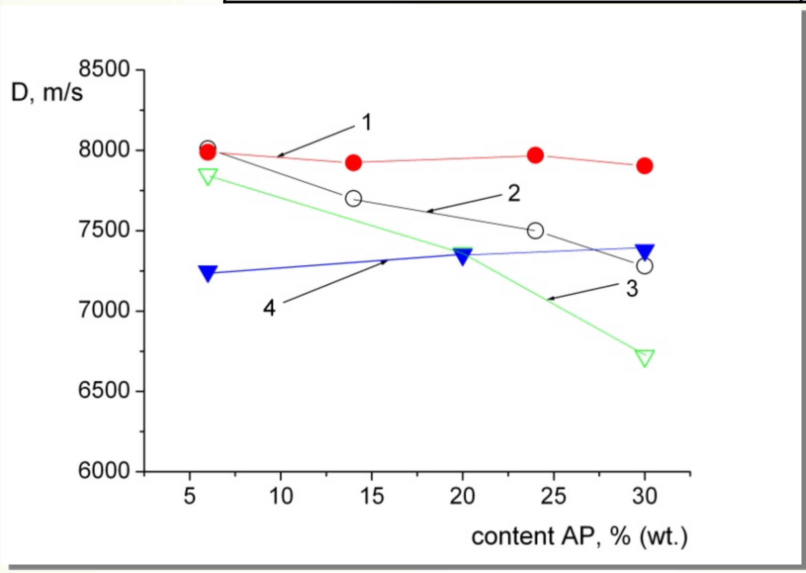
Value $D_{exp.}$ and D_{C-J} with a simultaneous increase in the content of the oxidizer and *Al* in EC are significantly and ambiguously different, due to the regime of imperfect detonation in such multicomponent systems.

3. Effect of Oxidizer Content

The effect of oxidizer content (6…30%) on the detonation velocity of EC model samples was investigated at two amounts (20 and 30%) of aluminum powder. The results are shown in Table 3, and the relation of experimental and calculated detonation of EC velocity to the components content – in Fig. 3. All Al and AP content changes in the formulation are made at explosive cost.

Table 3. Detonation velocities of EC with different oxidizer content (for 20 and 30% Al)

Parameter EC	*Oxidizer content, % (wt.)*						
	6		*14*	*20*	*24*	*30*	
Al content, % (wt.)	*20*	*30*	*20*	*30*	*20*	*20*	*30*
Detonation velocity, m/s : - $D_{exp.}$	*8010*	*7850*	*7700*	*7360*	*7500*	*7280*	*6720*
- D_{C-J}	*7930*	*7246*	*7922*	*7350*	*7969*	*7954*	*7379*



Results in Table 3 and Fig. 3 show that EC experimental detonation velocity for each of two quantities of *Al* decreases with the increase of AP content, and their difference is values increases too, but the calculated velocity D_{C-J} changes very little. In this case, D_{exp} and D_{C-J} intersect at 6% AP for 20% metal, and at 20% AP for 30% *Al*.

Fig. 3. Dependency of D_{exp} and D_{C-J} EC on AP content at 20 and (or) 30% Al:
1, 2 – calculation and experiment, respectively, at 20% Al;
3, 4 – calculation and experiment, respectively, at 30% Al.

4. Effect of Particle Size of the Component (Explosive and Oxidizer).

The effect of particle size of explosive on detonation velocity is studied in two series of experiments. In one, samples of EC are studied contenting a mixture of two faction explosive - small (35 *μm*) and middle (160 *μm*) at various its correlation, and in second – samples of EC, contenting the active binder and 50% explosive with a size of particles 7…500 *μm*. The results are shown, respect, in Table 4 and 5.

The effect of particle size of oxidizer at the content 14% is studied at use of two its faction: first – middle size of particles 20…27 *μm* and second - 220…270 *μm*. The content of *Al* powder in EC is 20%, and explosive ~ 50% (Table 4).

Table 4. Detonation velocity of EC in the dependence of particle size of the component (explosive and oxidizer)

Parameter EC	*HMX, №*		*Oxidizer, №*	
	1	2	1	2
Explosive content, % (wt.)	79	79	52	50
Particle size, μm (correlation of faction)	35 и 160 (0,33)	35 и 160 (0,8)	20…27	220…270
Detonation velocity, m/s - $D_{exp.}$ - $D_{C\text{-}J}$	8280 8159	8060 8159	7120 8439	7900 8439

The results given in Table 4 show that:

- the increase of small faction explosive content in EC formulation decreases $D_{exp.}$,
- the use in EC of oxidizer with more large on size of particles increase D_{exp}.

Table 5. Detonation velocity of EC at the different size of particles explosive

#.	Size of particles explosive, μm				Detonation velocity, m/s	
					$D_{exp.}$	D_{C-J},
1	7	-	-	-	7740	7900
2	-	35	-	-	7610	
3	-	-	160		7750	
4	-	-	-	250…500	7760	

The result in Table 5 show that a small decrease of detonation velocity is observer's only at use in EC explosive with particles in 35 *μm*. For the other brands the *D* values of the samples EC approximately 2% higher and almost the same, i.e. a noticeable effect of the dispersion of its particles in this series of experiments was not revealed.

5. The Effect of Diameter of the EC Charge

One of main problem at research of detonation ability explosives is determines its critical and limiting diameters. In this regard, the complex studies were carried out of effect on detonation velocity for EC with higher content oxidizer (30%) 3 diameters of charge – 20, 40 и 80 мм . Herewith in formulation EC In changed the content of *Al* (30, 35, 40%), as well as the of binder (Table 6). In purpose of obtain more full "picture" of effect of parameters EC on the detonation velocity the results of research are shown in two Figures: on Fig. 4 – the dependency $D_{exp.}(d)$ EC at various content of *Al* and type of binder,

on Fig. 5 - the dependency $D_{C\text{-}J}$ and D_{exp} BC on *Al* content and *d* of EC charge.

#	Al content, % (wt.)	Parameters of charge, mm		Detonation velocity, m/s	
		diameter	length	D_{exp}	$D_{C\text{-}J}$
1	30	20	240	6610	7125
		40	300	7050	7125
		80	200	7250	7125
		80*)	200	6300	7125
2	35	20	230	6520	6694
		40	300	6690	6694
3	40	20	240	6240	6330
		40	300	6670	6330
		80	200	7140	6330
		80*)	200	6200	6330

Table 6. The results of studies of effect of Al content and charge diameter on detonation velocity EC.

**) – inert binder,*

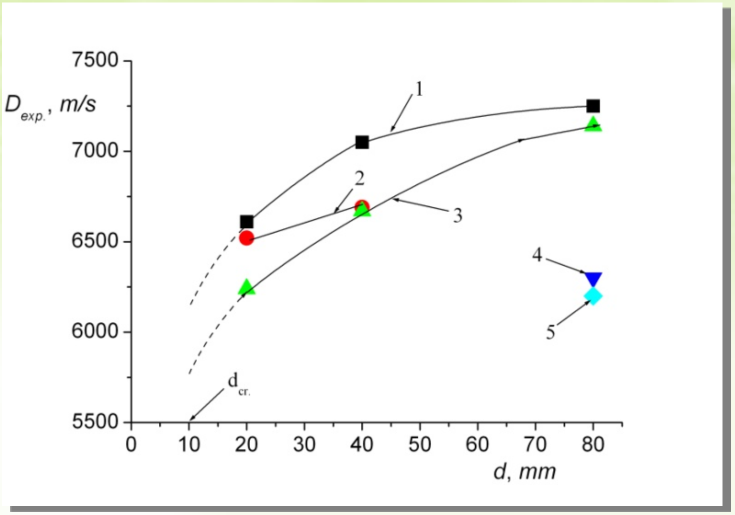


Fig. 4. Dependency of the experimental EC detonation velocity on the diameter of EC charge and the Al content (AP 30%) and type of binder:
1 – 30%, 2 – 35%, 3 – 40% Al,
4 и 5 – signs for EC on inert binder at 30 и 40% Al, respect

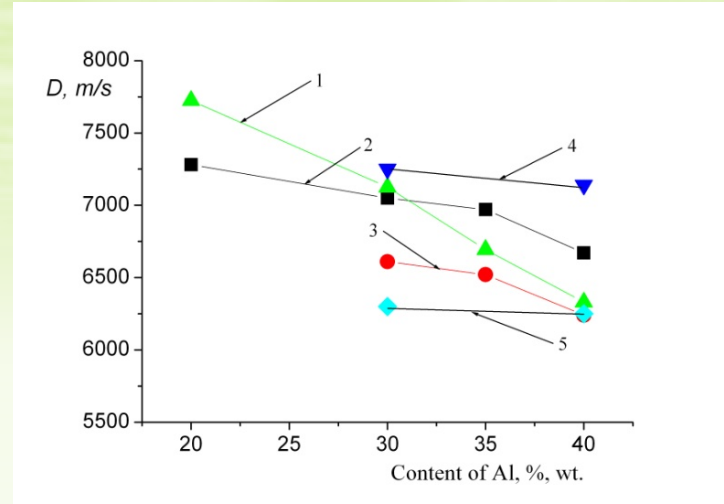


Fig .5. Dependency of the calculated and experimental EC detonation velocity on the Al content and d of EC charge (AP 30%):
1 – $D_{C\text{-}J}$ at ideal detonation and active binder,
2 – D_{exp}. для d = 40 mm; 3 – D_{exp}. для d = 20 mm;
4,5 – D_{exp}. для d = 80 mm, respect, for active and inert binder

The results studies (Table 6 and Fig. 4,5) show that at the increase of the charger diameter for the given EC formulation by 2 times (from 20 to 40 *mm*), the experimental detonation velocity increase on ≈ 7%, and then its growth rate decreases, that allows us to assume that the limiting diameter (prediction) for such composite explosive systems is about ≥ 80 mm. From graphical dependency *$D_{exp.}$(Al)* (Fig. 5) видно that the type of binder in EC essential effect on the detonation velocity and limiting diameter.

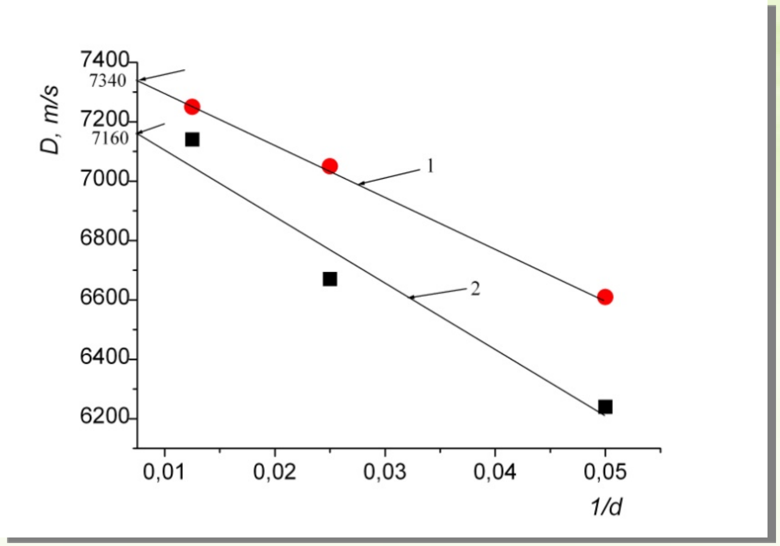


Fig. 6. Dependency of the experimental detonation velocity on reverse diameter of EC charge :
1 – EC with 30% Al, 2 – 40% Al

From graphic dependency - *D = f(1/d)* (Fig. 6) one can see that maximum values of detonation velocity of charge EC, respect at weight content of *Al* fuel 30 и 40%, are 7340 *m/s* and 7160 *m/s* that high calculating (Table 6) values and close to experimental one, i.e. the limiting diameter of detonation for such EC is about ≥ 80 *mm*.

Summary

1. Experimental and calculated studies of the effect of various parameters on the detonation velocity of aluminized mixed EC, such as the type, content and dispersion of the components, as well as the diameter of the EC charge, were carried out.

2. It was found that:

- the most noticeable decrease in Dexp. is observed when the content of metal fuel (Al) in EC is more than 20%,
- with an increase in the content of the EC oxidizer from 6 to 30%, the values of Dexp. are reduced by 10...15%,
- an increase in the particle size of explosive (from 35 to 160 microns) and oxidizer (from 24 to 240 microns) leads to a slight increase in the detonation velocity of EC (5...10%),
- the limiting diameter of detonation for EC with a high content of oxidant (≥ 30%) and metal (Al) fuel (≥ 30%) of NP-based active binder is about ≥ 80 mm.

3. The established dependence of the detonation velocity on the physical and chemical properties of the components and the formulation parameters of the EC will allow to predict their characteristics and efficiency in further studies, as well as to be useful in creating a theoretical model of detonation process in such systems

Thank you !