Joint Institute for High Temperatures,
Semenov Institute of Chemical Physics
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MECHANOACTIVATION AND DETONATION OF AMMONIUM PERCHLORATE – NANOALUMINUM MIXTURE

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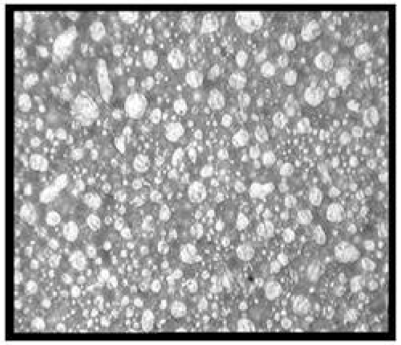
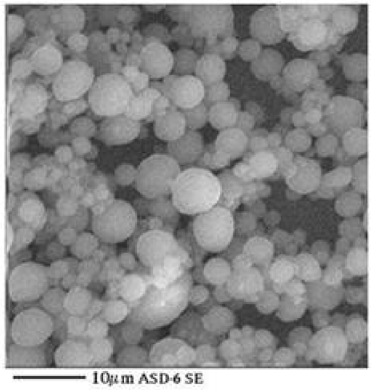
SHOCK INDUCED CHEMICAL REACTIONS IN OXIDIZER-FUEL MIXTURES

Composition (wt.)	ρ_{max}, g/cc	Reaction	Q, kcal/kg	$Q \cdot \rho \cdot 10^{-3}$, kcal/m^3
Al/S, 36/64	2.26	$2Al + 3S = Al_2S_3$	**1150**	2600
Al/MoO$_3$, 27/73	3.91	$2Al + MoO_3 = Al_2O_3 + Mo$	**1120**	4380
Al/Fe$_2$O$_3$, 25.5/74.5	4.23	$2Al + Fe_2O_3 = Al_2O_3 + 2Fe$	950	4020
Al/WO$_3$, 19/81	5.45	$2Al + WO_3 = Al_2O_3 + W$	710	3870
Al/CuO, 18.5/81.5	5.13	$2Al + 3CuO = Al_2O_3 + 3Cu$	970	4980
Al/BaO$_2$, 17.5/82.5	4.32	$4Al + 3BaO_2 = 2Al_2O_3 + 3Ba$	560	2420
Al/CrO$_3$, 35/65	2.76	$2Al + CrO_3 = Al_2O_3 + Cr$	1680	4640
Al/(-C$_2$F$_4$-), 26.5/73.5	2.31	$4Al + 3(-C_2F_4-) = 4AlF_3 + 6C$	**2070**	4780
Zr/(-C$_2$F$_4$-), 47.5/52.5	3.20	$Zr + (-C_2F_4-) = ZrF_4 + 2C$	1380	4420
Zr/MoO$_3$, 48.5/51.5	5.41	$3Zr + 2MoO_3 = 3ZrO_2 + 2Mo$	770	4170
Ti/(-C$_2$F$_4$-), 32.5/67.5	2.63	$Ti + (-C_2F_4-) = TiF_4 + 2C$	1350	3550
Ti/MoO$_3$, 33.5/66.5	4.63	$3Ti + 2MoO_3 = 3TiO_2 + 2Mo$	740	3430
Mg/(-C$_2$F$_4$-), 32.5/67.5	2.02	$2Mg + (-C_2F_4-) = 2MgF_2 + 2C$	**2280**	4610
Mg/Fe$_2$O$_3$, 31.5/68.5	3.21	$3Mg + Fe_2O_3 = 3MgO + 2Fe$	1010	3240
Mg/MoO$_3$,33.5/66.5	2.99	$3Mg + MoO_3 = 3MgO + Mo$	**1170**	3500
Mg/TiO$_2$, 38/62	2.74	$2Mg + TiO_2 = 2MgO + Ti$	490	1340
Mg/SiO$_2$, 44.5/55.5	2.15	$2Mg + SiO_2 = 2MgO + Si$	670	1440

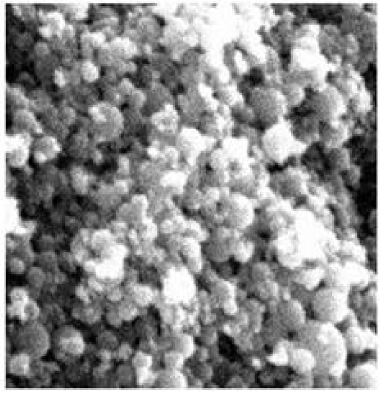
Auminium



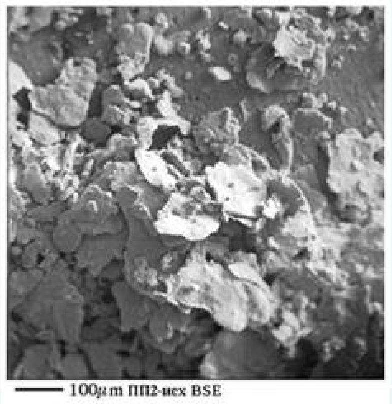
ASD-4 (<d> ~ 7 μm)



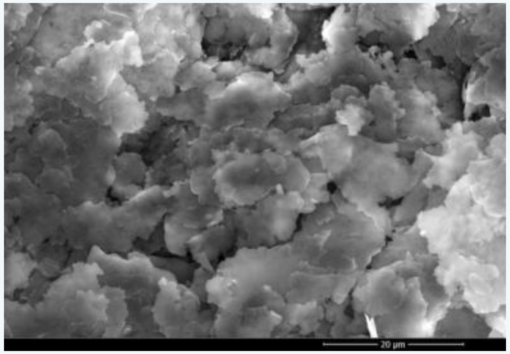
ASD-6 <d> ~ 3,6 μm



nAl <d> ~ 100 nm



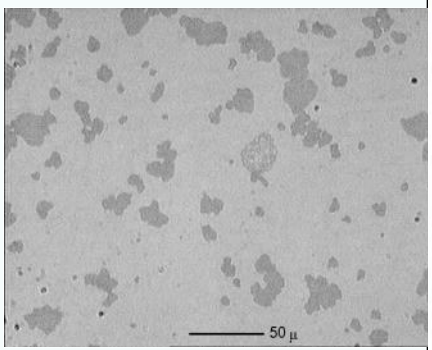
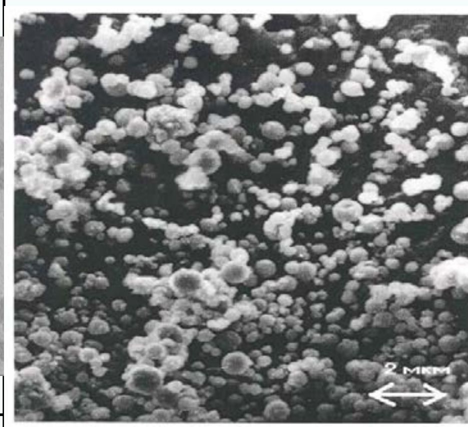
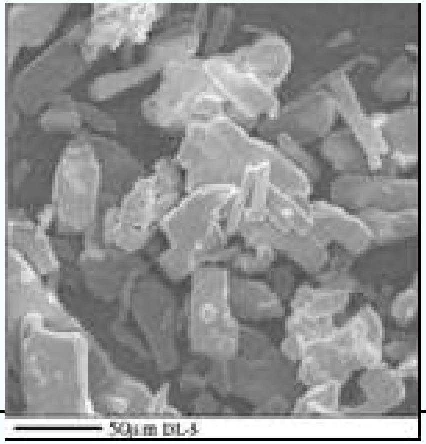
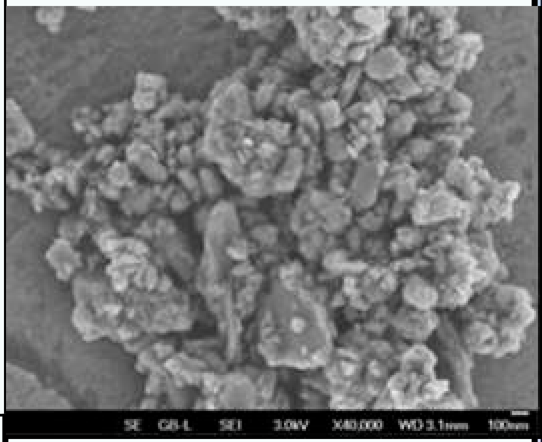
PP-2
<L> ~ 70 * 1 μm



Al - PAP-2
<L> ~ 30 * 1 μm

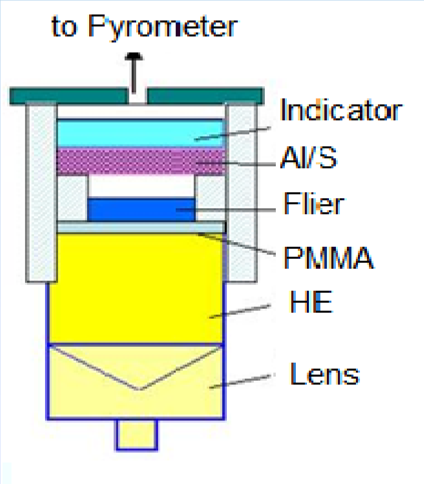
Al(N4), (S=2.7 m^2/g)
<L> ~0.5*21,3 μm

Initial Powders (oxidizers)

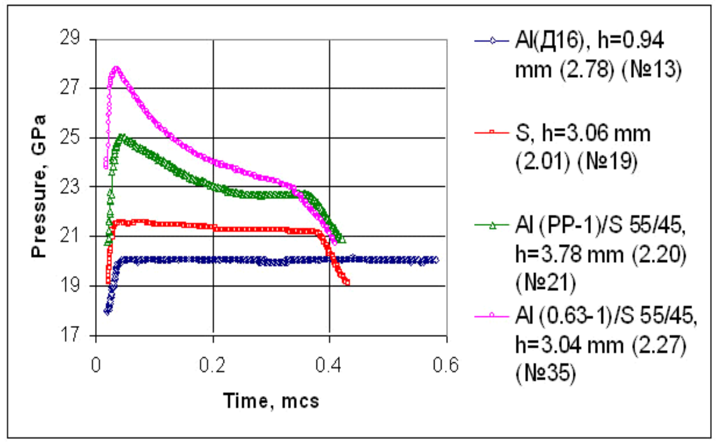
Teflon (F4-PN)	Teflon (FORUM)	MoO_3	Nano-MoO_3
			
$<d_1>$ ~ 10 – 300 μm (Most of particles) $<d_2>$ ~ 1.5 – 2.5 μm	$<d>$ ~ 0.6 μm	$<d>$ ~ 30 μm	Preliminary activation - $<d>$ ~ 60 nm

- Tested charges were prepared from the initial components by mixing in vibromill with consequent pressurizing.
- Mechanochemical activation was also used for mixture manufacturing

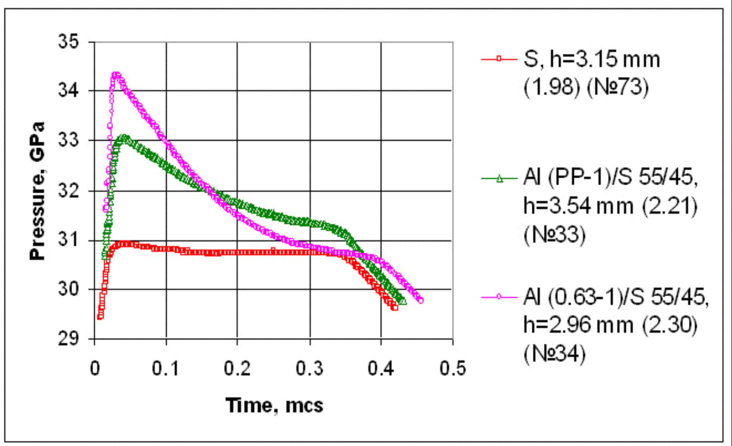
Shock induced reaction in Al/S

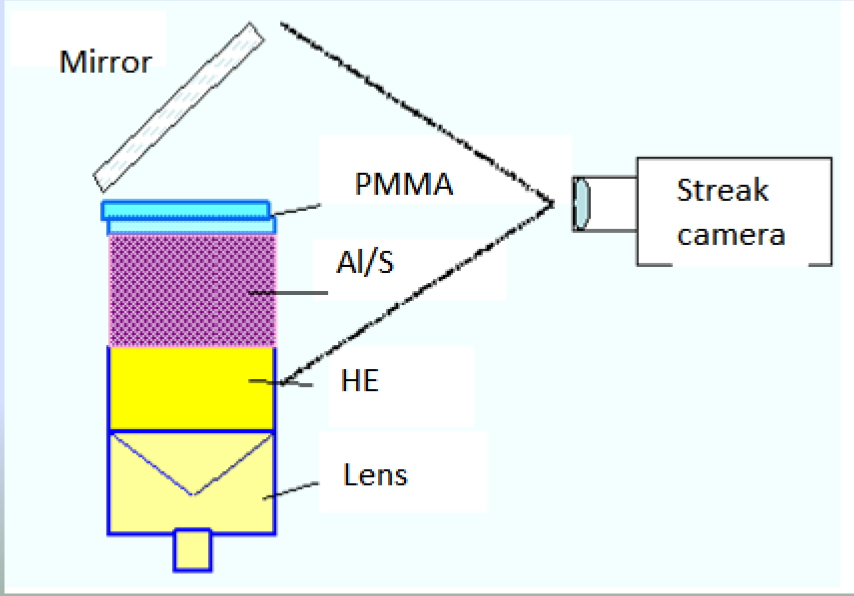


W = 3.61 km/s - CCl_4



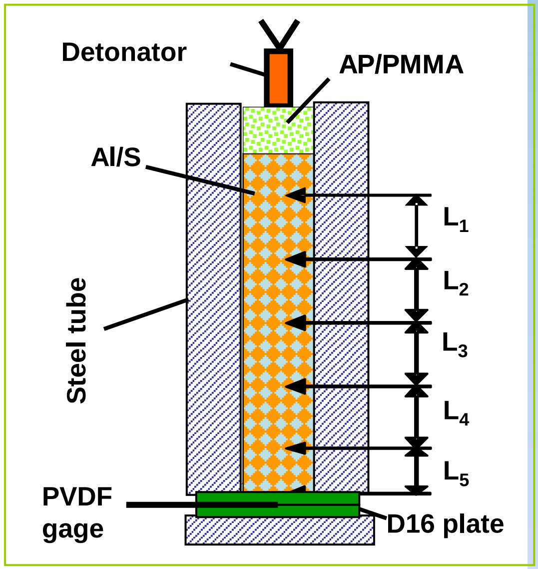
W = 3.61 km/s - $CHBr_3$





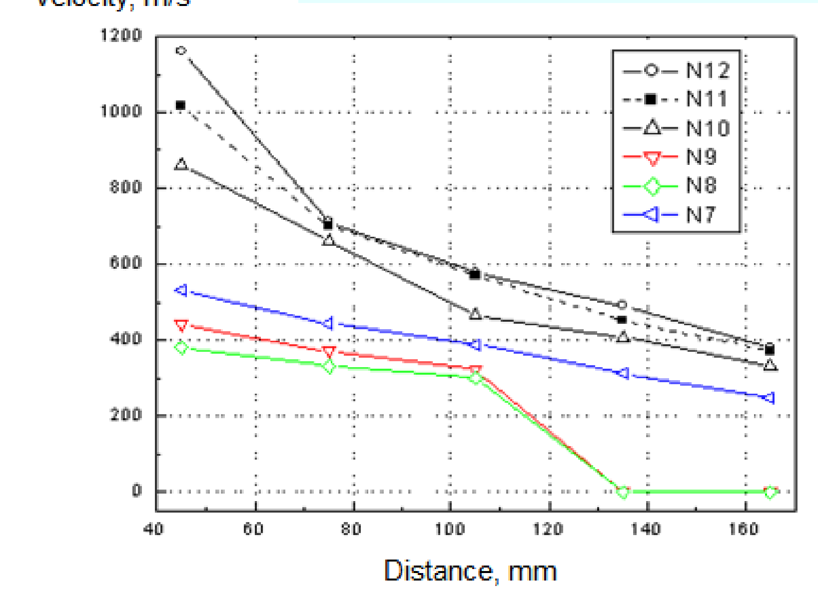
The reaction quickly decays in dense samples under powerful initiating

Detonation-like process in Al/S mixture

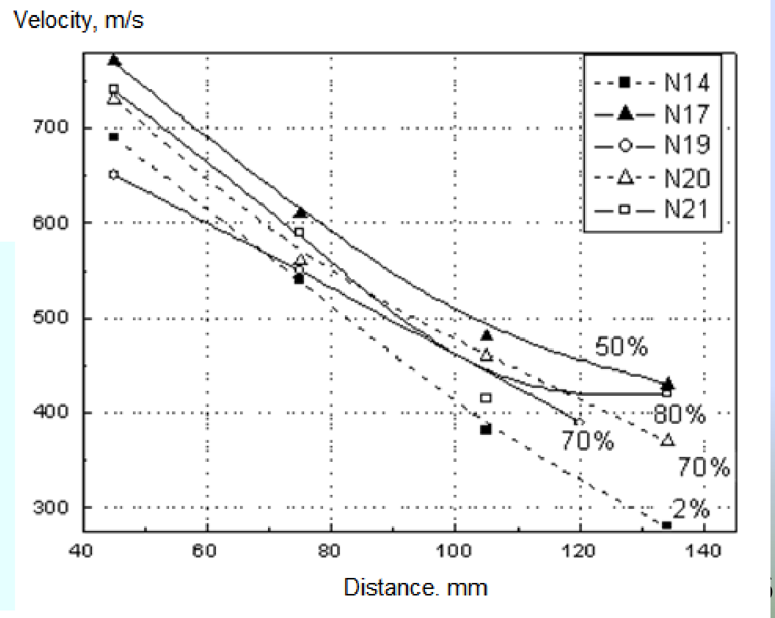


Fast reaction propagation due to formation of hot spots and jets of reaction products

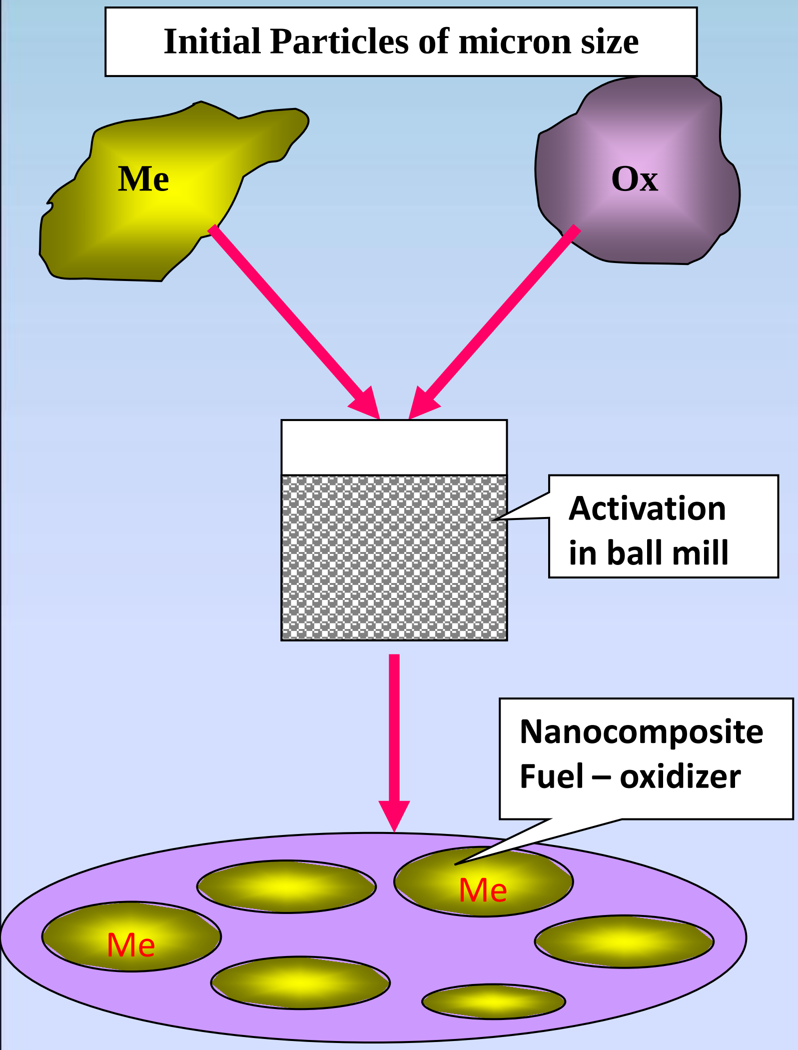
Fading mode in low dense charges



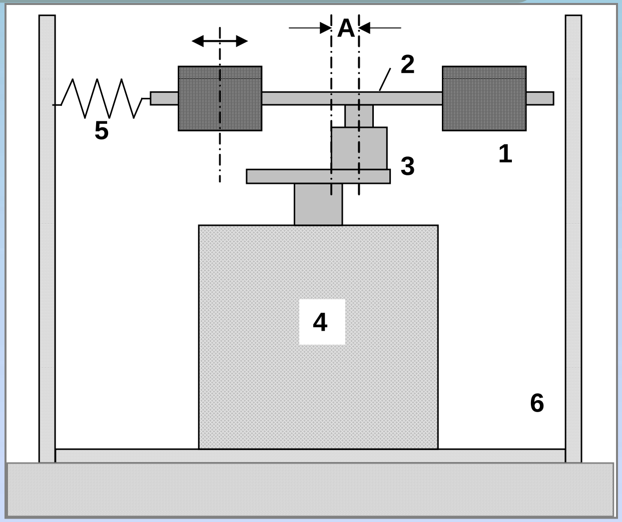
To accelerate the solid state reactions necessary to increase the effective surface area of contact of the reactants. Mechanochemical activation is one of the ways to increase the reactivity of the oxidizer fuel mixture



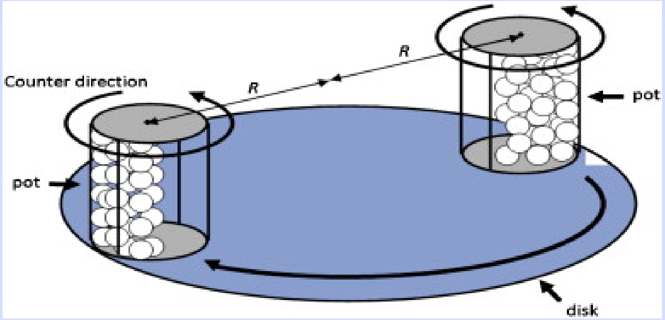
Mechanoactivated Energetic Composites (MAEC)

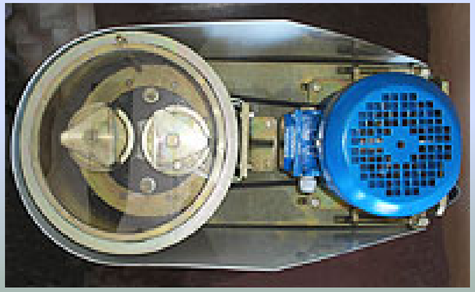


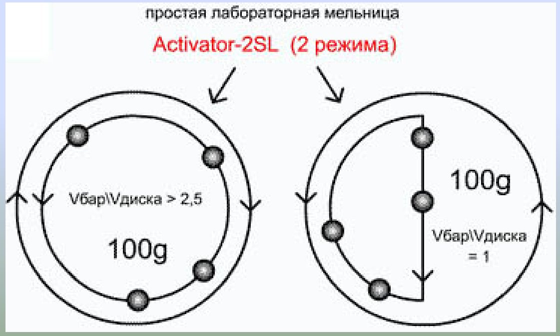
"Aronov" type Vibration mill



planetary ball mill "Activator – 2SL"

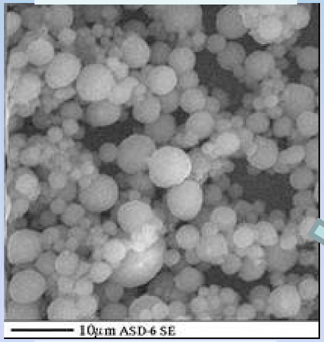




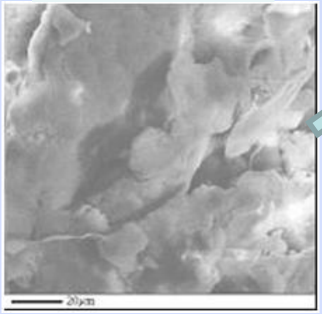


Formation of Mechanoactivated Energetic Composites Me / Teflon

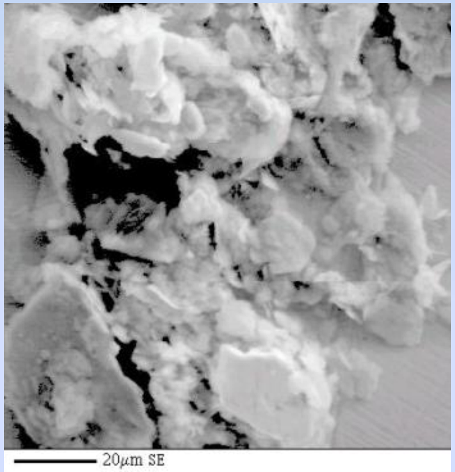
Al –ASD-6



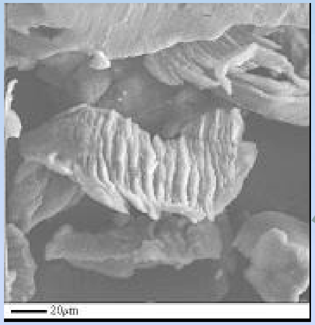
Teflon F4



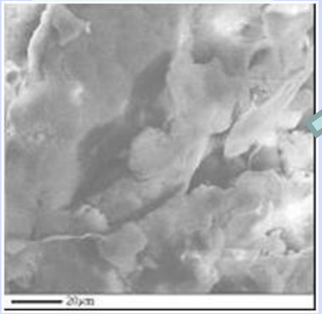
MAEC Al/Teflon



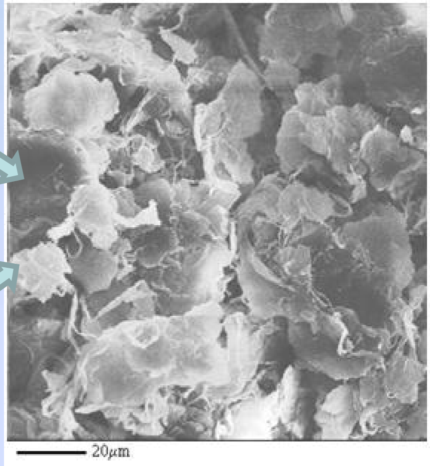
Mg–MPF-4



Teflon F4



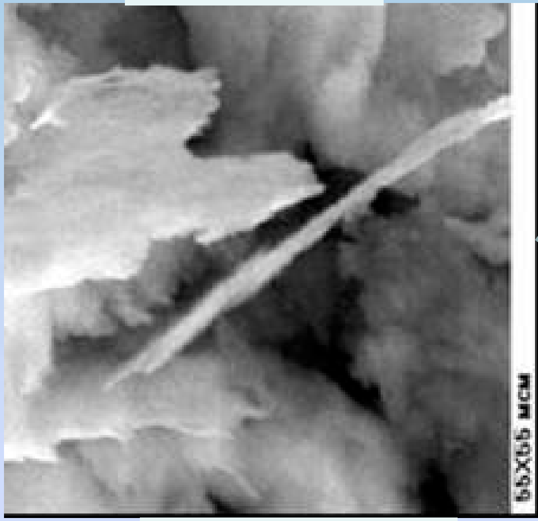
MAEC Mg/Teflon



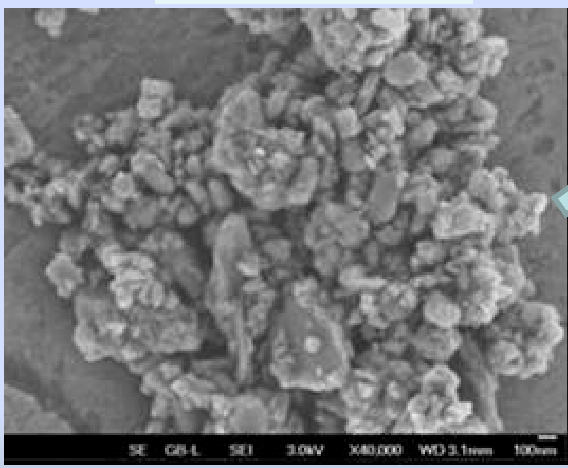
Obtained composites consists of flake particles of Teflon matrix with Metal inclusions

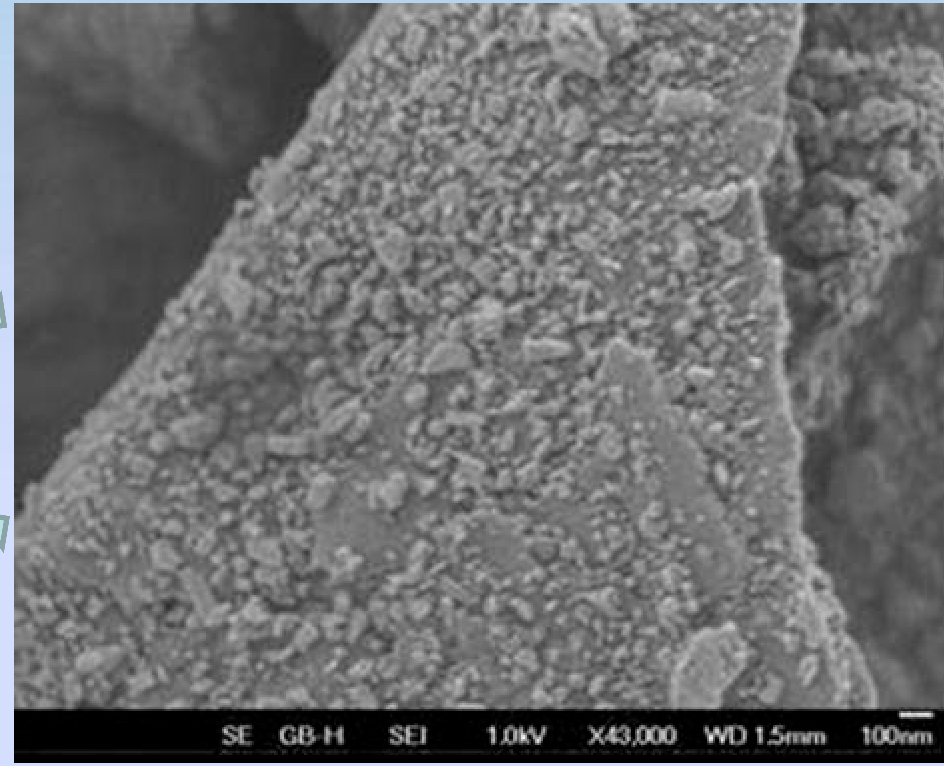
MAEC Al / MoO_3

Al –PAP-2



Nano MoO_3



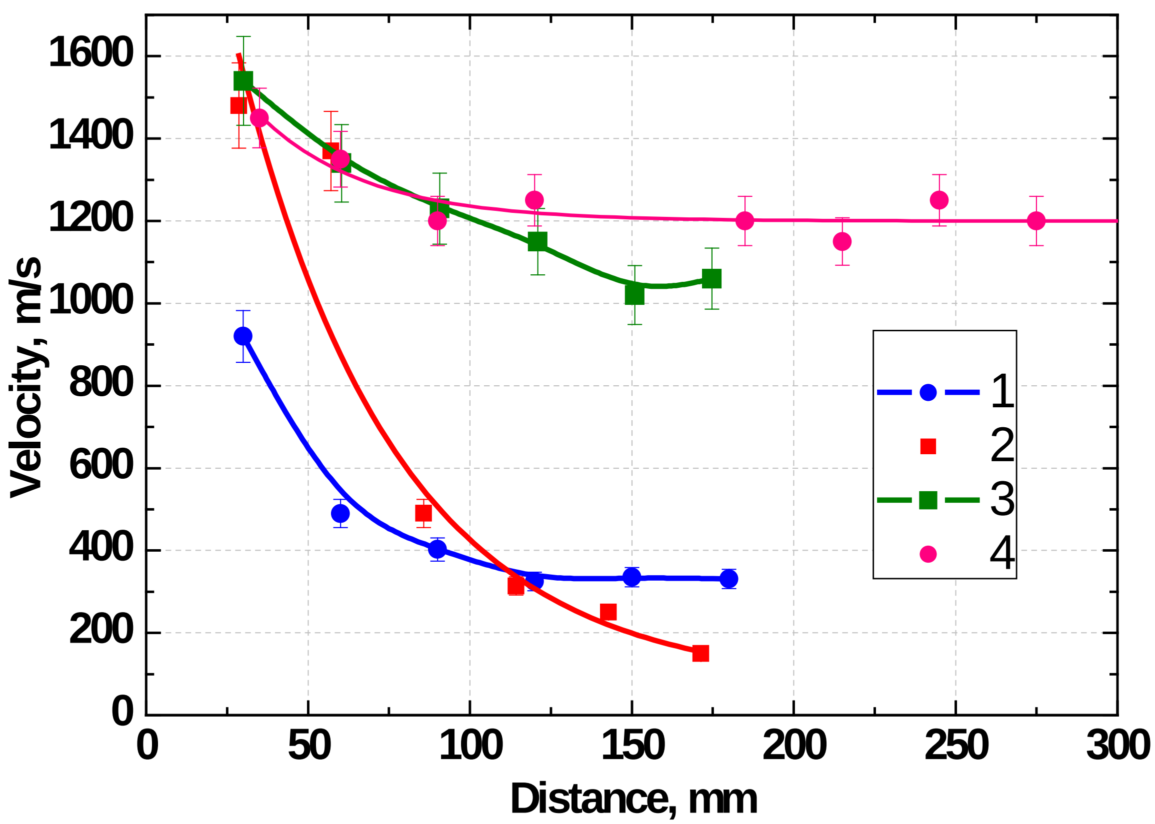


Self-accelerating combustion regime with transition to explosion obtained for low-dense mixtures Al/MoO_3

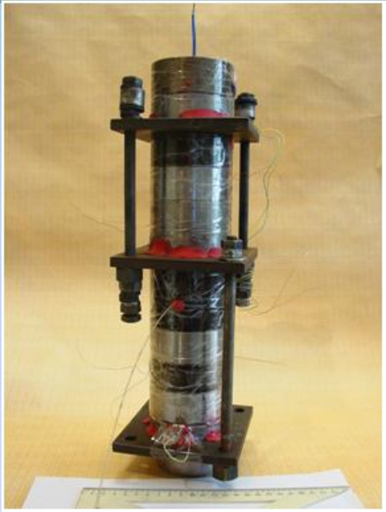
For usual mixtures burning rate **u < 1 m/s**

Mechanoactivated mixtures **u > 400 m/s**

Detonation-like processes in MAECs Al, Mg + Teflon, MoO_3



Velocity of propagation of shock induced reaction in different MAECs:
1 – Mg/MoO_3 34/66 (ρ_0=1.13 g/cc, ε=62%);
2 – Al/MoO_3 32/68 (ρ_0=1.43 g/cc, ε=62%);
3 – Mg/Teflon 35/65 (ρ_0=0.49 g/cc, ε=75%);
4 – Al/Teflon 27/73 (ρ_0=0.59 g/cc, ε=74%)



Detonation - supersonic process with constant velocity (sound speed C< 100 m/s, D = 800-1300 m/s)

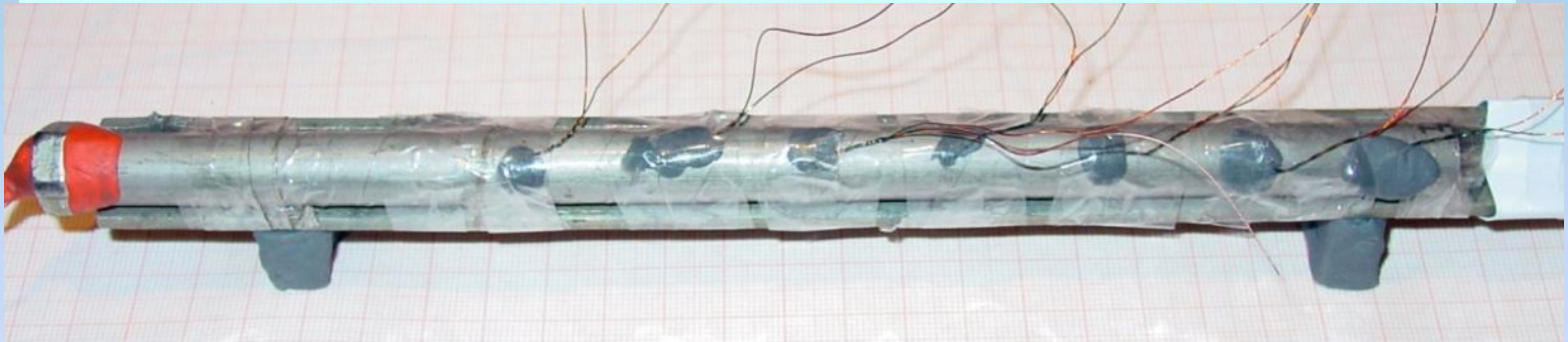
Materials Tested

Thermal effect of reactions Si, Al + PP, AP

Composition, Stoichiometric ratio	ρ_{max}, g/cc	Reaction	Q, kcal/kg	$Q \cdot \rho \cdot 10^{-3}$, kcal/$m^3$
$Si/KClO_4$ 28.8/71.2	2.46	$2Si + KClO_4 = 2SiO_2 + KCl$	2240	5515
Si/NH_4ClO_4 35/65	2.07	$9Si + 4\ NH_4ClO_4 = SiCl_4(g) + 8SiO_2(s) + 2N_2 + 8H_2$	2230	4612
$Al/KClO_4$ 34.2/65.8	**2.58**	**$8Al + 3KClO_4 = 4Al_2O_3 + 3KCl(s)$**	**2544**	**6560**
Al/NH_4ClO_4 27.7/72.3	**2.11**	**$10Al + 6NH_4ClO_4 = 5Al_2O_3 + 6HCl + 9H_2O + 3N_2$**	**2385**	**5032**

Deflagration to Detonation transition MAEC Si + NH_4ClO_4 (30 min)

DDT in stainless steel tube (10 mm dia) L = 2 cm stady-state regime D = 1900 m/s
nano-Si/NH_4ClO_4 (<d> = 60 - 100 nm) 29/71 density = 0.48 g/cc (24% TMD)



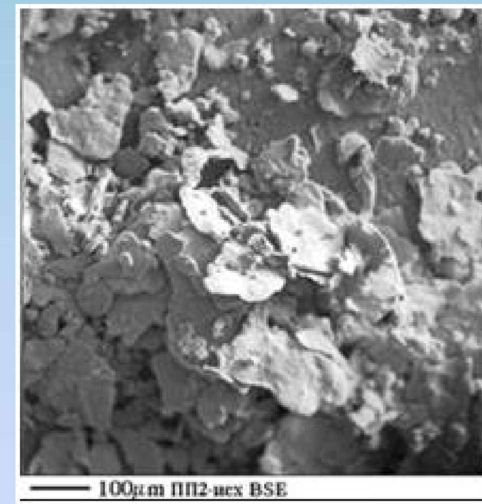
Ni-Cr wire initiation

D = 1900 m/s

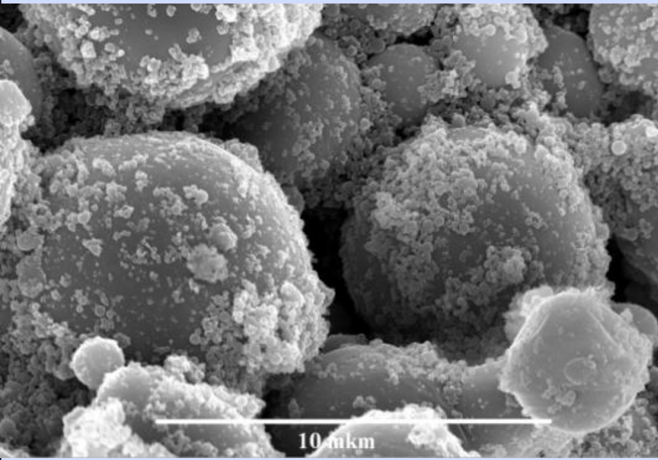
Materials Tested

NH_4ClO_4
PA1. <d> ~ 200 μm

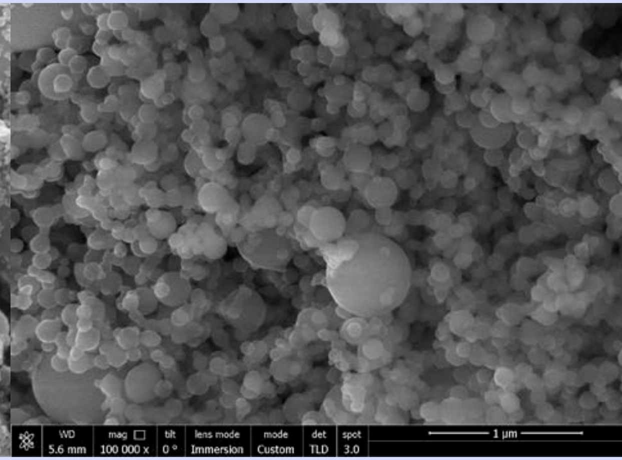
NH_4ClO_4
PA2. <d> ~ 20 μm



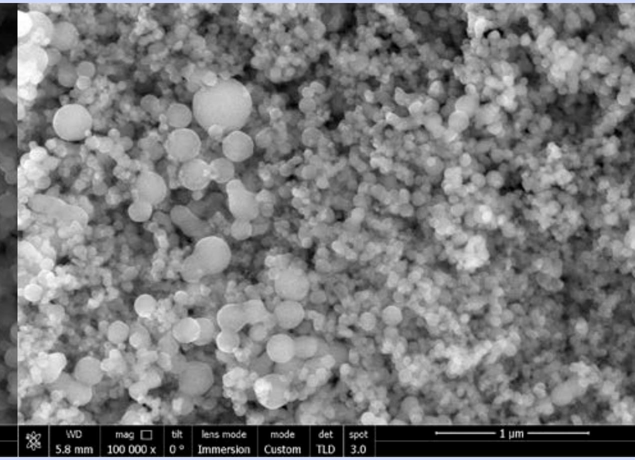
Al – PP-2
<L>70*1-5 μm



Al (8 m²/g) *(GNIIChTEOS)*
<d> ~ 260 nm two fraction
3-5 μm and 100-300 nm

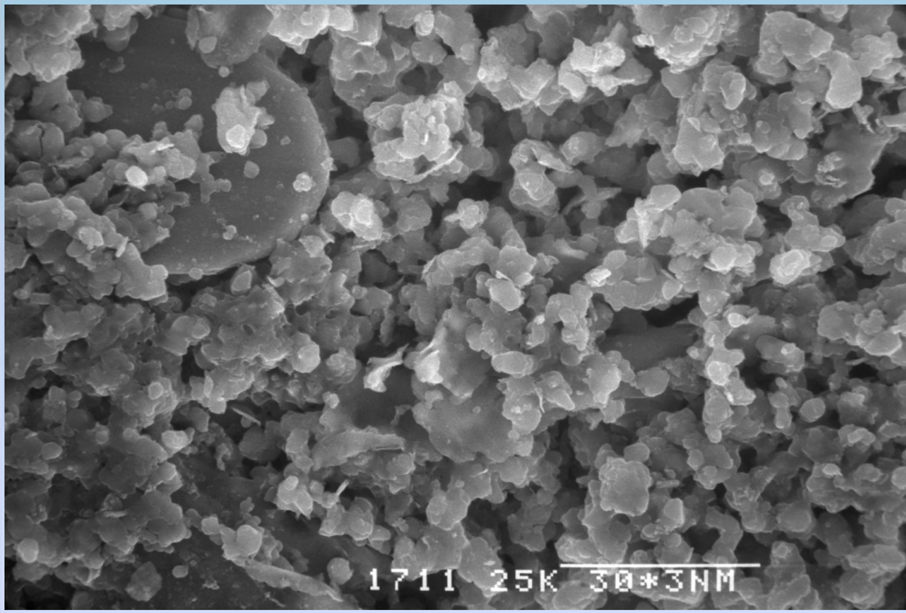


Alex *(Tomsk)*
<d> ~ 100-200 nm

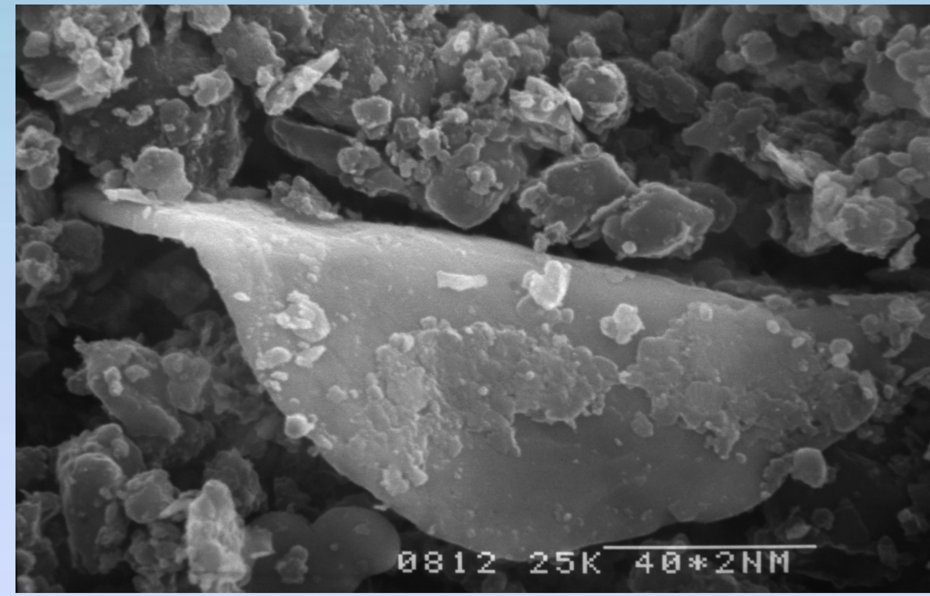


nAl *(INEP)*
<d> ~ 100 nm

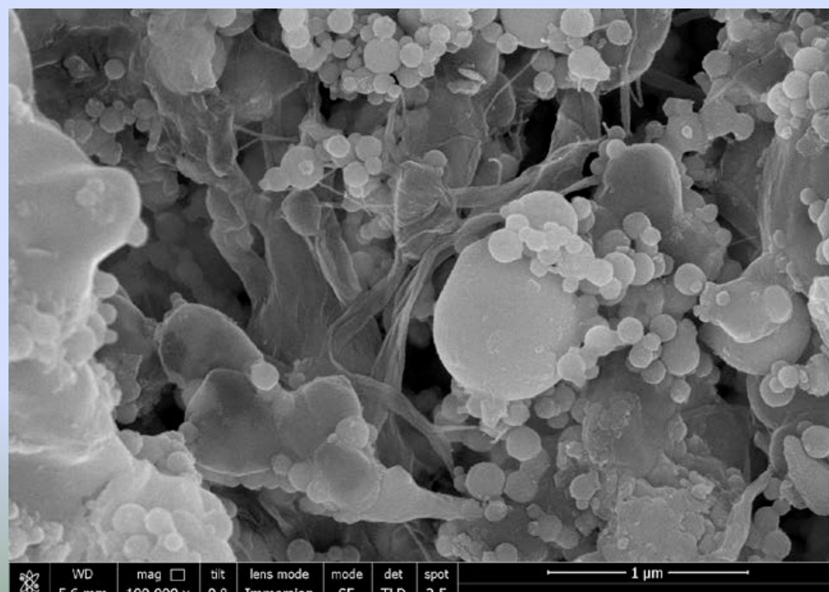
MAEC Al+AP



Al(PP-2)+AP

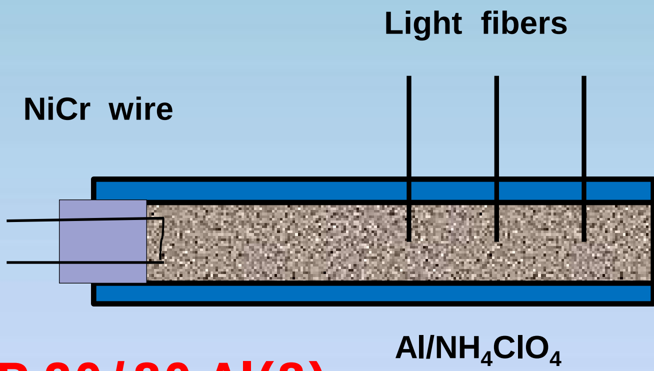


Al(8)+AP



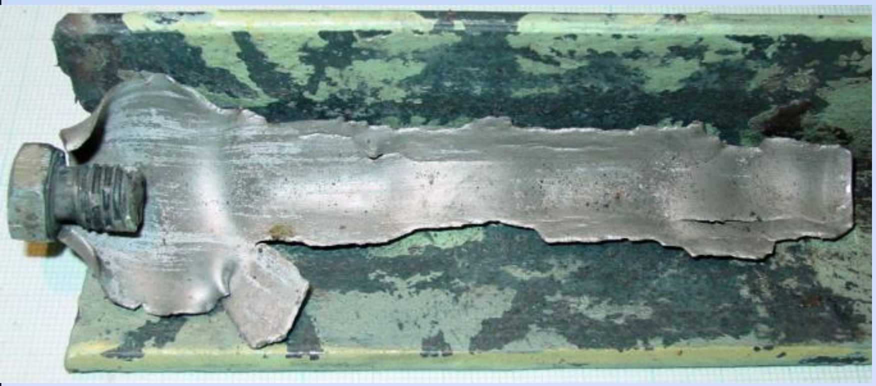
Alex+AP+3%Fluoroplast-42

Deflagration to Detonation Transition DDT



metal tube Ø 10 mm length 120 мм
charge with electric gauges or light fibers
porosity of charges – ε = 80-82%

Al / AP 20 / 80 Al(8)



t_a = 35 min, D = 2380 m/s
steel tube

t_a = 20 min, D = 2310 m/s
duralumin tube

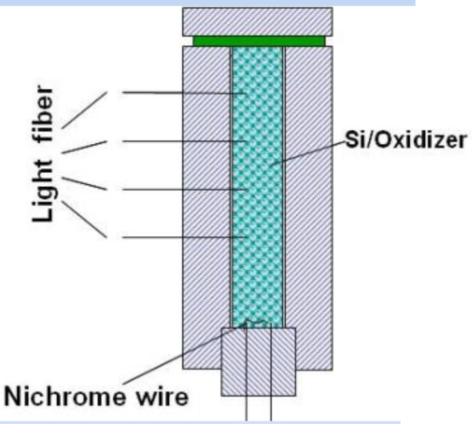
t_a = 40 min, D = 2300 m/s
duralumin tube

DDT Al/AP 20/80 Al(8) ε = 80-82%

Al/NH_4ClO_4

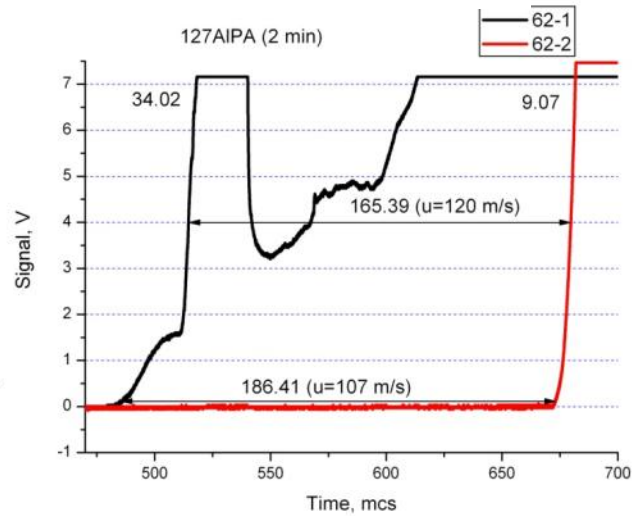
Al(8)

Signals

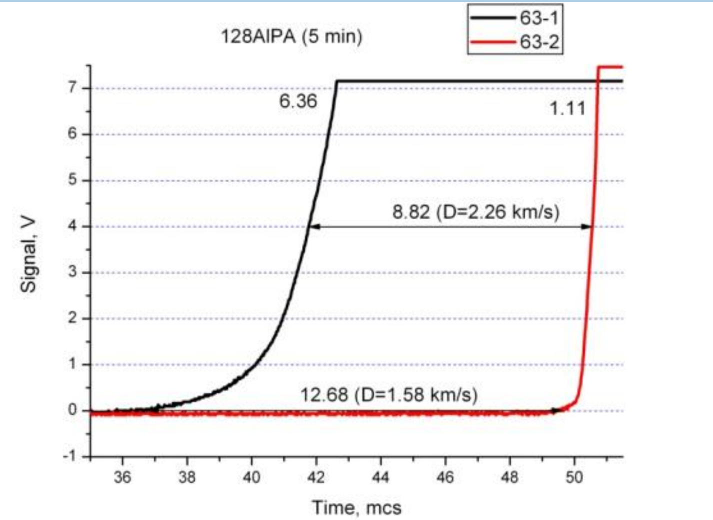


metal tube
Ø 10 mm
length 120 мм

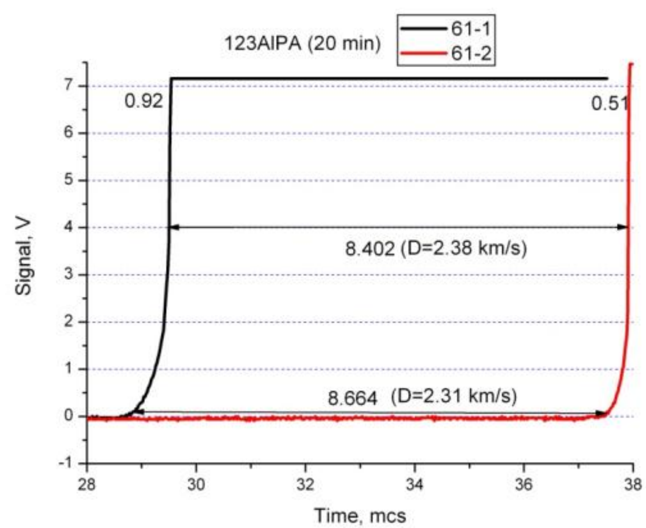
t_{act} = 2 min u=110 m/s



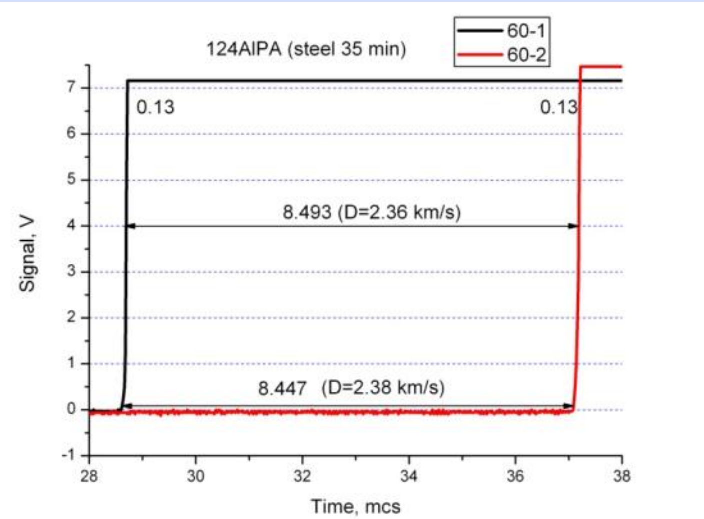
t_{act} = 5 min D=1600 m/s



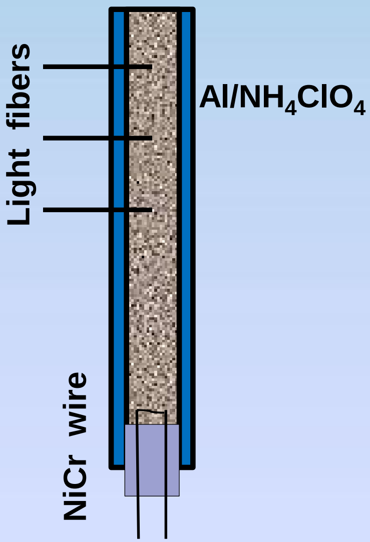
t_{act} = 20 min D=2310 m/s



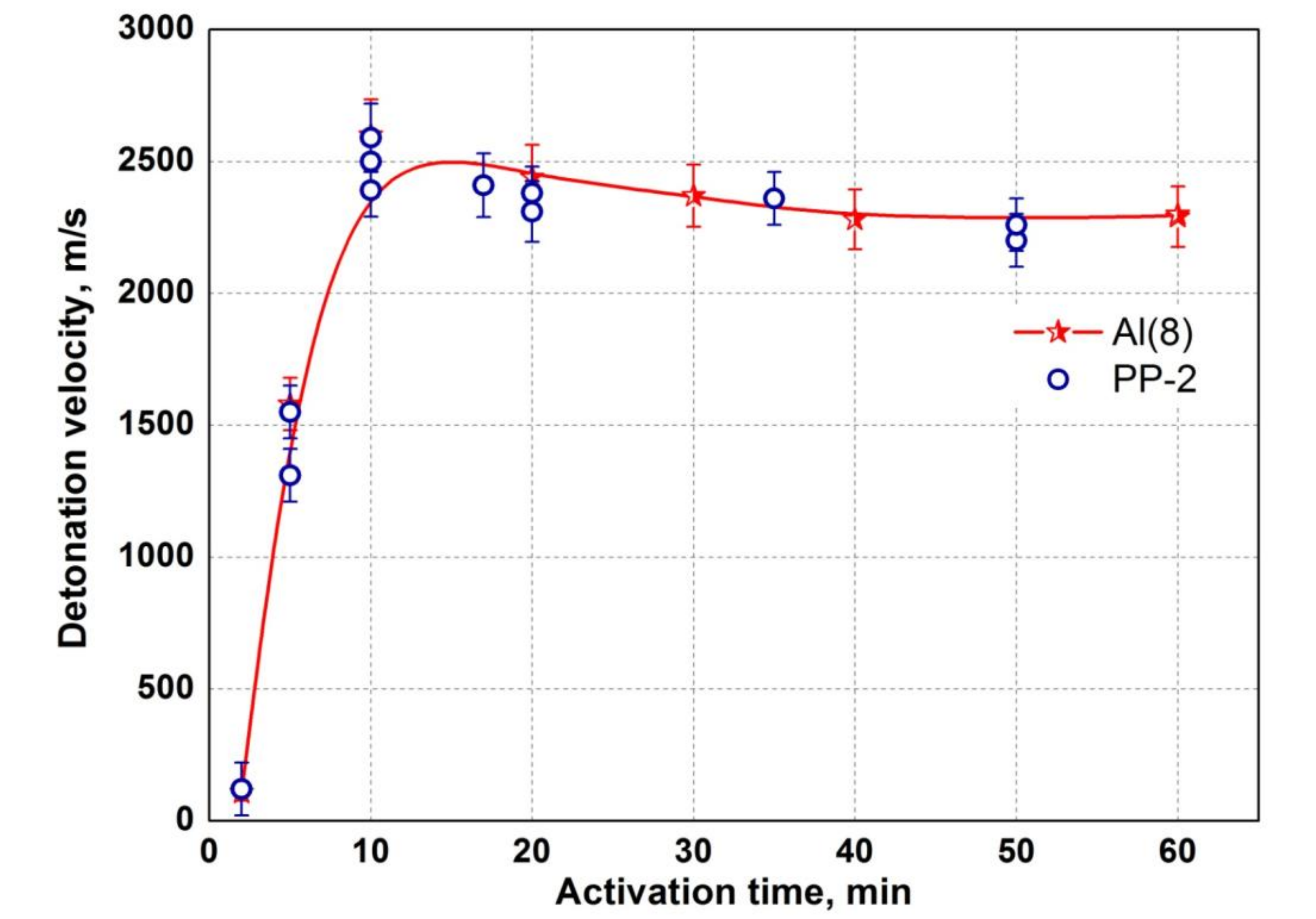
t_{act} = 35 min D=2380 m/s



DDT Al/AP 20/80 ε = 80-82%



aluminum
tube
Ø 10 mm
length 120 мм
ε = 80-82%



Det. Vel. *vs* Time of activation

Mechanical sensitivity

P_{cr} activated Al/AP in comparison with HE	
ВВ	**$P_{кр}$, ГПа**
Lead aside	**0,38 ± 0,03**
BTNEN	**0,79 ± 0,02**
HMX	**0,99 ± 0,03**
Al/AP (20/80)	**0,61 ± 0,02**

P_{cr} - critical pressure corresponding to the transition from mechanical destruction of charges in the shell of PMMA without an explosion to destruction with explosion

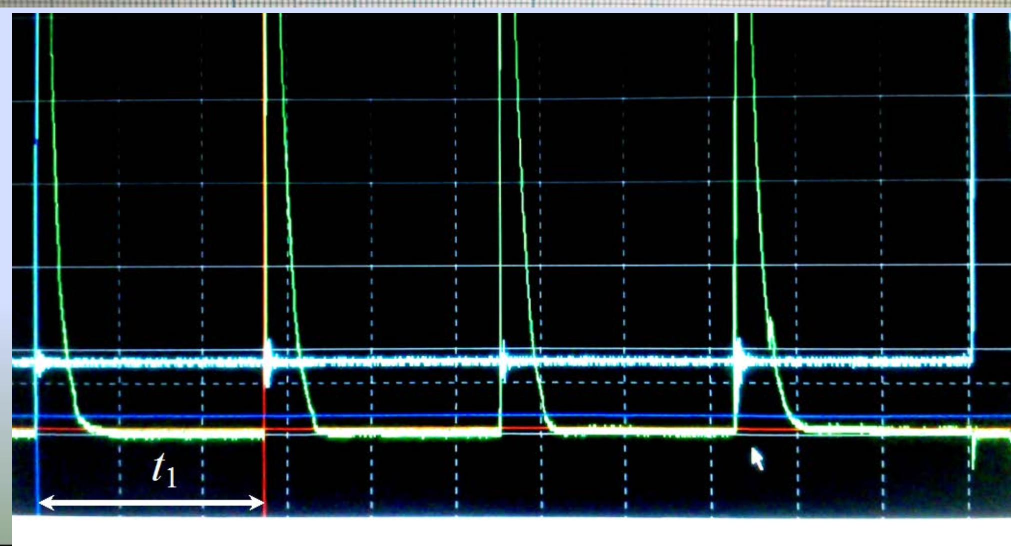
(method of the collapsing shell)
[*Schetinin V.G. // Physics of combustion and explosion, 1999, V. 35*]

Detonation in pressed charges

Al/AP different densities and diameters

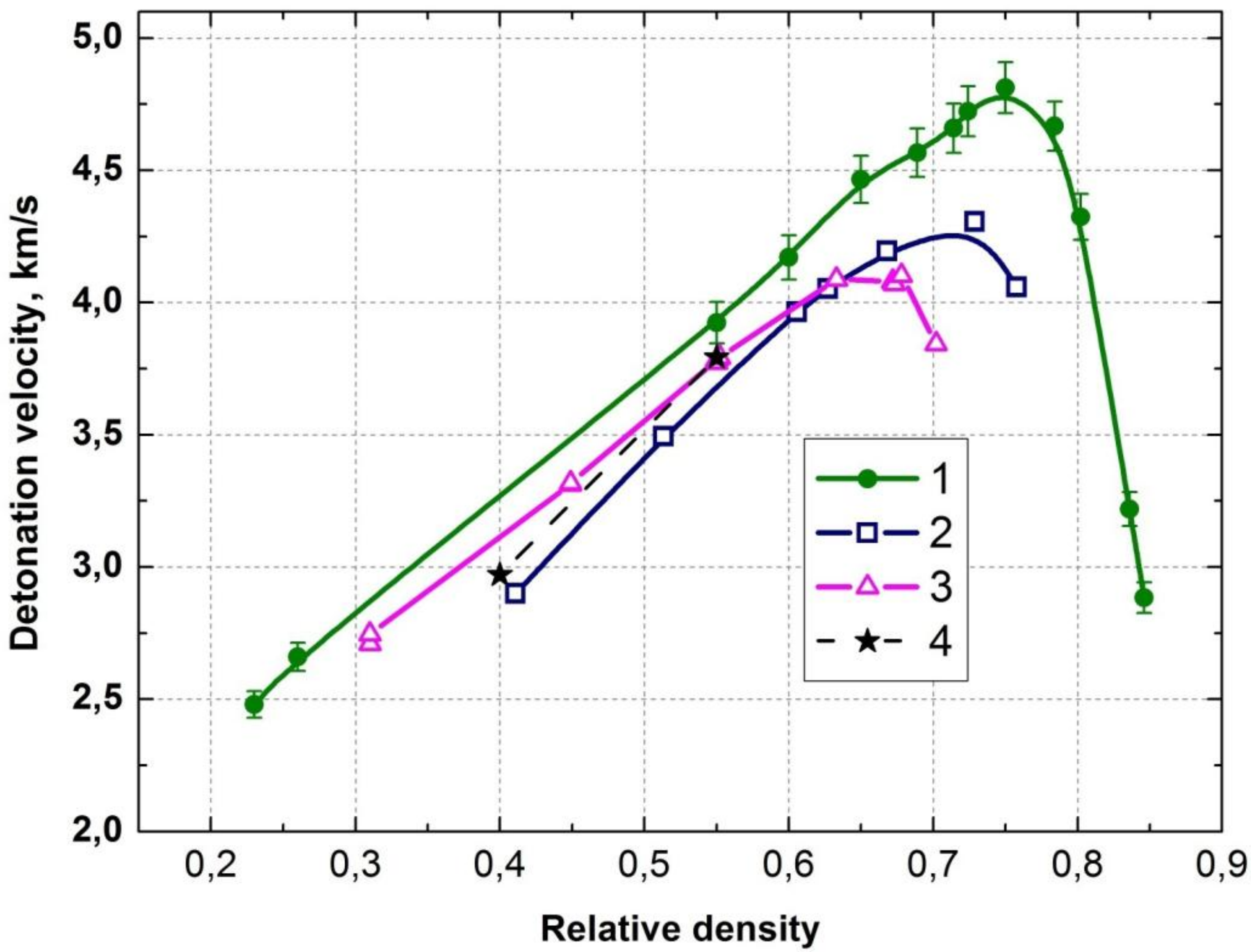
Experimental set up

Signals



Detonation velocity vs relative charge density

Al (PP-2)/AP 20/80 (charge diameter d = 25 mm)



1 - Al/AP 20/80
t_{act}= 10 min
Al – PP-2

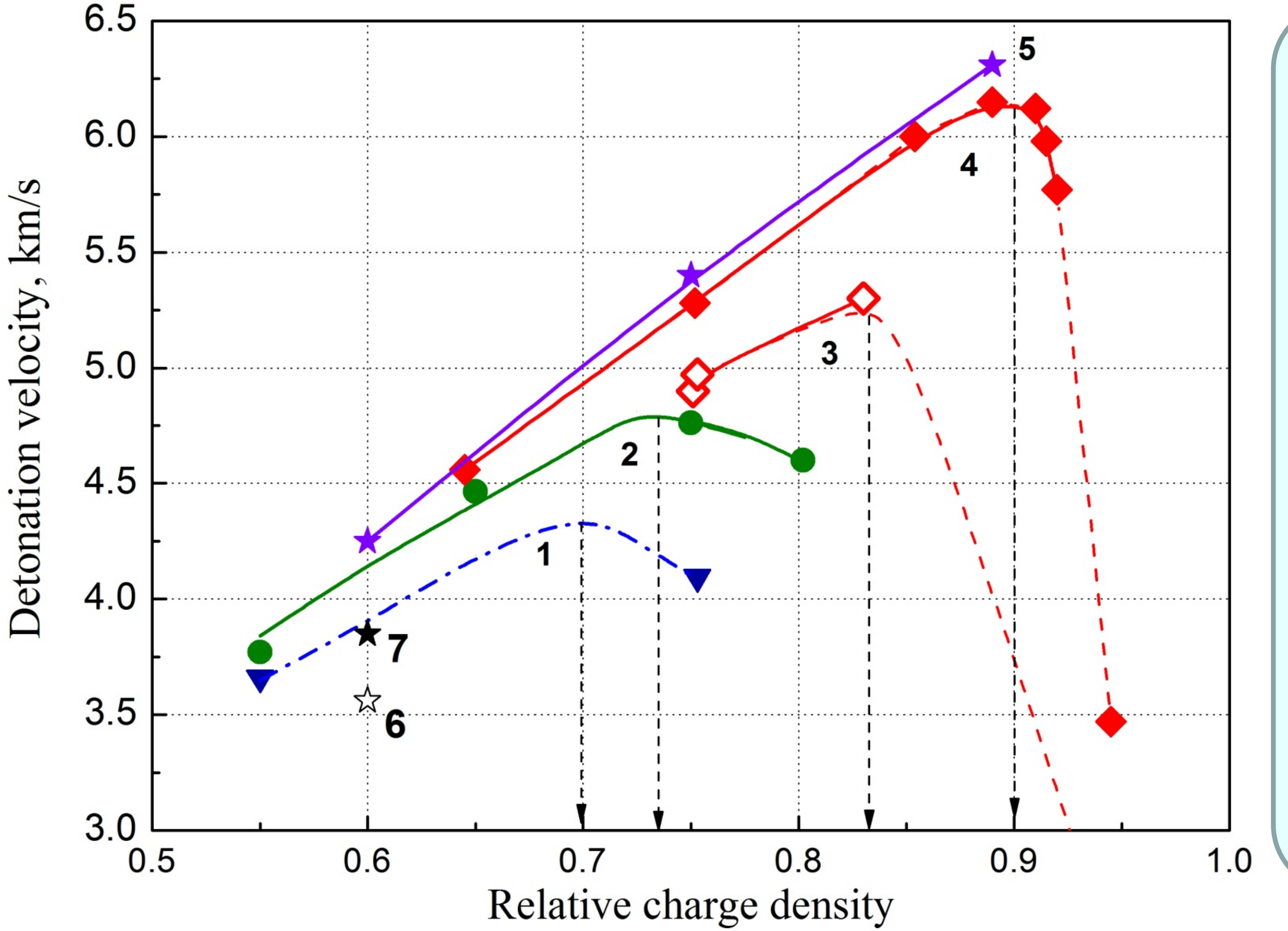
Donna Price data

2 - AP,
3 - Al/AP 10/90,
4 - Al/AP 20/80

[Donna Price, A.R. Clairmont, J.O. Erkman. *Explosive Behavior of Aluminized Ammonium Perchlorate* Naval Ordnance Laboratory Report NOLTR 72-15, White Oak, MD, USA, 1972].

Detonation velocity vs relative charge density

Al(PP-2), Alex/AP and nAl/AP 20/80 d = 25 mm



1 - nonactivated

2 - Al – PP-2
t_{act}= 10 min

3 – Al - Alex
t_{act}= 1

4 - Al - Alex
t_{act}= 10

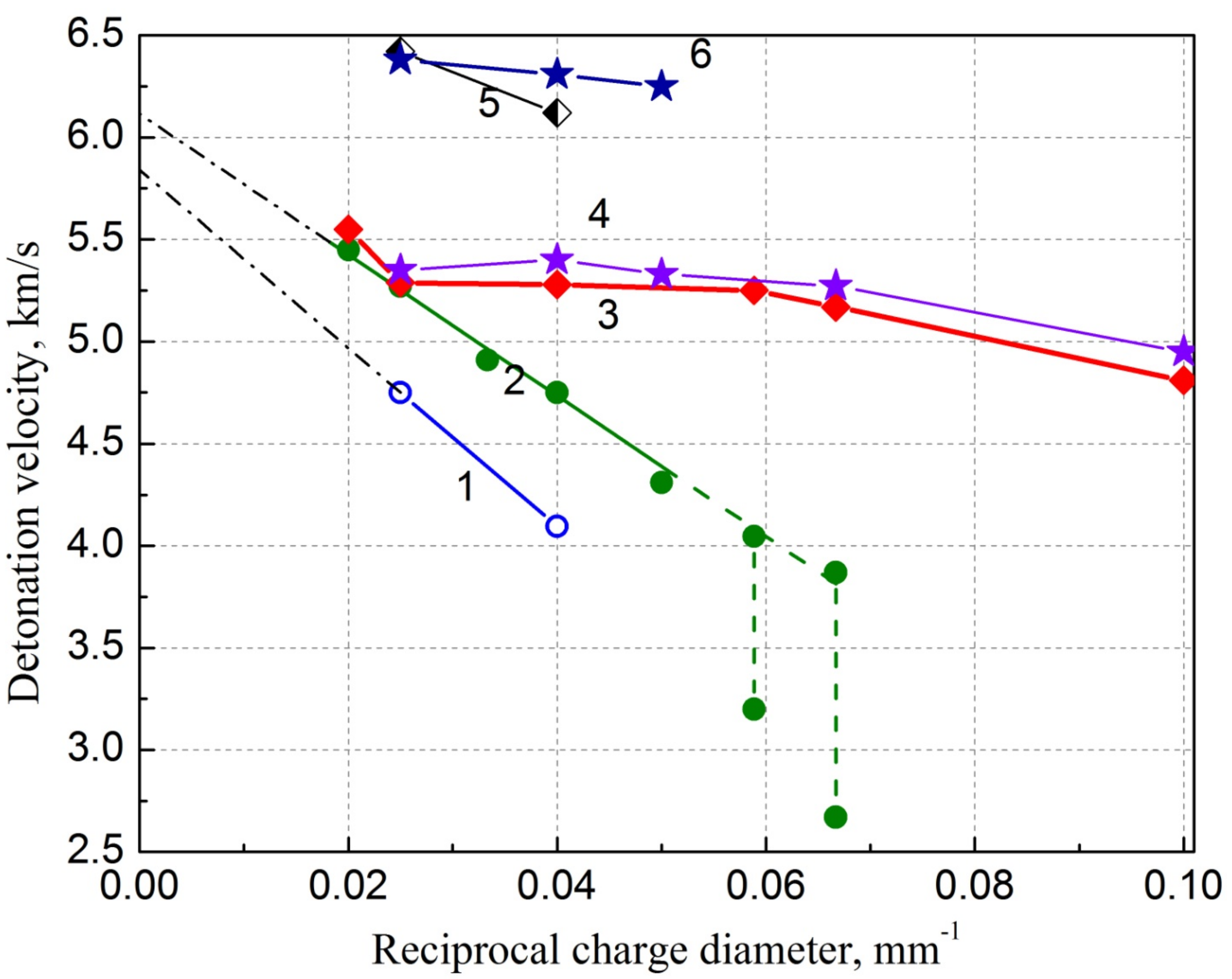
5 - Al - nAl
t_{act}= 10

6 – AP(non-act)

7 – AP(t_{act}= 10)

Detonation velocity vs reciprocal charge diameter (1/d)

Al/AP 20/80 (charge density 0.75 and 0.9 TMD)



0.75 TMD (1-4)

1 – non-activated

t_{act}= 10 min (2-6)

2 - Al – PP-2

3 – Al - Alex

4 - Al - nAl

0.9 TMD (5-6)

5 - Al - Alex

6 - Al - nAl

Conclusion

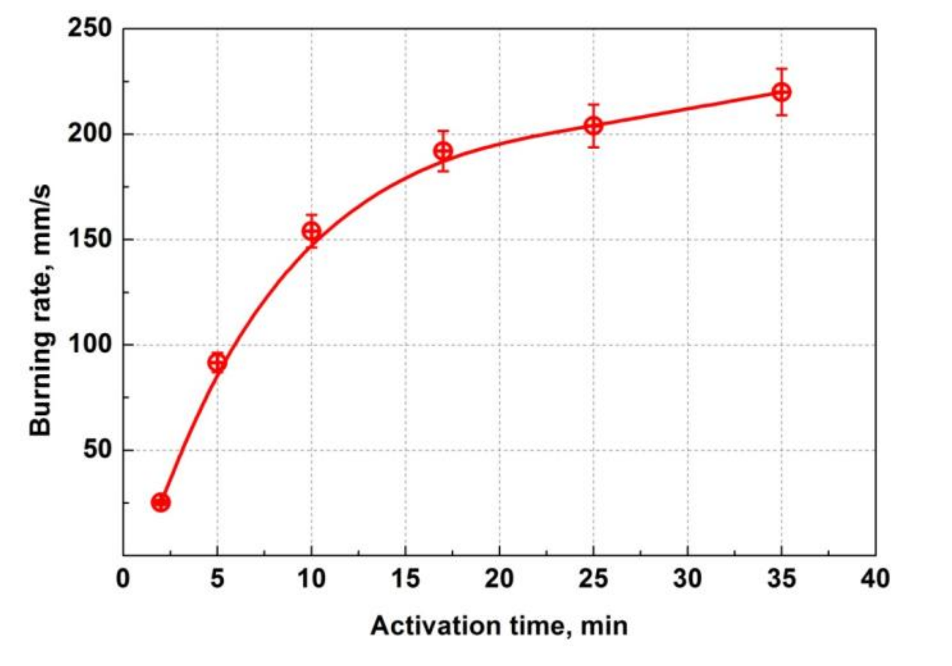
- The results of work allow to consider a method of mechanoactivation as a way to control detonation velocity of explosive compositions on the base of oxidizer-fuel mixtures
- Sharing nano-scale components and mechanical activation can significantly improve the detonation ability of oxidizer - fuel mixtures
- Mechanoactivated energetic composites on the basis of aluminum and perchlorates can be of interest as perspective energetic materials for new initiating and incendiary devices with increased requirements on rate of energy realize

Burning velocity of Al/$KClO_4$ (30/70) composite

Pressed charges, Ø = 12 mm, porosity = 10-15%

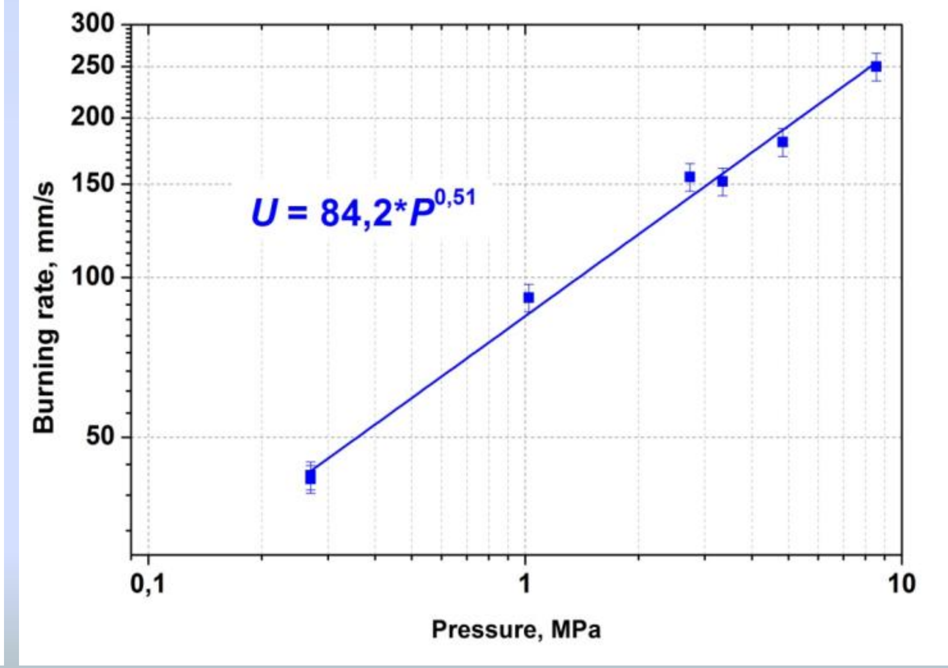
Burning velocity vs activation time

P_0 = 2 MPa

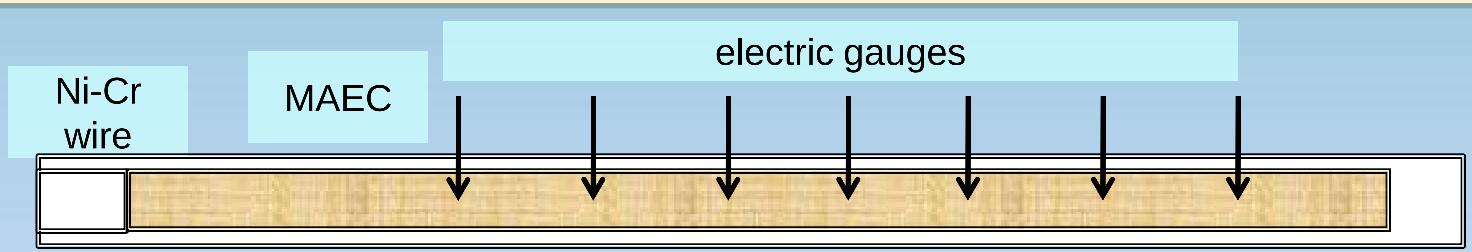


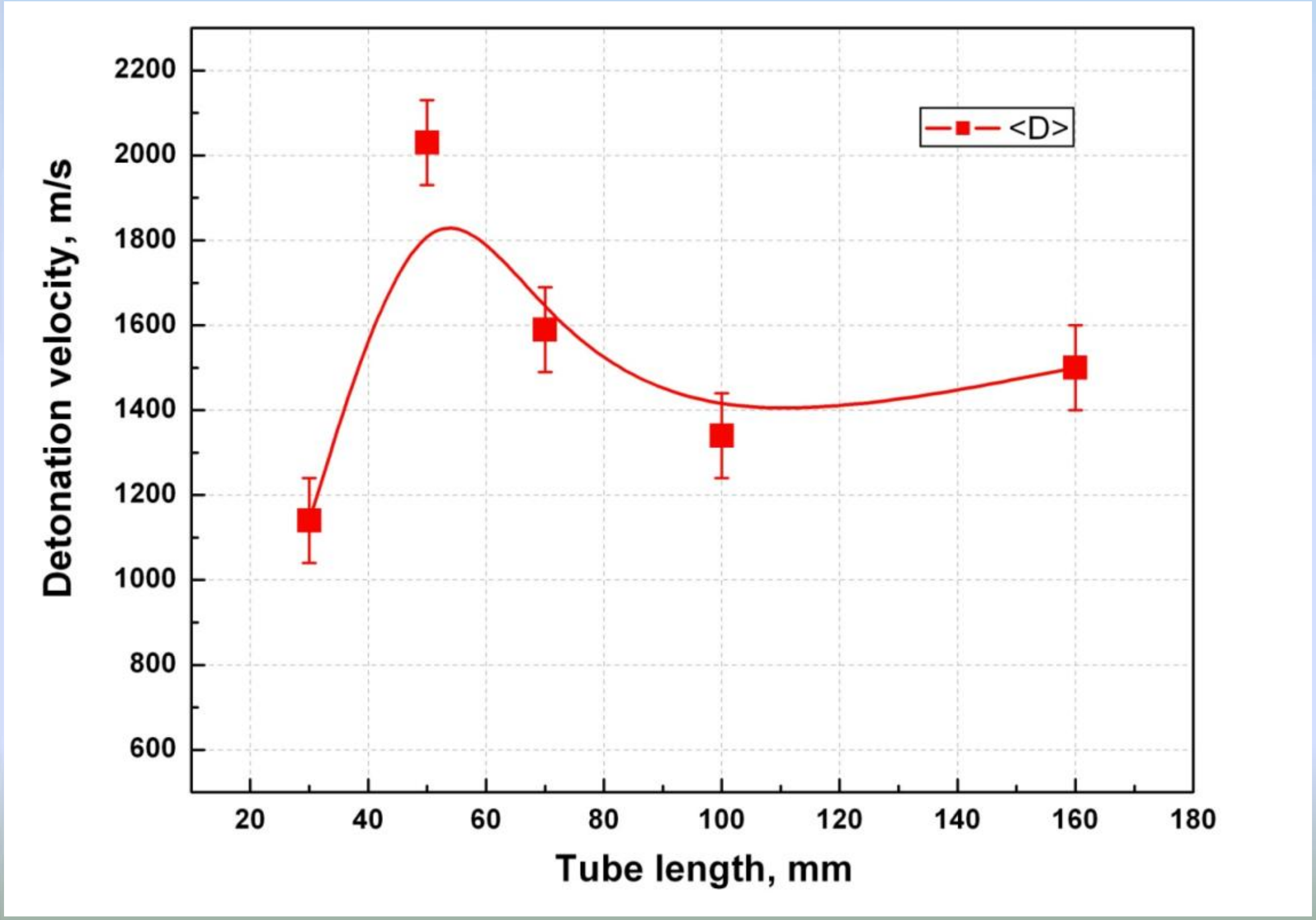
Burning velocity vs pressure (nitrogen)

t_{act} = 10 min



Detonation velocity $Al/KClO_4$ vs charge length





Ø = 18 mm

charge length = 180 mm

porosity = 82-84%