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Analysis of Double Base Propellant Influence on Detonation Process of Ammonals

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Abstract: Aluminum powder has been applied to various types of mining and military explosives for over a hundred years. A known solution is its application as an additive to ammonium nitrate that enhances detonation ability and detonation parameters. Besides aluminum powders, organic fuels are used as ammonals components. In the present work reuse of double base propellants as components of ammonals was proposed. The results of detonation velocity and performance measurements of double base propellants and ammonals mixtures are presented.

Keywords: ammonium nitrate based explosives, detonation parameters

Introduction

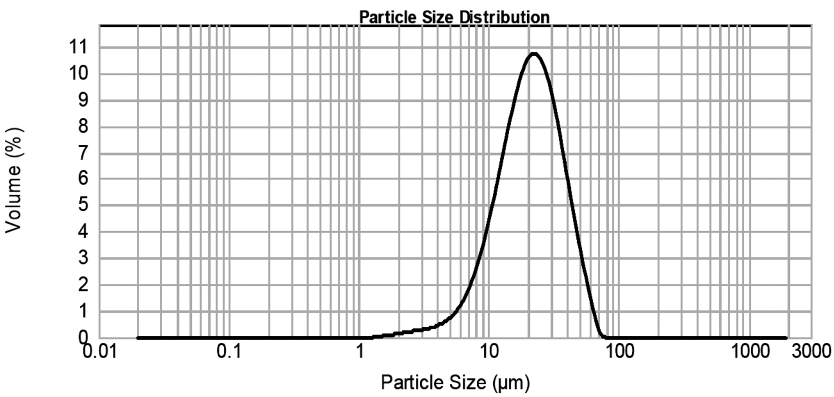
The first person who recommended aluminum powder as an explosive component was Deissler in 1897 [1]. Then aluminum powder as additive in explosives was proposed in some patents [2-4] and H. Kast presented capabilities of aluminized explosives in military applications. Before World War I aluminized explosives were occasionally used in mining industry. Certainly, interests in all sorts of explosives were enhancing during World War I. Some mixtures of ammonium nitrate and aluminum powder containing small amounts of trinitrotoluene and carbon found applications in Russia, United Kingdom and Austria. After World War I aluminum prices went down so from the economical point of view the incorporation of aluminum powder to some dynamite compositions was a profitable solution. Since then aluminum powder was present in every generation of mining explosives.

Kinetic and thermodynamic characteristics of aluminum reactions with decomposition products of remaining explosive components form the basis for the particular influence of aluminum on explosives detonation parameters. Detonation parameters of aluminized explosive mixtures were investigated in many papers [5-15]. In the present work the results of detonation velocity measurements and working capacity determined by blast wave measurements of ammonal and double base propellant mixtures were presented. Experimental variables were the amount of essential components, aluminum grain size distributions, double base propellant compositions and the shape of their grains.

Experimental

Components of explosives

Ammonals were prepared from crystalline ammonium nitrate (particle size below 0.5 mm) and different types of aluminum powders. Two types of aluminum powders were applied – flaked and atomized aluminum powders. Their particle size distribution was show in Figure 1. Some characteristic values were determined for the aluminum powders: mass median diameter d(0.5), size in microns at which 50% of the sample was smaller, d(0.1) and d(0.9) – size of the particle below which 10% and 90% laid (Table 1). Measurements were made by Mastersizer 2000 particle analyzer. Distilled water was used as a liquid dispersant.



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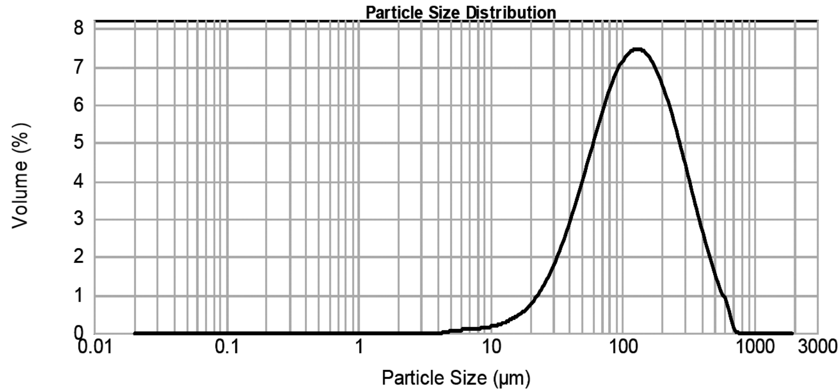

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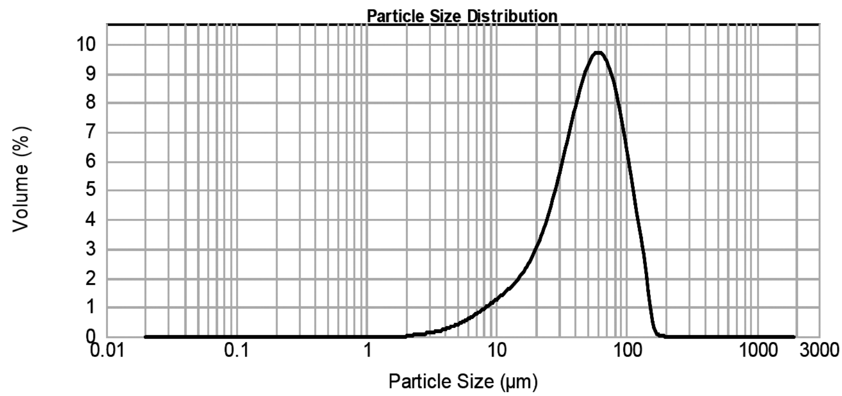

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Figure 1. Particle size analysis of aluminum powders: a – flaked Al_1, b – atomized Al_2, c – flaked Al_3.

Table 1. Particle size distribution of aluminum powders

Aluminium powder	d(0.1) [μm]	d(0.5) [μm]	d(0.9) [μm]
Al_1	10	21	40
Al_2	40	122	322
Al_3	16	50	101

Three types of double base propellants, differed in nitroglycerine and nitrocellulose content, were chosen. Their composition were given in Table 2.

Table 2. Double base propellants compositions

Component [%]	Double base propellant		
	P1	P2	P3
Nitroglycerine	40.0	36.7	26.5
Nitrocellulose	57.0	57.5	56.0
Dinitrotoluene	-	-	9.0
Modifiers	3.0	5.8	8.5

Propellants identified as P1, P2 i P3 were in the form of squares of 2×2 mm, having a thickness of 0.25 mm (Figure 2a). The propellant P3 was also in the form of cut cylinder with a diameter of 5.7 mm, bore 2.2 mm and thickness about 2.1 mm (Figure 2b).

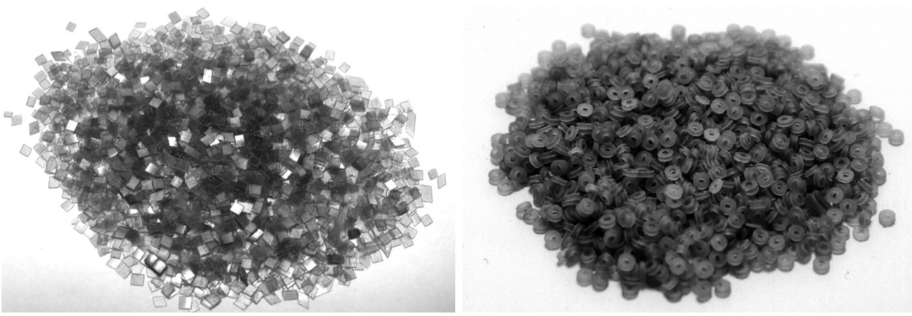

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Figure 2. Double base propellant: a – flakes, b – cut cylinders.

The explosive mixtures were prepared by mixing crystalline ammonium nitrate and one of the aluminum powders and then with the given double base propellant.

Detonation velocity

Detonation velocity was determined in steel pipes 36/42 mm for mixtures of propellant P1 and ammonals containing flaked aluminum powder Al_1 (Table 3) or atomized aluminum powder Al_2 (Table 4). Analogous measurements were made for compositions propellant P3 in the form of cut cylinders and ammonals mentioned above (Tables 5 and 6). Every explosive was initiated by RDX/Al booster and detonator.

Table 3. Detonation velocities of mixtures of ammonals containing aluminum powder Al_1 and propellant P1

No.	Explosive composition	Density [kg/m^3]	Detonation velocity [m/s]
1	Propellant P1	744	4290
2	Al_1/AN 3/97	856	3290
3	Al_1/AN/Propellant P1 3/77/20	855	4030
4	Al_1/AN/Propellant P1 3/57/40	867	4440
5	Al_1/AN 6/94	843	3450
6	Al_1/AN/Propellant P1 6/74/20	880	4100
7	Al_1/AN/Propellant P1 6/54/40	881	4460
8	Al_1/AN 10/90	844	3470
9	Al_1/AN/Propellant P1 10/70/20	854	3950
10	Al_1/AN/Propellant P1 10/50/40	842	4260

Addition of propellant P1 definitely enhanced detonation velocities of the investigated explosives. In the case of ammonals with the least aluminum content the enhancement was the most noticeable; the enhancement was 22% if the propellant content was 20% and 35% for 40% propellant content in the explosive. A slightly smaller acceleration of this parameter was observed in the case of 6% aluminum mixtures. For the mix with 20% of propellant P1 detonation velocity increased for 19% with respect to the reference explosive whereas the value increased 29% for the explosive containing 40% of the propellant. A significant increase of aluminum content in the mixes caused smaller increases in detonation velocities – it was only 14% and 23%.

From the above presented results it appears that the amount of propellant in the explosive influence more on detonation velocity. Despite the differences in aluminum content detonation velocities for explosives containing 20% of propellant P1 (compositions 3, 6, 9 – Table 3) were quite similar. The same effect was observed in the case of compositions 4, 7, 10 (Table 4) – the differences in detonation rates did not exceed 5%.

Detonation velocities of reference ammonals containing aluminum powder Al_2 were lower from the ones determined for ammonals containing aluminum powder Al_1, the differences were smaller with the increase in aluminum content in explosive mixture. Both for the mixtures of 20% and 40% of propellant P1 the increase of aluminum content caused that the enhancement of detonation velocities resulting from the propellant presence were lower and lower. In the case of composition 2 (Table 4) the detonation rate enhancement in comparison with composition 1 was 34%, detonation velocity of composition 5 in comparison with composition 4 was higher about 20%, while detonation velocity for composition containing 10% of aluminum powder and 20% of propellant P1 – only 10%. More significant enhancements of measured parameter concerning the reference ammonal was observed in the instance of mixtures containing 40% of the propellant; there were, respectively, for composition 3 – 56%, composition 6 – 38% and composition 9 – 22% (Table 4). Values of detonation velocities for the compositions containing 20% of propellant P1 were also similar, as for the compositions with flaked aluminum powder. The same phenomena repeated in the case of explosives mixtures of higher propellant P1 content. That provided exothermic decomposition of double base propellant in chemical reaction zone was decisive reaction that controlled detonation velocity of the investigated explosives; thermal effect of aluminum oxidation was an additional process.

Table 4. Detonation velocities of mixtures of ammonals containing aluminum powder Al_2 and propellant P1

No.	Explosive composition	Density [kg/m^3]	Detonation velocity [m/s]
1	Al_2/AN 3/97	852	2810
2	Al_2/AN/Propellant P1 3/77/20	881	3910
3	Al_2/AN/Propellant P1 3/57/40	904	4640
4	Al_2/AN 6/94	852	3240
5	Al_2/AN/Propellant P1 6/74/20	912	4100
6	Al_2/AN/Propellant P1 6/54/40	929	4640
7	Al_2/AN 10/90	875	3460
8	Al_2/AN/Propellant P1 10/70/20	917	4190
9	Al_2/AN/Propellant P1 10/50/40	941	4730

The same experiments were conducted using double base propellant P3 in the form of cut cylinders (Tables 5 and 6). Detonation rate of cut cylinder propellant was 1580 m/s (ρ_o = 721 kg/m^3) and was much lower than detonation rate of propellant flakes – 3610 m/s (ρ_o=836 kg/m^3).

As opposed to the previous results the additive of propellant P3 did not cause the significant detonation rate enhancements of the explosive mixtures. Small, about 3% increases of this parameter could be observed in the case of mixes 2 and 3 (Table 5), equally small acceleration of detonation velocity was observed for composition 5, containing 6% of aluminum powder and 20% of propellant. Detonation velocity of remaining compositions decreased – the decrease about 5% was observed for compositions 6 and 8 and 11% for mix 9 (Table 5). The results were connected with low detonation velocity of propellant P3 in the form of cut cylinders that are statistically arranged in the explosive – 1580 m/s.

Table 5. Detonation velocities of mixtures of ammonals containing flaked aluminum powder (Al_1) and propellant P3 in the form of cut cylinders

No.	Explosive composition	Density [kg/m^3]	Detonation velocity [m/s]
1	Al_1/AN 3/97	856	3290
2	Al_1/AN/Propellant P3 3/77/20	1096	3410
3	Al_1/AN/Propellant P3 3/57/40	1104	3400
4	Al_1/AN 6/94	843	3450
5	Al_1/AN/Propellant P3 6/74/20	1050	3600
6	Al_1/AN/Propellant P3 6/54/40	1059	3250
7	Al_1/AN 10/90	844	3470
8	Al_1/AN/Propellant P3 10/70/20	947	3310
9	Al_1/AN/Propellant P3 10/50/40	949	3090

Table 6. Detonation velocities of ammonals mixtures of containing atomized aluminum powder (Al_2) and propellant P3 in the form of cut cylinders

No.	Explosive composition	Density [kg/m^3]	Detonation velocity [m/s]
1	Al_2/AN 3/97	852	2810
2	Al_2/AN/Propellant P3 3/77/20	1095	2840
3	Al_2/AN/Propellant P3 3/57/40	1120	2920
4	Al_2/AN 6/94	852	3240
5	Al_2/AN/Propellant P3 6/74/20	1089	3280
6	Al_2/AN/Propellant P3 6/54/40	1093	3230
7	Al_2/AN 10/90	875	3460
8	Al_2/AN/Propellant P3 10/70/20	1091	3380
9	Al_2/AN/Propellant P3 10/50/40	1094	3270

The results of detonation velocity measurements for ammonals containing atomized aluminum powder Al_2 and propellant P3 in the form of cut cylinder showed that the addition of 20% of propellant P3 did not increased detonation velocity of mix containing 3% of aluminum powder and 40% of propellant P3 caused the increase of 3%. There were generally no differences in measured detonation velocities for explosives containing 6% of aluminum powder, regardless of propellant content. The decrease of 6% was noticed in explosive 9 (Table 6).

Working capacity

Working capacity was determined by blast wave method. We evaluated overpressure in the front of blast wave and calculated positive phase impulse values. Investigated mixtures were loaded into paper tubes having an outer diameter of 50 mm, an inside diameter of 45 mm. The weight of each charge was 350 g and density was 1000 kg/m^3. The explosives were initiated using boosters.

The charges were hung 1.5 m above the ground in such way that pressure transducers and centre of gravity of the charge laid in the same plain. First PCB pressure transducer was located at 2 m distance and the second one at 3 m away from the centre of the charge. The results of overpressure measurements and calculated impulses for ammonals containing double base propellant P1 were collected in Tables 7-9. Some reference experiments for trinitrotoluene (TNT) were also conducted. TNT charges weighed also 350 g, but their density was lower – 840 kg/m^3. Average overpressure values for TNT pellets were 109.12 kPa at 2 m and 54.26 kPa at 3 m. Positive phase impulses calculated for TNT were 53.53 Pa·s and 34.03 Pa·s at 2 m and 3 m, respectively. The results of tests and calculations were presented in Tables 7-9 and Figure 3-5.

Table 7. Parameters of blast waves for ammonals containing flaked aluminum powder (Al_1) and propellant P1

No.	Explosive composition	Overpressure [kPa]		Impulse [Pa·s]	
		2 m	3 m	2 m	3 m
1	Al_1/AN 3/97	71.23	40.57	31.75	23.35
2	Al_1/AN/Propellant P1 3/77/20	83.68	48.03	39.54	29.24
3	Al_1/AN/Propellant P1 3/57/40	111.70	58.66	48.84	31.49
4	Al_1/AN 6/94	87.42	49.53	39.85	28.89
5	Al_1/AN/Propellant P1 6/74/20	106.28	56.03	47.69	30.97
6	Al_1/AN Propellant P1 6/54/40	122.42	64.75	53.27	33.41
7	Al_1/AN 10/90	104.71	56.89	47.36	30.37
8	Al_1/AN/Propellant P1 10/70/20	122.45	59.26	51.23	31.64
9	Al_1/AN/Propellant P1 10/50/40	113.42	63.87	54.28	34.12

There is no result for ammonal mixture containing 3% of atomized aluminum powder in the Table 8 as the explosive did not detonated under experiment conditions.

Table 8. Parameters of blast waves for ammonals containing atomized aluminum powder (Al_2) and propellant P1

No.	Explosive composition	Overpressure [kPa]		Impulse [Pa·s]	
		2 m	3 m	2 m	3 m
1	Al_2/AN 3/97	no detonation			
2	Al_2/AN/Propellant P1 3/77/20	65.04	39.59	30.91	22.94
3	Al_2/AN/Propellant P1 3/57/40	115.37	57.77	50.17	36.19
4	Al_2/AN 6/94	180.93	39.15	30.98	23.42
5	Al_2/AN/Propellant P1 6/74/20	95.74	52.69	44.45	32.22
6	Al_2/AN/Propellant P1 6/54/40	128.39	61.86	53.13	33.96
7	Al_2/AN 10/90	93.21	57.35	48.05	35.48
8	Al_2/AN/Propellant P1 10/70/20	117.36	59.26	53.23	37.82
9	Al_2/AN/Propellant P1 10/50/40	136.36	67.12	58.30	38.74

Table 9. Parameters of blast waves for ammonals containing atomized aluminum powder (Al_3) and propellant P1

No.	Explosive composition	Overpressure [kPa]		Impulse [Pa·s]	
		2 m	3 m	2 m	3 m
1	Al_3/AN 3/97	72.48	31.13	35.08	19.94
2	Al_3/AN/Propellant P1 3/77/20	111.55	35.28	42.89	24.45
3	Al_3/AN/Propellant P1 3/57/40	130.62	50.15	53.03	34.01
4	Al_3/AN 6/94	94.46	42.99	43.30	26.09
5	Al_3/AN/Propellant P1 6/74/20	119.66	44.65	49.97	31.36
6	Al_3/AN/Propellant P1 6/54/40	135.80	53.43	56.13	35.44
7	Al_3/AN 10/90	117.26	48.33	52.43	31.92
8	Al_3/AN/Propellant P1 10/70/20	135.23	51.16	55.65	34.87
9	Al_3/AN/Propellant P1 10/50/40	137.31	54.39	59.00	38.60

Calculated impulses against aluminum Al_1 and propellant P1 contents were presented in Figure 3. The positive phase impulse of ammonal containing 6% of aluminum powder was equal to the impulse calculated for ammonal mixture of 3% of aluminum and 20% of propellant P1. Similarly, ammonal that contained 10% of aluminum showed the impulse equivalent to the impulse of ammonal mixture containing 6% of aluminum Al_1 and 20% of propellant P1. Similar value of the impulse was obtained for ammonal containing 3% of aluminum powder Al_1 and 40% of the propellant.

While in the case of ammonals without the propellant the increases of positive phase impulses were comparable with respect to aluminum content, the propellant P1 additive caused that at a constant propellant content increasing aluminum content in the mixtures did not follow the increase of the impulses – they were lower and lower. It was particularly visible for compositions containing 40% of propellant P1. The lower aluminum powder Al_1 content was the higher increases in impulses as the propellant P1 content in ammonal grew. The lowest increases in impulses were observed in the case of ammonals of 10% aluminum content.

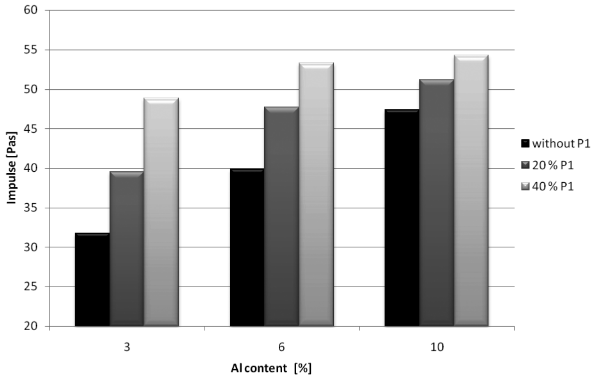

Figure 3. Positive phase impulses at 2 m for ammonals containing aluminum powder Al_1 and propellant P1.

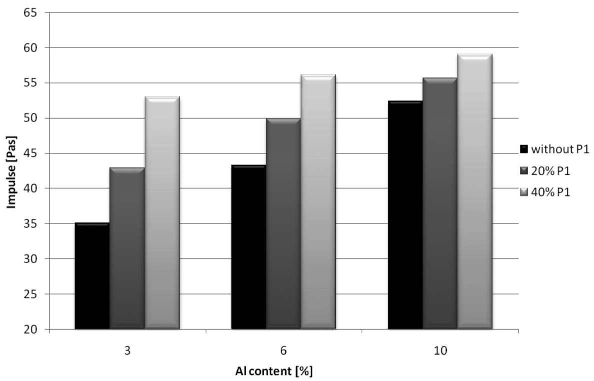

Figure 4. Positive phase impulses at 2 m for ammonals containing aluminum powder Al_3 and propellant P1.

Calculated impulses at 2 m distance for ammonals containing propellant P1 and flaked aluminum powder Al_3 were shown in Figure 4. Obtained values were slightly higher than these for ammonals containing flaked aluminum powder Al_1. The increases in impulses values along with the increases of propellant P1 content were similar to the ones for explosives described above. The addition of 20% of propellant P1 to ammonal containing 3% of aluminum powder Al_3 caused the impulse enhancement by 22%, whereas the addition of 40% of the propellant – enhancement by 51% in comparison to the reference ammonal was recorded. In the case of ammonals containing 6% of aluminum powder Al_3, the addition of 40% of propellant P1 caused impulse enhancement by 30% and for explosive containing 10% aluminum – by 12.5%.

Similar values for ammonals with the addition of propellant P1 and atomized aluminum powder Al_2 were presented in Figure 5. As the investigated mixtures were less sensitized by atomized aluminum powder Al_2 there was a lack of the result for ammonal containing 3% of the powder. The impulse values for ammonals containing 10% of aluminum powder Al_2 were slightly higher as compared with ammonals containing 10% of aluminum powder Al_1. Also in this case the lower aluminum powder content in explosive mixture was the higher increases in impulses were observed with the increase of propellant P1 content in the ammonals.

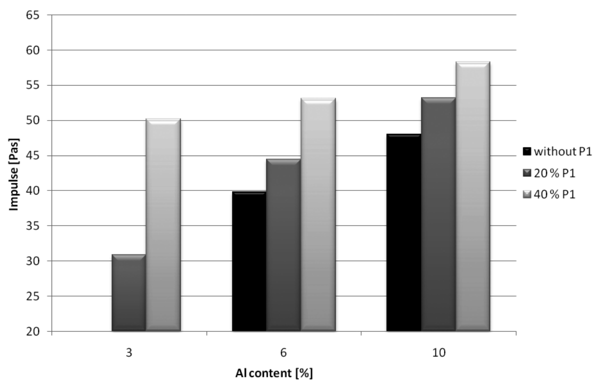

Figure 5. Positive phase impulses at 2 m for ammonals containing aluminum powder Al_2 and propellant P1.

The results of tests performed for ammonals with the addition of propellant P2 were presented in Tables 10 and 11. Tests were conducted for ammonals containing flaked aluminum powder Al_3 and atomized aluminum powder Al_2.

Table 10. Parameters of blast waves for ammonals containing flaked aluminum powder (Al_3) and propellant P2

No.	Explosive composition	Overpressure [kPa]		Impulse [Pa·s]	
		2 m	3 m	2 m	3 m
1	Al_3/AN/Propellant P2 3/77/20	87.42	38.32	37.17	20.41
2	Al_3/AN/Propellant P2 3/57/40	96.38	45.51	44.28	22.11
3	Al_3/AN/Propellant P2 6/74/20	100.99	44.06	43.94	21.53
4	Al_3/AN/Propellant P2 6/54/40	115.66	48.52	49.92	22.31
5	Al_3/AN/Propellant P2 10/70/20	127.53	48.23	50.31	22.08
6	Al_3/AN/Propellant P2 10/50/40	128.23	47.65	51.10	21.15

Table 11. Parameters of blast waves for ammonals containing atomized aluminum powder (Al_2) and propellant P2

No.	Explosive composition	Overpressure [kPa]		Impulse [Pa·s]	
		2 m	3 m	2 m	3 m
1	Al_2/AN/Propellant P2 3/77/20	59.09	29.18	25.07	17.29
2	Al_2/AN/Propellant P2 3/57/40	91.94	41.79	37.35	23.38
3	Al_2/AN/Propellant P2 6/74/20	91.83	42.72	39.72	20.85
4	Al_2/AN/Propellant P2 6/54/40	112.49	46.31	45.87	23.46
5	Al_2/AN/Propellant P2 10/70/20	121.43	47.57	49.63	21.91
6	Al_2/AN/Propellant P2 10/50/40	125.91	49.63	52.23	23.51

Calculated impulses for ammonals containing propellant P2 were presented in Figure 6 and 7. Both in the instance of ammonals with the addition of propellant P2 of 20% and 40% the lower impulses were gained for the mixtures containing aluminum Al_2. The higher increase in impulses was noted for explosives containing 3% of aluminum Al_2, when the propellant content increased from 20% up to 40%. Twofold increase of the propellant amount in the analogous explosive containing aluminum powder Al_3 gave the increase of the impulse about 19%. As the previously discussed explosives the lowest impulse enhancements were observed in the case of ammonals containing 10% of aluminum powder. Twofold increase of propellant amount resulted in 5% impulse growth in ammonal containing aluminum Al_2 and 1.5% in ammonal containing Al_3.

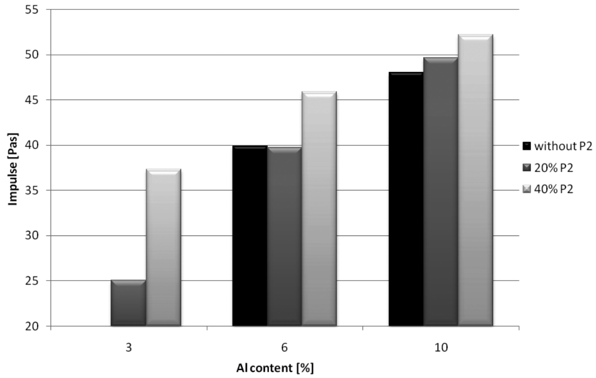

Figure 6. Positive phase impulses at 2 m for ammonals containing aluminum powder Al_2 and propellant P2.

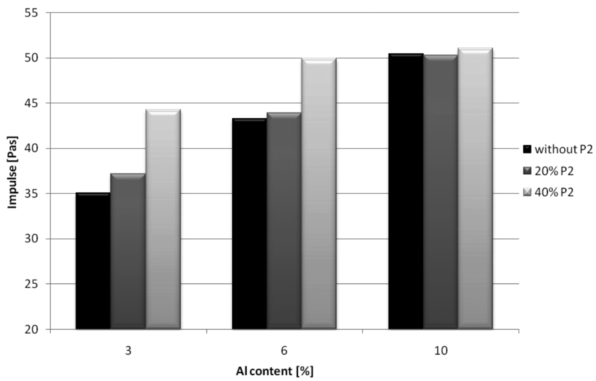

Figure 7. Positive phase impulses at 2 m for ammonals containing aluminum powder Al_3 and propellant P2.

Parameters of blast waves determined for ammonals containing aluminum powder Al_3 and propellant P3, having the lowest detonation parameters, were presented in Table 12. The results of the tests differed from the previously described explosives. The double base propellant P3 content in the explosive mixture resulted in 6% increase in positive phase impulse for ammonal containing 3% of aluminum powder, 7% increase for ammonal containing 6% aluminum and 5% decrease for ammonal containing 10% of aluminum powder.

Table 12. Parameters of blast waves for ammonals containing flaked aluminum powder (Al_3) and propellant P3

No.	Explosive composition	Overpressure [kPa]		Impulse [Pa·s]	
		2 m	3 m	2 m	3 m
1	Al/AN/propellant 3/77/20	83.88	37.06	39.52	22.30
2	Al/AN/propellant 3/57/40	78.18	40.03	41.94	25.32
3	Al/AN/propellant 6/74/20	92.83	43.29	43.21	28.15
4	Al/AN/propellant 6/54/40	101.79	45.66	46.20	28.21
5	Al/AN/propellant 10/70/20	118.08	50.70	52.95	31.47
6	Al/AN/propellant 10/50/40	112.38	46.85	50.22	30.40

Conclusion

Tested explosive mixtures contained two types of explosives: double base propellant, of detonation ability, and ammonals. That is why during detonation process competitive reactions proceeded. Detonation decomposition of double base propellant occured within molecule. Whereas explosive decomposition of ammonals started from exothermic decomposition of ammonium nitrate, the decomposition products reacted with aluminum and the sum of energies generated during the reactions decided the final effect.

Analysis of the detonation measurement results showed that the higher values of detonation velocities were obtained in the case of explosive mixtures containing propellant P1, which means higher nitroglycerine content in comparison with explosives containing propellant P3. Interesting results were obtained by changing the type of aluminum powder. Detonation velocities of ammonals that contained small (3% and 6%) amounts of flaked aluminum powder Al_1 were higher (Tables 3 and 4). The addition of a propellant completely changed situation – higher parameters were observed in the case of explosive mixtures containing aluminum powder Al_2. It appeared that explosive decomposition of double base propellant was a factor supporting the oxidation of aluminum powder in chemical reaction zone in detonation wave. The higher detonation velocity of the above mentioned explosives containing aluminum powder Al_2 resulted from the higher aluminum content in the powder [7]. Dominant reaction in detonation wave at 40% of the propellant was the decomposition of double base propellant. as well it strongly influenced the working capacity of the investigated explosives.

The results of the experiments showed that detonation parameters of ammonals could be adjusted in the wide range by the addition of double base propellants. The modified forms of ammonals can be applied in opencast mining. The application of double base propellants in mining blasting agents is an appropriate way of taking advantage of energy they posses.

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