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ALUMINUM PARTICLE SIZE EFFECT ON THE EXPLOSIVE CHARACTERISTICS OF HIGH EXPLOSIVE MIXTURES.

Seleet M. M. *, Ismail M. M. *, and Hashem M. E. *

ABSTRACT

The energy output of high explosives can be increased by the addition of certain metallic fuels to the explosive compositions. Aluminum is the most common fuel additive due to its high reliability and low cost as well as its high heat of combustion. In this paper, aluminized high explosive compositions based on RDX, TNT and aluminum powder (12, 40, 75 µm) were prepared on the Lab scale. In these compositions, the weight percentage of aluminum was 5, 10, 15, 20 and 25 %. Some of the explosive characteristics of the compositions were determined experimentally and theoretically. The effects of weight percentage and grain size on the characteristics of such compositions were recognized.

KEY WORDS

Explosives, Aluminized Explosives, Energized Explosives.

NOMENCLATURE

Q_V	Heat of explosion, kJ/kg
ΔHc	Heat of combustion at constant pressure, kJ / kg
V_O	Specific volume of gases, m^3/kg
τ	Delay time period, s
E	Activation energy, kJ/mol
K_w	Heat capacity of water
CJ	Chapman-Jouget state

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* Egyptian Armed Forces.

1. INTRODUCTION

In general the energy of high explosives as represented by the thermodynamic free energy ∆G can be increased by raising the contribution of the heat of explosion, “Q_v” [1-2]. In purely organic explosives, it is evident that the available heat of explosion “Q_v” is limited by the heats of combustion of the constituent fuel elements (carbon and hydrogen). A simple way to increase the value of “Q_v” is by adding, to the explosive, an elemental fuel which has a high heat of combustion [1-13].

If the heat of combustion of the fuel at constant pressure is “∆Hc” [kJ/mol], then the contribution of the fuel to the heat of explosion will be “∆Hc/m” [kJ/g] where “m” is the gram atomic mass of the fuel. Accordingly, the light elements of the periodic table provide the hottest fuels. Several metal fuels can be used with high explosives in order to increase their heat of explosion and performance [3]. However, aluminum is the most common fuel additive due to its higher availability and low cost as well as its relatively large heat of combustion.

In this paper different aluminized high explosive compositions based on RDX, TNT and aluminum powder (12, 40, 75 µm) were prepared on the Lab scale. In these compositions, the weight percentage of Aluminum was 5, 10, 15, 20 and 25 %. The weight ratio of the RDX to TNT in the all compositions was kept constant 60/40 in order to make a comparison with the reference explosive mixture compound B (RDX/TNT–60/40). Some of the explosive characteristics of the compositions were determined experimentally and theoretically. The effects of weight percentage and grain size on the characteristics of such compositions were recognized.

2. EXPERIMENTAL.

2.1. Samples Preparation

The prepared compositions were based on RDX, TNT and military grade aluminum powder (12, 40 and 75 µm). To guarantee the homogeneity of the prepared compositions, compound B explosive (RDX/TNT – 60/40) was used as source of both RDX and TNT. The weight percentage of aluminum powder was changed for every particle size as shown in Table (1). Compound B was melted in a suitable glass flask (300 ml) in a water bath and kept at 90 ºC for approximately 30 minutes. After complete melting of the explosive, the amount of aluminum was added gradually during mechanical stirring. Upon the complete addition of aluminum, the mixture was then stirred for a approximately 30min. The molten mixture was then poured into PVC tubes of length 200mm and internal diameter of 20mm, where the mixture begins to solidify. At this moment hand pressing of the mixture inside the PVC tubes started in order to avoid air bubbles and to get suitable density. Each PVC tube accommodates approximately 125 g of the prepared formulation and the rest of the formulation was kept for the rest of the tests. The prepared aluminized high explosive sample was accurately weighed.

2.2 Determination of Sensitivity to Impact

Sensitivity to impact test was carried out using IKA-MASCHINENBAU apparatus. The experiment was conducted using a weight of a constant mass (5 kg) and by changing the drop height. For each drop height, six consecutive trials were performed. The minimum height at which 100% initiations occurred was determined (the upper sensitivity limit); thus the energy required to initiate the explosives could be estimated. It is to be noted here that the explosive sample used in this test was taken from the casted mold, and grinded to the required grain size suitable for the test.

2.3. Determination of Sensitivity to Friction

Sensitivity to friction test was determined using BAM friction test apparatus (Chilworth Technology). The test was conducted in such a way that the loading on the pistil was varied and the percentage of initiation was determined. Ten consecutive trials were performed for each loading. The load at which 100 % initiation occurred was determined and thus the force in Newton could be estimated.

2.4. Determination of Sensitivity to Thermal Stimuli

The sensitivity to heat was obtained by determining the deflagration temperature for the prepared samples using deflagration test apparatus (Chilworth Technology). In determining the ignition temperature, a sample of the explosive was heated while the temperature was uniformly increased [5°C/min], up to the development of the explosive conversion. The ignition temperature was determined as the average of three parallel test samples.

2.5. Heat of Combustion Measurements

The measurements were carried out using an Autobomb (Sanyo Gallenkamp PLC) and Gallenkamp Autothemocalc II. This instrumentation offers the automatic calculation and manipulation of the data using a personal computer. The combustion of the samples was carried out in an atmosphere of oxygen at a pressure of approximately 25 bars. The calibration of the instrument and the measurements were carried out according to the standard procedures.

2.6. Measurements of the Velocity of Detonation

The measurments were carried out using “explomet-fo-multichannel” apparatus (KONTINITRO AG). This instrumentation has six synchronous timers which measure time intervals between the illumination of seven optical probes. For each timer, it displays the measured time in microseconds and calculates the velocity in m/s. To perform this test the explosive mixtures were casted into PVC tubes of internal diameter 20mm and length of 200mm. The densities of the explosive charges in (g/cm^3) are given in Table (2). On using this technique, Initiation was performed using standard number eight plain detonator and a suitable booster charge of pressed Hexogen. It is to be noted here that for each mixture two results were performed and the average result of the two was recorded.

2.7 Brisance Test

This test was carried out using the brisance testing unit according to KAST [14]. The testing unit consists of an easily movable steel cylinder which is placed onto a copper cylinder in a precisely centered position with the aid of a special guiding cylinder. In order to centre the test charge and to obtain a direct contact between the test charge and the steel cylinder without including any gaps, a special preload body is used. The individual components are arranged in a solid pulse-resisting steel frame to guarantee a good reproducibility of the experimental data recorded. The compression values of the copper cylinder are measured by means of a micrometer screw and used to determine the brisance value from appropriate tables.

3. RESULTS AND DISSCUSSIONS

3.1 Sensitivity to Impact Results

The results of this test are illustrated in Figure (1). It can be seen that the sensitivity of aluminized high explosives to impact decreases by increasing the weight percentage of the aluminum. Therefore, Al is a good additive for desensitization of sensitive high explosives. This may be attributed to the fact that aluminum is an inert material and acts as a flegmatizer. This result is in an agreement with reference 4. Also, it is shown that the formulations with the smallest particle size of Al (12μm) are more sensitive to impact, while formulations with the larger particle size of Al (40 and 75 μm) need more impact energy to be initiated. This may be attributed to the possibility that the hot spots, produced on the microscopic level, may lose some of its energy to the neighboring aluminum particle. So, the larger the aluminum particle size, the larger its thermal conductivity, and the larger the lost energy. Consequently, formulations with larger particle size need more impact energy, i.e. have lower sensitivity.

3.2 Sensitivity to Friction Results

The results are tabulated in Tables (6, 7, and 8) and illustrated in Figure (2). It is obvious that the sensitivity of aluminized high explosives decreased with increasing the weight percentage of Al [4]. This may be attributed to the fact that Al is an inert material and acts as a flegmatizer. Also, it is shown that the formulations with the largest particle size of Al used (75μm) are less sensitive to friction. This may be explained on the fact that any two surfaces, when rubbed together, generate high temperature. Adding an inert material, with high thermal conductivity as aluminum, will have a cooling effect, hence more applied load is required, i.e. with increasing the aluminum particle size, the cooling effect increases, and consequently the sensitivity decreases. From these results it is evident that addition of Al to explosives, besides providing high energy, has a markedly great effect in decreasing the sensitivity of explosives to friction (more than 2 times less sensitivity). Therefore, Al could be considered as a flegmatizer for sensitive high explosives.

3.3 Sensitivity to Thermal Stimuli Results

The results are illustrated in Figure (3). It is clear that the ignition temperatures of compound B and all the formulations of aluminized high explosives (different Al particle size) are very close to each other in the range of (226-239) °C. Thus, the addition of Al to the explosives has an insignificant effect on the ignition temperature of such explosives. However, this slight effect may be attributed to the high thermal conductivity of Al which could facilitate the ignition process. Also, it is evident that formulations based on Al (12μm) showed the highest sensitivity to heat. This may be attributed to the fact that smaller grain size of Al would provide larger surface area which may help in the ignition process of the formulations.

3.4 The Heat of Combustion Results

The results are illustrated in Figure (4). It is obvious that there is a significant increase in the heat of combustion with the increase in the weight percentage of aluminum. This increase ranges from 2-20% and may be varied depending on the conditions of the test and the characteristics of aluminum. However, the maximum weight percentage of aluminum to be added can be determined when other parameters, such as the specific volume of gases and the velocity of detonation, are considered.

Also, it is evident that the heat of combustion values are higher for the smallest particle size of the used Al (12µm). This may be due to the fact that with the smallest particle size of Al, the total available surface area will increase, consequently, the total number of superficial aluminum will increase. So, both the combustion heat and weight residue of solid products will increase.

3.5 The Velocity of Detonation Results

The results are illustrated in Figure (5). It can be seen that the velocity of detonation decreases with increasing the weight percentage of Al in the explosive formulation. For formulations containing 20 and 25 weight percent of aluminum of particle size 40 and 75 µm, the velocity of detonation is 30% less than the reference explosive. Aluminum will not directly represent a reaction partner in the detonation zone as the other explosive ingredients have already negative oxygen balance on their own. Therefore, the Al powder is reducing the reacting molecules. The Al particles, on their own, will be compressed by the shock or detonation wave but contribute to the reaction behind the detonation front. Consequently, the detonation velocities of aluminized compositions are less than that of non-aluminized compositions.

Also, it was shown that the detonation velocity of aluminized formulations based on the smallest particle size of used Al (12µm) are higher than those based on larger Al particle size at the same Al weight percentage. This may be due to the fact that smaller particle size of Al could increase the density of explosive formulation which results in an increase in the velocity of detonation.

3.6 The Brisance Test Results

Only samples containing Al (12µm) were tested. The results are presented in Table (2). It can be seen that the brisance of the tested samples slightly increased (3-7 %) up to a weight percentage of 15 % Al, then the brisance started to decrease again. The slight increase in brisance may be attributed to the high energy output of the exothermic reactions in presence of Al. This slight increase manifests itself by the slight decrease in the velocity of detonation.

The slight decrease in brisance (2-3 %) for samples containing more than 15% Al may be explained by the fact that a sharp decrease in the velocity of detonation could not be compensated by the high exothermicity of the reactions. In other words, in this regime (high percentage of Al > 15%) the detonation velocity has the dominant effect on the brisance.

4. CONCLUSIONS

In general, the presented work has revealed the following important conclusions:

1. The processing and casting of the aluminized explosives were reasonable until 15% Al weight percentage. When the weight percentage of Al exceeds 15% the processing was more difficult. This difficulty was not recognized in case of using (12μm) particle size Al even at 25% of Al.
2. Addition of Al (12, 40 and 75 μm) decreases sensitivity to impact and friction compared with the reference explosive compound B. This decrease is proportional to Al content. Therefore, Al with certain particle size could act as a flegmatizer when added to explosives.
3. The aluminized formulations based on Al (12μm) are more sensitive to mechanical stimuli than those based on 40 and 75μm. this may be due to the increase in the surface area of the particles and consequently an increase in the entrapped air which acts as hot spots upon initiation.
4. The addition of Al to the explosives has no significant effect on the ignition temperature of such explosives. However, Formulations with different content of (12μm) particle size Al showed the highest sensitivity to heat.
5. Aluminum has a great effect on increasing the heat of combustion/explosion of the explosives. Also, the heat of combustion increases with the decrease of particle size of the used Al.
6. The velocity of detonation decreases by increasing the Al content in the explosive formulation. The detonation velocities of aluminized formulations based on the smallest particle size of used Al powder, namely (12μm) are higher than those based on larger Al particle size.
7. The brisance of the aluminized high explosives was slightly increased (3-7 %) up to 15 % Al, then started to decrease again.

Thus from the point of view of processing, performance, sensitivity, and cost, the optimal weight percentage of aluminum must be approximately 10-15%.

REFERENCES

[1] Turnbull J. H. and Walter K., "The Thermochemistry of High Explosives", Shrivenham, (1982).

[2] Nicolich S., Doll D. and Gunger M., "Recent Development in Reduced Sensitivity melt pour explosives",34 rd International Conference of ICT, Karlsruhe, Germany, (2003).

[3] Drezen E. L., "Phase Changes in Metal Combustion", Aerochem Research Laboratory, USA, (2000).

[4] Held M., "Aluminized High Explosives Charges", 33 rd Annual International Conference of ICT, Karlsruhe, Germany, (2002).

[5] Youhua Q. and Shiquan L., "Study on Dispersed Combustion Characteristics of Al Powder by the Explosion of Central Charge", 33rd International Conference of ICT, Karlsruhe, Germany, (2002).

[6] Brousseau P. and Cliff M. D., "The Effect of Ultrafine Al Powder on the Detonation Properties of Various Explosives", 32 nd Annual International Conference of ICT, Karlsruhe, Germany, (2001).

[7] Ramaswamy A. L. and Kaste P., "Combustion Modifiers for Energetic Materials", 34Th International Conference of ICT, Karlsruhe, Germany, (2003).
[8] Ishida T. and Kato Y., "Detonation Pressure of Aluminized Explosives by Means Of Shock-Induced Polarization", 23rd International Conference of ICT, Karlsruhe, Germany, (1992).
[9] Maranda A. and Stanislaw, "Behavior of Al and TNT in the Detonation Wave of Ammonium Nitrate Explosives", 27Th International Conference of ICT, Karlsruhe, Germany, (1996).
[10] Trzcinski W. A. and Paszula. J, “Confined Explosions of Aluminized High Explosives", 31st International Conference of ICT, Karlsruhe, Germany, (2000).
[11] Langer G., "The Influence of Particle Size of A.P and Al on the Performance of Underwater Explosives", 34th International Conference of ICT, Karlsruhe, Germany, (2003).
[12] Sirringhous U. and Wild.R, "Influence of Al /AP on the Performance of Underwater Explosives", Propellants, Explosives, Pyrotechnics 24,140-143, (1999).
[13] Alexandre L., "Expertise of Nanometric Al Powder on the Detonation Efficiency of Explosives", 32ndAnnual International Conference of ICT, Karlsruhe, Germany, (2001).
[14] SuĆeska M. , “Test Methods for Explosives”. Springer-Verlag, New York Inc., (1995).

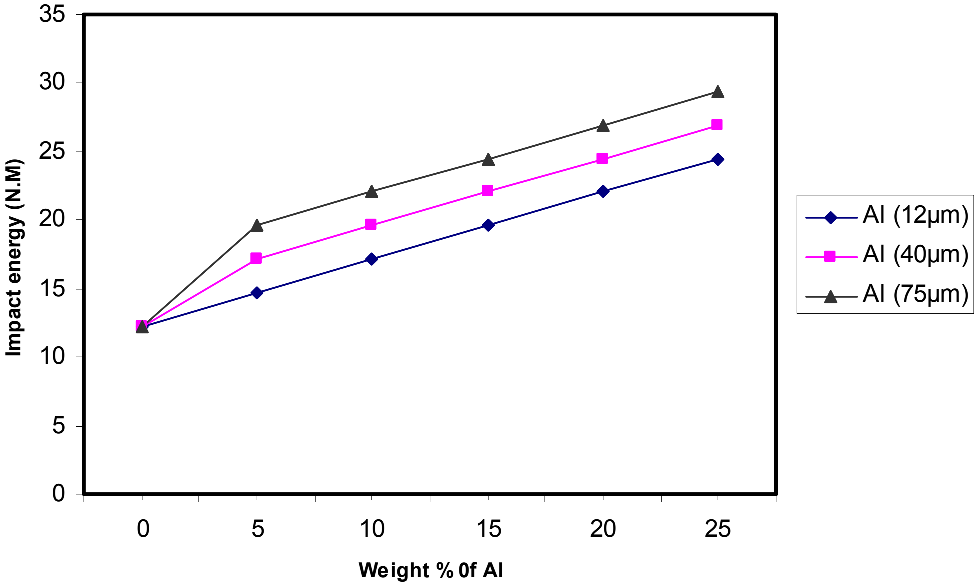

Fig. 1. Impact energy of 100 % initiation vs. aluminum content of aluminized mixtures for different particle size.

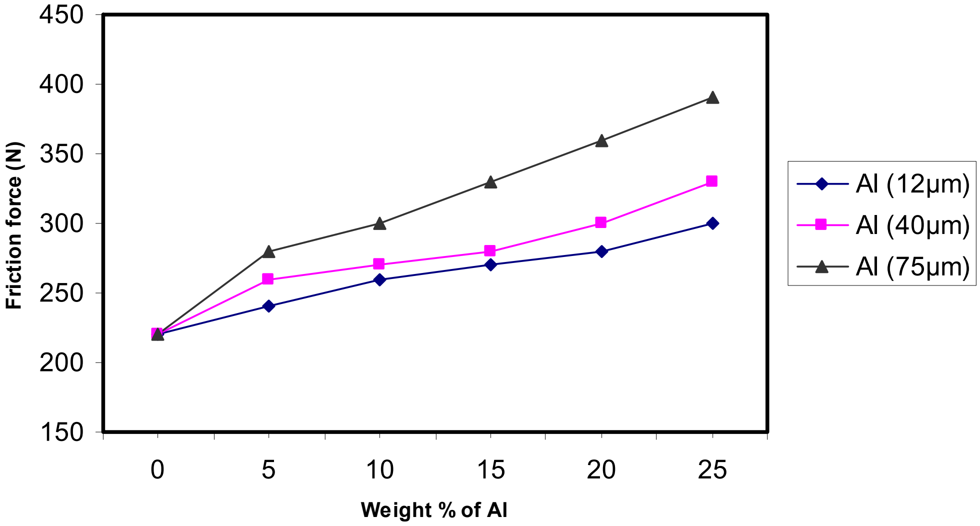

Fig. 2. Minimal applied load of 100 % initiation vs. aluminum content for aluminized mixtures of different particle size.

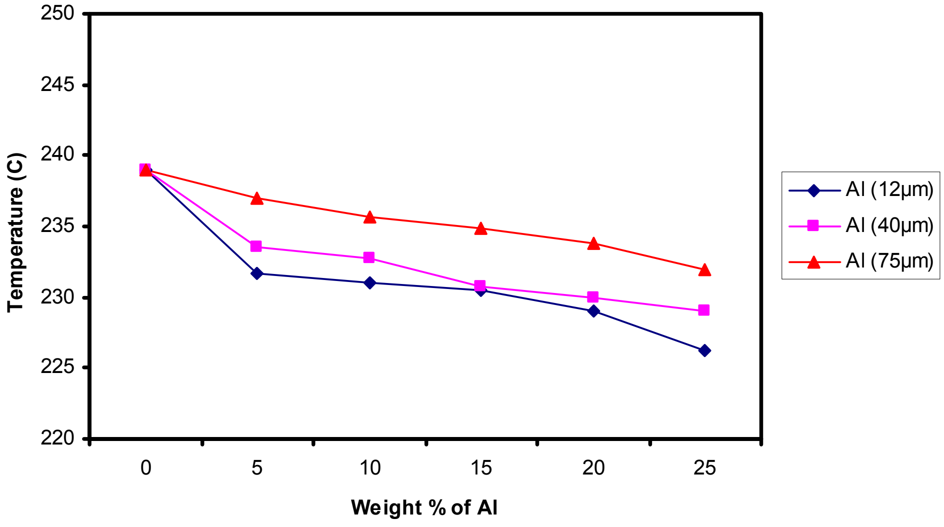

Fig. 3. Ignition temperature of different aluminized high explosive formulations vs. aluminum content for different particle size.

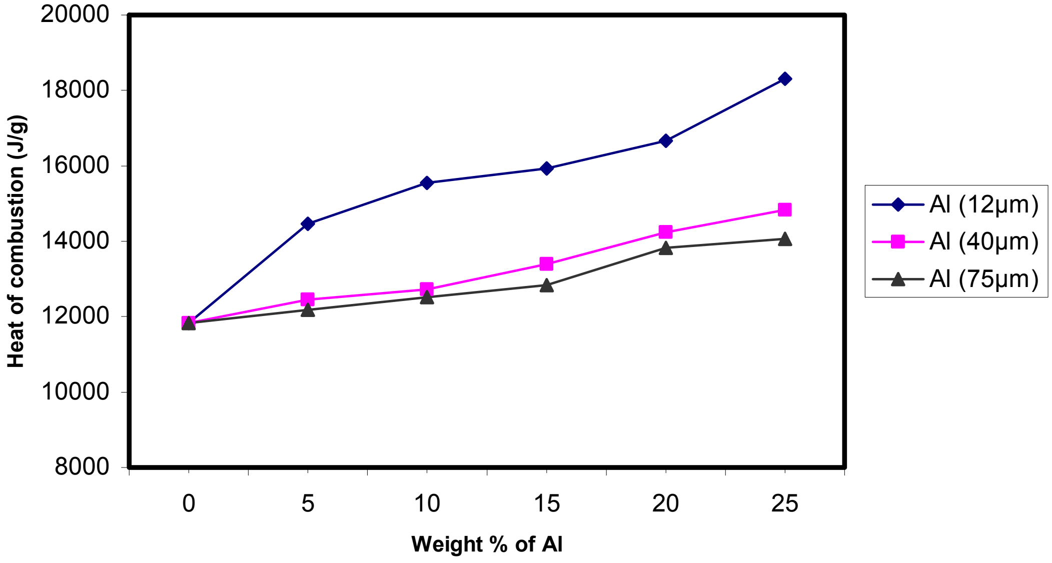

Fig. 4. Variation of combustion heat, of aluminized mixtures, with the aluminum content (wt %), for different particle size.

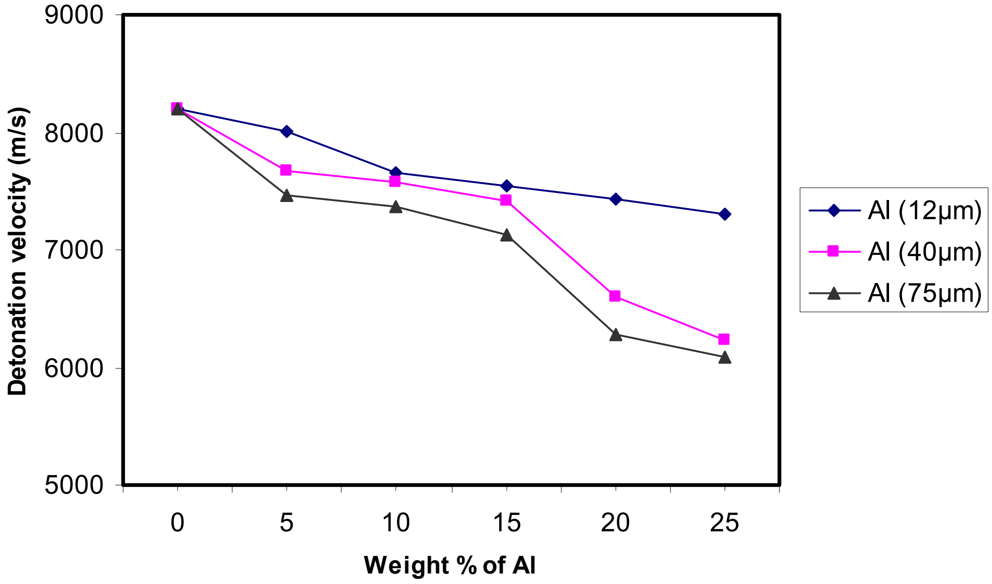

Fig. 5. Variation of detonation velocity, of aluminized mixtures, with the aluminum content (wt %), for different particle size.

Table 1. Compositions of prepared aluminized mixtures.

Sample	Al particle size, (μm)	Weight percentage			Density (kg/m^3)
		RDX	TNT	Al	
S_0	-	60	40	-	1600
S_1	12	57	38	5	1680
S_2		54	36	10	1700
S_3		51	34	15	1800
S_4		48	32	20	1850
S_5		45	30	25	1900
S_6	40	57	38	5	1650
S_7		54	36	10	1680
S_8		51	34	15	1700
S_9		48	32	20	1750
S_{10}		45	30	25	1800
S_{11}	75	57	38	5	1620
S_{12}		54	36	10	1650
S_{13}		51	34	15	1680
S_{14}		48	32	20	1700
S_{15}		45	30	25	1750

Table 2. Brisance of aluminized mixtures containing aluminum of particle size 12μm.

Sample code	Al %	Pressure (kPa)
S_0	0	1059
S_1	5	1088
S_2	10	1127
S_3	15	1136
S_4	20	1039
S_5	25	1023