



Effect of Tungsten on Aluminized Melt Cast High Explosive Formulations

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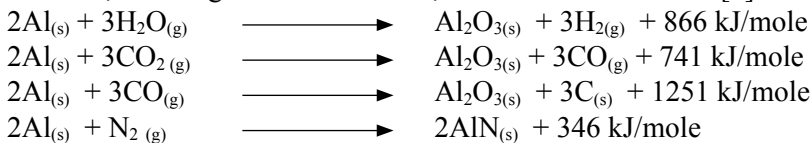
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Abstract: Aluminized 2,4,6-trinitrotoluene (TNT) based, melt-cast, high explosive compositions are widely used in warheads. These compositions offer a blast effect over a larger period due to the secondary combustion of aluminum. During recent times tungsten based explosives have been reported for lethality at close range to avoid collateral damage in low intensity conflicts (LIC) and find application in shaped charges to enhance their penetration capability. This paper reports findings on tungsten-based, melt-cast, explosive formulations. The compositions were prepared by substituting aluminum with tungsten in the reference aluminized, high explosive formulation. The compositions were characterized for their sensitivity to mechanical/shock stimuli, velocity of detonation (VOD) and blast performance. The study reveals that the impact sensitivity remains comparable on incorporating 10% tungsten at the cost of aluminum whereas an increase in tungsten content to 20% leads to an increase in impact sensitivity. However friction sensitivity and shock sensitivity remained more or less unchanged. The velocity of detonation (VOD) of tungsten-loaded, aluminized formulations is found to be comparable to the standard aluminized formulation. The peak over pressure of tungsten-based formulations is lower than the reference, aluminized composition at close range but is almost unchanged at long range. The impulse of tungsten-based formulations is also lower than the reference, aluminized composition. The reduction in impulse at close range is substantial on replacing 10% aluminum with inert tungsten.

Keywords: tungsten, MOUT, low intensity conflict, peak over pressure, impulse

Introduction

Aluminized, TNT-based, melt-cast, high explosive compositions find application as high explosive fillings in various blast warheads and projectiles due to the overall enhanced energy release over extended time. On initiation of an aluminized explosive composition the reaction takes place in two stages. The detonation products of the CHNO type of explosive (CO, CO₂, H₂O, N₂ etc.) at high temperature react with the aluminum, producing energy due to the exothermic reaction. The basic chemical processes involving Al in the explosion phenomenon, resulting in the blast effect, are summarized below [1]:



(the subscripts “s” and “g” refer to the solid and gas phases, respectively).

In air-blast, up to 20% addition of aluminum is useful or adds to the destructive power. The addition of aluminum powder to high explosive compositions increases the value of the impulse. Other metals like titanium, zirconium etc. may also be added to aluminized compositions in order to achieve incendiary and localized effects. Metals like molybdenum, zirconium, titanium and tungsten have evinced interest for compositions for achieving localized effects accompanied by a reduction of the detonation/blast parameters. Among these metals, fine zirconium and titanium powders are pyrophoric in nature and pose hazards. Tungsten metal is a better choice due to its high density and having an inert nature. Several researchers have reported high density explosive formulations incorporating tungsten powder. Weinland et al. [2] have reported that tungsten improves the impulsive effect from the explosive to surrounding bodies. Spencer et al. [3] have patented a high density tungsten-loaded, castable explosive, consisting of 50-90 wt% tungsten powder, 3-40 wt% of a high energy explosive, 3-16 wt% of an energetic binder, and 2-10 wt% aluminum powder, as having significant cost advantages over tungsten case and/or lined penetrator warheads. Hisaatsu Kato et al. [4] studied shaped charges composed of an inner layer of tungsten loaded with high density PBX and an outer layer of high velocity PBX. The inner layer PBX compositions were loaded with 20, 40 and 60% of tungsten powder. It was observed that the initial jet velocity and jet penetration velocity in the target plates were largely increased due to the effect of the overdriven detonation in the tungsten-loaded, high density explosive, thereby improving the performance of a shaped charge.

The above research work has evinced interest in the field of tungsten-based,

melt-cast, explosive formulations. A systematic study has been initiated during the present work to observe the effect of incorporating tungsten powder in explosive formulations by substituting aluminum in a standard, melt-cast, aluminized explosive formulation with tungsten. In the present paper, the loading of tungsten powder in the formulations has been restricted to a maximum of 20%. The formulations have been characterized for their sensitivity to mechanical/shock stimuli, velocity of detonation (VOD) and blast performance. The research is aimed at arriving at optimized, melt-cast formulations and generating initial data for exploring them in various applications, for example for defeating structures by high-order shock transfer and for the development of munitions for military operations in urban terrain (MOUT) etc.

Experimental

Materials

Aluminum powder (particle size 15 μm) and tungsten powder (particle size 25-30 μm) were obtained from indigenous sources. TNT and RDX, available from a production unit, were used during this work. Trimodal RDX has been used in the formulations. The distribution of particle sizes of the RDX used is given in Table 1.

Table 1.

Sl No.	Particle size of RDX (μm)	Percentage (%)
01	300-500	25
02	75-300	40
03	30-75	35

Explosive formulations

A combination of 15 μm aluminum and 25-30 μm tungsten was used to obtain homogeneous mixtures of metals. The formulations are summarized in Table 2.

Table 2.

Formulation	RDX	TNT	Al	W
Reference	40	30	30	--
RTAW-1	40	30	20	10
RTAW-2	40	30	10	20

Processing

The compositions were processed by the standard, melt-cast technique involving addition of RDX/TNT (60/40) to molten TNT with continuous stirring. This was followed by the addition of a combination of aluminum powder and tungsten powder to the melt with stirring in separate installments. The mixture was stirred for about 10-15 minutes and then transferred to a mould. After cooling to ambient conditions, the charge was removed and machined to the required dimensions.

Test / Characterization methods

Determination of sensitivity characteristics

The impact sensitivity of the explosive compositions was determined by the fall hammer method (2 kg drop weight), applying the Bruceton staircase approach. The results are reported in terms of a statistically obtained 50% probability of explosion (h_{50}). Friction sensitivity of the compositions was determined on a Julius Peter's apparatus by the standard method up to 36 kg load. Two samples for each composition were tested for confirmation of the friction sensitivity. Shock sensitivity was determined by the standard card-gap test, using cellulose acetate sheet as the attenuator and a CE pellet (tetryl) as the donor charge. Five charges were fired for confirmation of the value of the shock sensitivity.

Determination of the velocity of detonation (VOD)

The VOD was determined by the ionization probe technique. The pin-type ionization probes (twisted enamel copper wire), were located at predetermined points, and an oscilloscope (YOKOGAWA DL9140, 1 GHz) was used for data acquisition.

Determination of blast parameters

The blast parameters were measured at various distances from the point of explosion using free-field, blast-pressure transducers (piezoelectric gauges, M/S PCB Piezotronic INC, USA,) and the data was recorded on an oscilloscope. The mounting of the gauge was done with the help of G.I. Pipe. The gauges and sensing elements used for the experiments (rise time = 1 μ s, resolution = 0.005 PSI and linearity = 1% FS) were of special construction. The sensing element in the transducer was a quartz crystal with an inbuilt driving amplifier in an aerodynamic design. The quartz sensor had two pressure sensitive axes. The aerodynamic design of the transducers eliminates the stresses on the

crystal on the undesired axis without disturbing the field conditions. The response time of the transducer was 1 μ s. These transducers are acceleration compensated and have an inbuilt amplifier. The charge amplifier converts the charge output from the transducer to a voltage. The constant current source for the amplifier keeps the sensitivity of the transducer almost constant irrespective of changes in the supply voltage and eliminates the effect of the long cable. The gauges were connected to the multi-channel, high-speed data acquisition system with the help of co-axial cable through cable compensating units and an ICP constant current power supply unit (24 V, 2-20 mA). This enabled the operation of the system to be monitored with the meter, which detects faults such as cable shot or open and problems connected with the transducer/amplifier. The resonant frequency of the transducer was 500 kHz, which dictates the maximum usable frequency to be transmitted to the cable.

Cast, high explosive charges were mounted on a wooden batton and placed at a height of 2 m with the help of a wooden stand. The piezoelectric gauges were placed at 2, 3 and 4 m distance, aligned from the centre of the charge in an axial plane. The explosive charges were detonated by an RDX/Wax (95/5) booster in combination with an electric detonator. On detonation of the charge, the blast wave is generated and, as it crosses the blast pressure gauge, the piezo-electric crystal develops a charge which is amplified. The line power unit decouples the signals from the bias voltage and a pressure-time curve is obtained as a display on the data acquisition system. A multichannel, high speed data acquisition system, with a maximum sampling rate of 100 ns, was used to record the shock wave, pressure-time history. The system was PC based. Software had been developed to compute peak over pressure, time duration, shock arrival time, positive/negative impulse and shock wavefront velocity.

Results and Discussion

Sensitivity and explosive characteristics

The theoretical maximum density (TMD) of the formulations was computed using the relation $TMD = 100 / (R/d_1 + T/d_2 + A/d_3 + W/d_4)$. In this relation R, T, A and W are the wt% of RDX, TNT, aluminum and tungsten respectively in the HE compositions, and d_1 , d_2 , d_3 and d_4 are the crystal densities of RDX, TNT, Al and tungsten respectively. The results of the characteristics determined for these formulations are given in Table 3.

Table 3.

Formulation	Density (kg/m ³)	TMD (kg/m ³)	Percent of TMD	VOD (m/s)	Sensitivity		
					Impact h ₅₀ (m)	Friction (kg)	Shock (GPa)
Reference	1830	1920	95.31	7400	0.78	36	2.5
RTAW-1	1970	2050	96.09	7300	0.82	36	2.3
RTAW-2	2150	2190	98.17	7250	0.54	36	2.1

It may be inferred that a density of about 95, 96 and 98% of TMD has been achieved for the cast charges of Reference, RTAW-1 and RTAW-2 compositions, respectively. The density of tungsten-based charges is also somewhat higher than that of aluminized composition. This can be attributed to the relatively high density of tungsten compared to aluminum. The h₅₀ values determined remained unchanged on addition of 10% tungsten (RTAW-1) to the reference composition. However, increasing the tungsten content to 20% led to a decrease in h₅₀. This may be attributed to the fact that it acts as grit due to its hardness. The friction sensitivity of the formulations remained unaffected. The shock sensitivity values of the reference (without tungsten), RTAW-1 (with 10% tungsten) and RTAW-2 (with 20% tungsten) compositions are about 2.5 GPa, 2.3 GPa and 2.1 GPa respectively, which are more or less unchanged.

Velocity of detonation (VOD) and blast performance

A marginal decrease in the velocity of detonation was recorded on replacement of aluminum powder with tungsten powder, which can be attributed to the highly inert nature of tungsten. The reported VOD is an average of three trials for each formulation.

Two charges, each of 1.0 kg mass and having L/D ~1, were prepared for the three formulations and the charges were evaluated for peak overpressure and impulse at close range (scaled distance ≤ 4 m/kg^{1/2}) and at long range (scaled distance > 4 m/kg^{1/2}). The plots of P_{max} vs. scaled distance and impulse vs. scaled distance are shown in Figure 1 and Figure 2, respectively. It can be seen from the curves in Figure 1 that the peak over pressure of the tungsten-based formulations RTAW-1 and RTAW-2 are lower than that for the reference formulation, i.e. the aluminized composition, at close range but are almost equal at long range. This can be attributed to the reduction in intensity of the blast wind effect due to absorption of heat by tungsten during the detonation phase, and thus reduction in the kinetic energy of the gaseous products. P_{max} for the RTAW-1 and RTAW-2 formulations are practically identical.

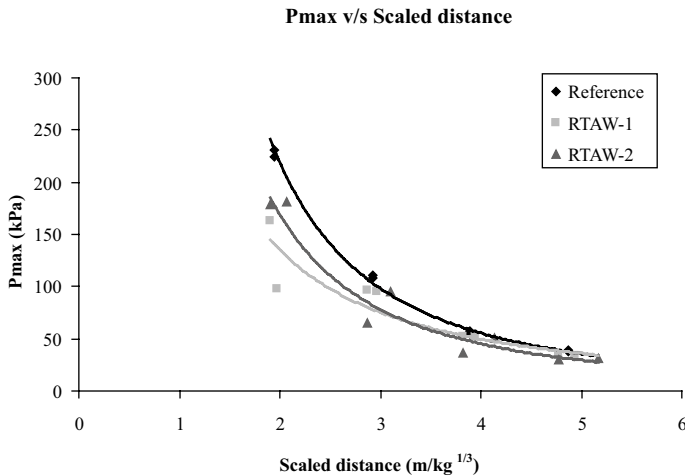


Figure 1. P_{\max} (kPa) vs. scaled distance (m/kg^{1/3}).

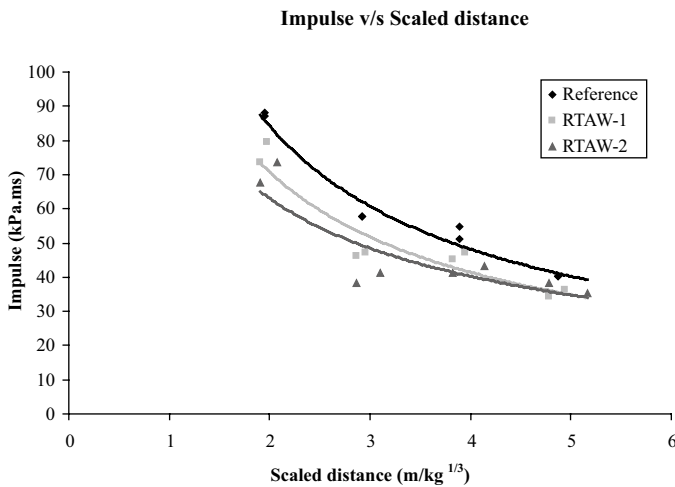


Figure 2. Impulse (kPa·ms) vs. scaled distance (m/kg^{1/3}).

From Figure 2, it is discernable that the impulse of the tungsten based formulations RTAW-1 and RTAW-2 are also lower than for the reference formulation i.e. the aluminized composition. The reduction in impulse at close range is substantial on replacing 10% aluminum with inert tungsten (RTAW-1). Increasing the tungsten content to 20% (RTAW-2), shows only a marginal reduction compared to RTAW-1. It can also be seen that the decrease in impulse of tungsten-based formulations is more gradual and tends to merge with the

reference at long range. This trend can be attributed to the high inertia of tungsten particles.

Conclusion

This study reveals that tungsten does not have much effect on the sensitivities of compositions except for a decrease in h_{50} for the 20% tungsten containing formulation. The VOD of tungsten-based compositions is marginally reduced as compared to an aluminized composition. The blast effects i.e. P_{\max} and impulse, are reduced on substituting aluminum with tungsten at short range. However the decrease in these parameters in the tungsten compositions is gradual compared to the sharp reduction in aluminized formulations. These trends can be attributed to the high density and inertia of tungsten particles. The study suggests that further development of tungsten based compositions would find application in attaining localized explosive effects.

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