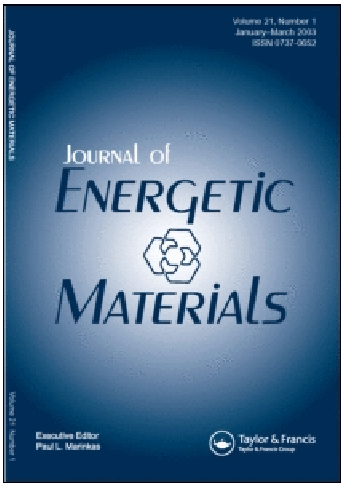

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THE EFFECT OF SOME ADDITIVES ON THE CLOSED BOMB BURNING AND IGNITABILITY OF RDX/TNT (60/40)

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ABSTRACT

The burning and ignition properties of Composition (Comp) B are studied so that formulation modification could be made that would reduce gun projectile in-bore thermal explosions. Comp B first burns on its surface like a gun propellant; then, at a pressure near 100 MPa, a sudden breakup burning phase develops. New surface area is created at a phenomenal rate, and this is the cause of the catastrophic reaction rates that it can experience. Coating its RDX constituent with a protectant significantly slows this reaction rate. It appears to do this by inhibiting the rate at which the RDX is released from the TNT matrix for burning, probably by infinitesimally delaying the ignition of the RDX in the particle ignition sequence. A new test that evaluates explosive ignitability as a function of pressure and energy indicates that an RDX protective coating may also increase the level of thermal ignition and delay the onset of a thermal explosion. Collectively, these three desirable properties, caused by a single modification, may significantly reduce the incidence of in-bore explosions where casting flaws would have precipitated this event.

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INTRODUCTION

Composition (Comp) B is a powerful explosive; however, it cannot be used in the projectiles of new high performance guns because of its susceptibility to in-bore thermal explosions. The cause is attributed to the presence of an occasional casting flaw which under the stress of launch induced set-back forces causes the explosive to break up. Then in crushed, broken, or moving material, adiabatic compression and/or friction would stimulate a thermal ignition; and, because Comp B burns so rapidly, the projectile violently ruptures before it can exit the gun barrel. This premature problem, although occurring at an unacceptable level, is a rare event. This suggests that this hazard is a borderline result that is started when the right condition or combination of conditions are present. Techniques that would minimize the creation of casting flaws are being investigated. This study, however, is concerned with modifying the properties of Comp B to reduce further the likelihood of an in-bore explosion from Comp B castings that might escape the gauntlet of improved manufacturing procedures.

A threefold approach is being pursued. The explosive's mechanical properties should be improved. Even a modest improvement would favorably shift the relationship between casting flaws and launch induced set-back forces. When breakup still occurs, the minimum amount of heat energy needed to cause thermal ignition should also be increased. Then, in situations where a thermal reaction might still be initiated, the speed of burning should be slowed so that a safe out-of-bore explosion would result from the in-bore thermal ignition. Simultaneously, improving each of the contributory factors (castability, strength, ignitability, and burning speed), may reduce the incidence of in-bore explosions sufficiently to permit the use of a modified Comp B in the advanced weapon systems. The results of previously reported work suggest that some of these goals are attainable.

A study of the burning properties of Comp B and TNT [1] indicated that these materials break up during the combustion process and burn on the surface of their fragmented parts. The breakup of TNT, a major constituent of Comp B, takes place along cleavage paths at the boundary of neighboring crystals [2]. The size, shape, and number of the fragments is determined by the casting procedure. The wax additive, which is used in standard Comp B does not interact with its TNT component to modify or change its burning behavior. Unlike TNT, Comp B initially burns on its surface like a gun propellant [3]; then, at a pressure near 100 MPa, a sudden transition to a breakup burning phase takes place. New surface area is created at a phenomenal rate, and this is the cause of the catastrophic reaction rates that Comp B can experience. This transition appears to be too sharp and sudden to be explained only by breakup or melting of the TNT binder. The heat-of-reaction of HMX (an explosive similar in structure to RDX) increases, sharply, by 102 calories/g at 30 MPa static pressure [4]. A similar response for RDX could contribute toward Comp B's sharp transition to the breakup burning phase. The presence of the standard wax additive (1% added to the melt) in the 60/40 mixture of RDX/TNT significantly slows the burning of the reactive constituents during breakup. It appears that it does this because some of the wax (insoluble in TNT) migrates to the surface of the RDX particles where it inhibits the reaction rate. Coating the RDX particles with various protectants is, therefore, the approach being taken here to slow the reaction rate of Comp B.

It is believed that in-bore explosions begin with a finite heat source (hot-spot), in powdered or broken material that is being subjected to pressure. A test developed to simulate these conditions [5] shows that Comp B is more sensitive to thermal ignition in a projectile launch environment than, individually, are its constituents (RDX/TNT). Heat transfer in relation to physical properties cause this, suggesting the possibility that an RDX protectant may serve the double purpose of increasing the minimum energy of ignition in addition to slowing the deflagration rate of Comp B.

PROCEDURE

This work is concerned primarily with protective coatings for RDX that would reduce the deflagation hazard of Comp B, but, since this hazard is primarily related to casting flaws the burning behavior of Comp B with TNT modifiers, which may reduce their creation is also examined. Small quantities of hexanitrostilbene (HNS), a mild explosive or polysulfone can provide a fine random crystal structure to the TNT matrix that can improve cast quality [6]. The polysulfone also has the potential for functioning as a protective coating for the RDX. In addition, under field conditions, Comp B can exhibit exudation problems that can be controlled by an anti-exudate, a 50/50 mixture of cellulose propionate and plasticizers [7,8]. Its effect on Comp B burning is also examined. The explosive portion of all the formulations tested is a 60/40 mixture of class 1 RDX (177 μm) and TNT except for one formulation where an RDX with a smaller particle size (105 μm) was used. The additives are added as a percentage of the original RDX/TNT mix. Single effects were first obtained, and then increasingly interactive multiple effects, by introducing additives to the TNT melt and/or as protective coatings of the suspended RDX. The general formulations are listed in Table 1.

Specimens were prepared for closed bomb testing in the form of cast solid cylinders and crushed powder. The cylinders were 2.54 cm in diameter and the lengths were adjusted to produce a constant 32.00 gram mass. Crushed samples (27.00 grams each) were obtained from cast specimens which had been broken into a fine powder with gentle impact blows. Three g and one g, respectively, of class 7 black powder were used to initiate the solid and

TABLE 1. Additive in 60/40 Mixtures of RDX/TNT

Sample no.	Additive in TNT	Additive on RDX
84-018	None	None
84-023	1% Petrolite Wax	None
84-066	1% Petrolite Wax, 0.12% HNS	None
84-080	1% Petrolite Wax, 0.12% HNS, 0.5% Anti-Exude	None
84-072	1% Petrolite Wax, 0.12% Polysulfone	None
84-082	0.12% HNS, 0.5% Anti-Exudate	1% Petrolite Wax
84-083A	0.12% HNS	1% Polycarbonate 0.5 Anti-Exudate
84-025	0.5% Anti-Exudate	1% Polysulfone
84-026	0.5% Anti-Exudate	0.5% Polysulfone
84-038	None	1% Cellulose Propionate, plasticized
84-039	None	1% Polysulfone
84-083B*	None	1% Polysulfone*

*Fine particle RDX.

crushed samples. The black powder was ignited with an M-100 electric match. Each specimen was burned in a 178 cc closed bomb producing pressure-vs-time data in response to the output of a piezo pressure transducer. The data was recorded with a Nicolet Explorer III Digital oscilloscope and stored on magnetic discs.

The results of these tests are presented in the form of dp/dt vs. pressure. A graphical example of the data is shown in Figures 1 and 2. Both compare the burning of standard Comp B (dotted curve) with a polysulfone-coated RDX formulation for the solid and crushed versions, respectively. In Table 2, an attempt is made to

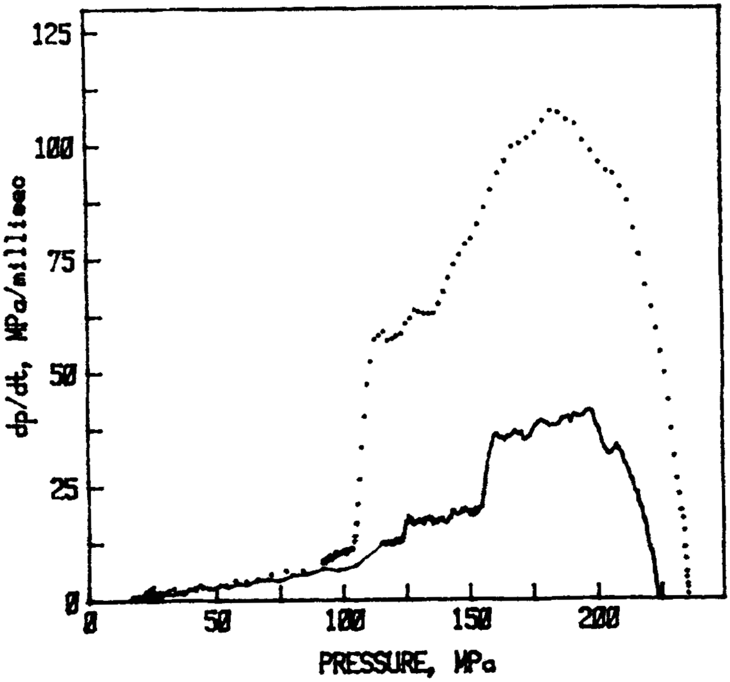

Fig. 1 - Comp B vs. polysulfone coated RDX/TNT (solid)

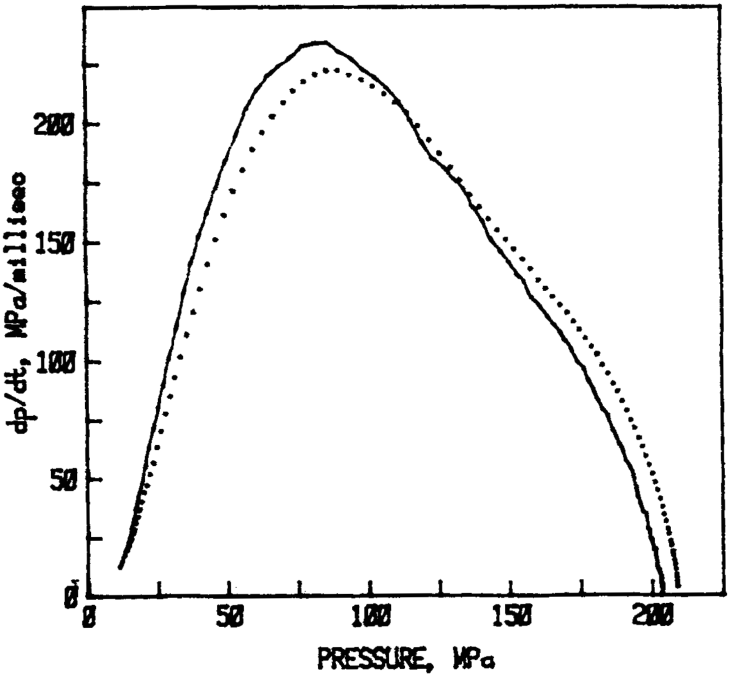

Fig. 2 - Comp B vs. polysulfone coated RDX/TNT (crush)

Table 2. Closed Bomb Results

Sample no.	Max Pressure, MPa		Max dp/dt MPa/ms		Pressure at max dp/dt, MPa		Area MPa^2/ms	
	Solid	Crushed	Solid	Crushed	Solid	Crushed	Solid	Crushed
84-018	234	210	153	255	186	93	15056	34320
84-023	234	209	106	217	188	92	9991	28016
	235	211	106	227	187	96	10398	32441
84-066	250	210	161	290	177	88	17513	37515
	225	209	162	241	162	89	16947	32718
84-080	213	210	119	240	174	90	10112	31854
	212	210	125	258	168	90	10479	33265
84-072	218	213	118	244	168	106	10592	34853
	221	212	113	170	174	118	10804	24490
84-082	212	209	60	230	168	85	4954	31849
	197	212	47	247	160	88	3613	31925
84-083A	214	210	58	244	168	87	5051	31746
	215		62		185		5244	
84-025	219	212	41	249	187	83	3106	33933
	224	204	41	230	196	79	3384	28812
84-026	222	209	83	252	187	80	7034	34122
	219		84		178		7107	
84-038	225	204	49	272	186	90	3780	34143
	226	207	49	239	185	91	3652	31551
84-039	230	204	53	292	189	92	4818	35924
	231	211	54	220	119	114	4408	31763
84-083B	232	200	40	250	177	74	3960	33161
	226	207	34	219	191	93	3113	29436

reduce all the test data to a few pertinent values for comparison. These include the maximum pressure (an indication of the energy provided by the reaction), the maximum dp/dt (representing the greatest surface area exposed for burning), and the pressure at the maximum dp/dt (related to the fraction of material consumed). However, the most important value listed in the table is the measurement of the area under the entire curve. When all things are equal such as mass, composition, and vessel volume, each dp/dt value represents the surface area taking part in the reaction in relation to the volume fraction of sample burned. A measurement of the area under the curve provides a number that can be used to evaluate the effect of an additive on the reaction rate of the compositions's reactive constituent (RDX/TNT). This value, however, applies to a specimen of a particular mass and configuration burned in a particular vessel. The ratios developed cannot be extrapolated to any other conditions. This is because the dp/dt vs pressure curve (for materials which fragment on burning) combines the effect of several fundamental properties. Principally, these include the rate of surface area creation with the intrinsic burning rate of the fragmented parts. Presently these values are unknowns. Therefore, the quickness curve (dp/dt vs pressure) is limited to use as a comparator. This comparison, however, is useful to evaluate the degree of effectiveness various additives contribute toward the attempt to slow the burning of RDX/TNT (60/40). In Table 3, the area under the quickness curve for standard Comp B is assigned a value of 100% for each of the two geometrical configurations and a relative comparison based on this value is made for each appropriate experimental formulation.

The ignition test is performed on powdered explosive samples and provides a relative ignitability data as a function of pressure and energy. A 1-gram sample is compressed beween 1.27 cm punches within a floating sleeve. At a desired pressure level (monitored with a piezo force gage) an 80 μsec, one half sine wave, energy pulse is dumped into a platinum heater that is located in the center of the specimen. It has been found that explosives could be ignited over a wide range of energy levels as

Table 3. Relative Reaction Rate with Respect to Regular Comp B

Sample no.	Solid (%)	Crushed (%)
84-018	148	114
84-023*	100*	100*
84-066	169	116
84-080	101	108
84-072	105	98
84-082	42	105
84-083A	50	105
84-025	32	104
84-026	69	113
84-038	36	109
84-039	45	112
84-083B	35	104

*Regular Comp B.

long as the test specimen was at a high enough pressure. In this test, the 50% threshold pressure of ignition at a fixed level of energy deposition is determined by varying the pressure according to a 25 shot Bruceton stair-step procedure [9]. This is done at several energy levels for each explosive. A plot of the reciprocal of the threshold pressure versus the input energy should generate a reasonably straight line that can be used to evaluate the ability of an additive to change the ignitability of the RDX/TNT mixture. The sensitivity hazard increases in proportion to the reciprocal of the threshold pressure of initiation.

The ignitability test was performed on three psuedo Comp B variations. These specimens were not melt-cast. A fixed quantity of RDX (coated or uncoated) was blended with an appropriate amount of finely ground TNT. This was done in order to test the protective coating concept without risking (at this time) exposing bare RDX, a possible result of the crushing process, to the test. The control for the series was a 60/40 blend of RDX/TNT with uncoated RDX. Its ignitability was compared against that of pseudo Comp B's with an insulator (polysulfone) and a conductor (aluminum) coated on the RDX. The pressure at which 50% of the trials (threshold pressure) would be ignited by a specific energy input is listed in Table 4. A plot of the reciprocal of the pressure with respect to the input energy is shown in Fig. 3. In every series, approximately one-half of the tests result in a violent thermal explosion. The force gage, mounted with the test fixture, provides a signal which responds to this event in relation to the onset of the energy pulse. This measures the time to a violent reaction and is also listed in Table 4. These data are plotted with respect to the threshold pressure of initiation and shown in Fig. 4.

CLOSED BOMB RESULTS

All the protectants, which were coated on the RDX, significantly slowed the burning of cast RDX/TNT (60/40). Even the wax, which is normally mixed into the TNT melt, slowed burning more effectively as an RDX protectant. It is difficult to rank the effectiveness of the several coatings tested because identical

TABLE 4. Ignition Test Results

Energy (Joules)	Threshold Pressure (MPa)	Explosion Time (ms)
	Polysulfone Coated RDX	
0.0951±0.0011	94.8±6.0	4.7±3.2
0.0771±0.0011	97.2±8.5	4.3±2.6
0.0610±0.0009	110.0±13.3	2.5±0.9
0.0418±0.0012	131.6±6.3	0.9±0.2
	Uncoated RDX	
0.0922±0.0010	81.6±1.8	4.8±2.7
0.0761±0.0011	93.1±5.4	4.1±1.0
0.0603±0.0010	100.0±6.2	1.6±0.4
0.0438±0.0006	128.2±10.0	0.6±0.3
	Aluminum Coated RDX	
0.0915±0.0020	77.8±10.6	5.6±2.8
0.0726±0.0021	89.5±2.8	3.9±2.8
0.0582±0.0014	103.3±15.2	2.0±0.8
0.0423±0.0071	129.3±13.7	0.5±0.2

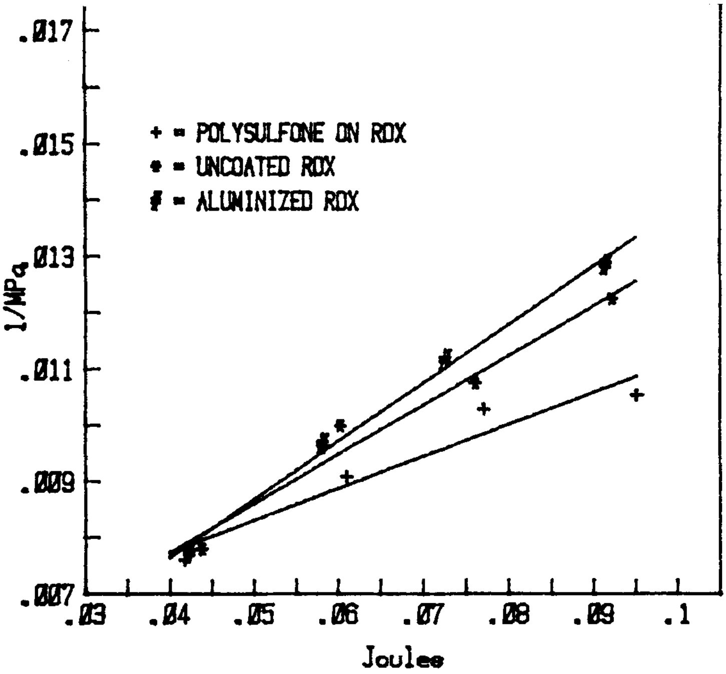

Fig. 3. Reciprocal of pressure vs. energy

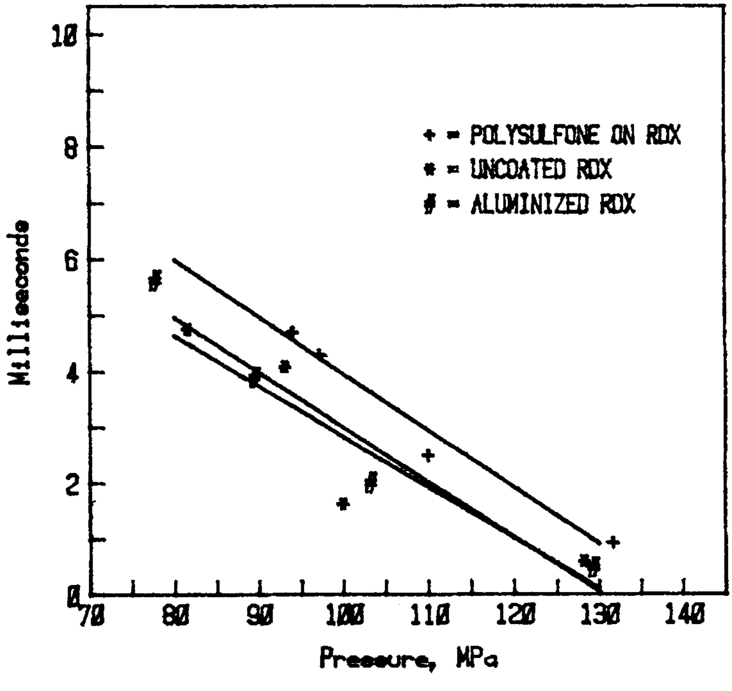

Fig. 4 - Cookoff vs. pressure

experiments were not conducted with all the additives. The tests were performed with all, part, or none, of the TNT modifiers, and because the reactions taking place are not understood completely, it would not be valid to extrapolate a ranking. It is premature, however, to select the ideal coating for RDX only on the basis of closed bomb results. None of the coatings tested failed to slow the burning of the explosive. This indicates that there is a wide choice of materials available. The final selection should be based also on the coating's ability to provide additional desirable properties to the explosive.

Crushed specimens of the explosives were tested because of work of Collett [10]. He launched and recovered four M549 shells that had 100 mil cavities machined in the base of the explosive (cast Comp B). These shells were launched at 5000 g, 8000 g, and 10,000 g acceleration. The base of the shells launched at 8000 g and 10,000 g were completely filled with rubble from the breakup of the explosive. It was also suspected that there might have been significant quantities of powdered explosive associated with the rubble. If an in-bore explosion is initiated in powdered and broken material, the burning properties of this type of explosive must also be examined. The data shows that, in the powdered form, the additives whether in the TNT or coated on the RDX do not modify the burning of RDX/TNT. This indicates that the protective coatings, all of which slow the burning of the cast material do so because they inhibit the rate at which RDX particles are released from the TNT matrix for burning. It probably does this by infinitesimally delaying the ignition of the RDX in the particle to particle ignition sequence.

Particle size of HMX has a significant effect on the burning of propellant containing 58% HMX [11]. This material, like Comp B, broke up on burning for formulations with an HMX particle size of 45 and 92 microns. However, when the micron size was reduced to 4.1 typical gun propellant surface burning was approached. In order to test whether a similar trend occurred with Comp B, a formulation with a smaller RDX particle size was made. The results show that reducing the particle size from 177 μm to 105 μm does not significantly slow its burning. It appears that a much smaller RDX particle size would be needed to slow Comp B's burning, and it would be difficult, if not impossible, to melt-pour this RDX/TNT mixture.

Of the TNT modifiers, only HNS appears to have a detrimental effect on the burning of Comp B. It appears to negate the beneficial effect provided by wax in standard Comp B. However, this speedup in burning is canceled when the anti-exudate is added to the mixture. Whenever the anti-exudate is used, a significant reduction in the maximum pressure (energy) is observed. In some cases, the slowness of burning, caused by RDX protectants, contributes to this by increasing heat-leak through the walls of the closed bomb, but the predominant cause is attributed to side reactions which absorb energy from the reactive RDX/TNT mixture. This is desirable for slow cook-off hazards, and it is unlikely that at detonation velocities (the working region of Comp B) there would be sufficient time for these side reactions to take place. This is supported by the burning of the crushed specimens. These samples burn at a much faster rate than the solid castings and several orders of magnitude slower than they would if stimulated to detonation velocities. The crushed specimens do not exhibit the energy-absorbing side reactions, thus suggesting that the exudation controlling additive can also decrease the severity of some cookoff hazards without seriously affecting performance. Although it is not established with absolute certainty, it appears that the anti-exudate and polysulfone (as a TNT modifier) do not inerfere with the ability of protectant coatings from slowing the burning of cast RDX/TNT. From the perspective of burning properties, these additives can be included in the TNT matrix if warranted by the cast quality and exudation control they provide.

IGNITION TEST RESULTS

The ignition tests were performed on pseudo Comp B in order to evaluate the feasibility of utilizing RDX protectants to reduce the sensitivity of RDX/TNT to in-bore type thermal ignition. The results are quite encouraging. Polysulfone, a candidate for use as an RDX protectant, as well as a TNT modifier, does reduce the sensitivity to thermal ignition in relation to the same formulation with uncoated RDX. The sensitivity of the formulation with aluminized RDX increases slightly, and this would appear to make this explosive more hazardous. The sensitivity of the three formulations converge as the pressure is increased to 130 MPa, indicating that the physical properties of the coating limit its effective working range.

A pleasant surprise was provided by the time-to-explosion results. The polysulfone coating increased the time to violent reaction by almost a millisecond across the entire threshold pressure range. It appears to do this in conjunction with its ability to slow burning and decrease the thermal sensitivity. If this is indeed a valid result, it means that the chance of a safer out-of-bore explosion is increased even if all the prospective improvements fail to prevent an in-bore initiation.

The encouraging results of the ignition test must be confirmed with Comp B formulations made in the traditional manner. In addition, the comparisons of RDX/TNT ignition properties caused by candidate RDX coatings should be made with respect to that of regular Comp B. In regard to the ignition test, the results are not as precise as is desired. The correlation coefficients (r^2) for the reciprocal of pressure vs. energy curves is 0.93, 0.97, and 0.99, respectively, for formulations with polysulfone coated, uncoated, and aluminized RDX. These correlation coefficients are much poorer for the time to reaction vs. pressure curves; r^2 is 0.97, 0.83, and 0.95 for the same respective order. The ignitability test is a new test and as such it evolves as understanding grows with use. It is expected that experimental reproducibility will improve as experience develops the needed refinements.

CONCLUSIONS

This work establishes that a protectant coated on the RDX in a cast of 60/40 RDX/TNT will significantly slow the burning of these reactive constituents. All the coatings tested successfully performed this function; however, when these formulations were burned in their crushed form, the protectants did not slow the burning. This indicates that, in a cast, an additive on the surface of the RDX inhibits the rate at which the RDX is released from the TNT matrix for burning. It probably does this by sequentially delaying the ignition of the RDX particles. Preliminary results also indicate that additives which can slow the burning of RDX/TNT may also increase its minimum energy of ignition and delay the onset of a thermal explosion. These results must be confirmed and a search made for the ideal coating that will best perform all three desirable properties; which collectively should significantly reduce the incidence of in-bore explosions where casting flaws would have precipitated the event. The presence of TNT modifiers, which are intended to control cast quality and exudation, do not appear to interfere with the ability of RDX protectants to slow burning.

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