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DEVELOPMENT OF VIBRATION RESISTANT PROPELLANTS FOR THE M91 PAD CARTRIDGE

1. Integrated Molded Charge

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ABSTRACT

A case bonded, integrated, molded propellant charge (consisting of RDX-cellulose acetate) was developed which met the ballistic requirements for the M91 PAD cartridge and which provided high resistance to both vibration and temperature. The charge consisted of small granulation propellant molded into a monoperforated cylinder which was bonded to the case. The required black powder was sealed in the perforation by means of an adhesive cellophane disc affixed to the top surface of the molded charge.

Thermal stability tests revealed the cartridge to be substantially superior to cartridges containing the nitrate ester single base propellant previously used in this cartridge, and similar to the ammonium perchlorate-cellulose acetate (HES 5808.7) propellant currently used as the standard. Neither the physical nor ballistic properties of the experimental cartridges were affected by severe vibration. While the same vibration caused no change in the ballistic performance of the standard cartridge, pulverization and subsequent deposition of the black powder on the surface of the loose propellant grains was found to occur.

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INTRODUCTION

The employment of PAD systems in the rocket and missile field has necessitated even more rigorous vibration requirements than those stipulated for aircraft. In view of this, the program described herein was undertaken to develop a PAD cartridge capable of withstanding severe vibration requirements without impairment of properties or performance. The M91 cartridge was selected as the test vehicle since it is used in the miniature initiator (M27/M28) intended to replace the widely used M3 initiator. A modified version of the M91, designed to meet rigorous National Aeronautics and Space Administration (NASA) vibration requirements, was previously developed for Project Mercury.[1]

To reduce the effect of vibration upon the explosive constituents of the cartridge, a star-shaped polyethylene insert was used to separate the loose multiperforated nitrate ester propellant grains. In addition, the black powder contained in the cartridge was encased in a small polyethylene capsule. While this system was able to meet the vibration requirements, it was believed that still further improvement in vibration resistance could be attained by developing a charge designed for high vibration resistance, thus eliminating the need for the inert separator and capsule. There was also the question as to high temperature stability, i.e., the ability of the nitrate ester propellant used in the modified cartridge to withstand extended high temperature storage without impairment of ballistic performance.

Previous investigations conducted at this arsenal[2] resulted in the development of ammonium perchlorate-cellulose acetate (AP-CA) and cyclotrimethylenetrinitramine-cellulose acetate (RDX-CA) propellants for the M73 cartridge. Both types exhibited thermal stability superior to that obtained with the double base nitrate ester propellant (M5 composition, RAD 7944) previously used in this cartridge. In view of the higher thermal stability of these types, it was decided to base the development of a vibration-resistant system upon these new formulations, rather than the nitrate ester formulations. Since black powder, the booster powder used in the M91 cartridge, exhibits satisfactory thermal stability, no change in the ignition booster was made.

It was believed that high vibration resistance could best be attained by the use of an integrated propellant charge either fitting tightly in the case or bonded to the case wall. A charge of this type would vibrate in unison with the case and would not be subjected to case impact during vibration, as are the loose granular propellant grains customarily loaded in PAD cartridges.

Two approaches to the development of an integrated propellant charge exhibiting the high mass burning rate required for satisfactory performance of PAD initiators were followed. One involved a single molded charge of desired configuration consisting of small granulation extruded propellant. The other involved a single multiperforated, extruded grain. With the molded charge, the required high mass burning rate could be met by an integrated piece which would burn in accordance with the characteristics of the constituent granular propellant. Thus, use of a fine granulation propellant would obviate the need for a composition having a very fast linear burning rate. This approach was based upon work previously conducted wherein an integrated, self-contained, molded charge, consisting of fine granulation propellants was developed for 7.62 mm application.[3]

The development of an integrated, molded charge for the M91 cartridge is described in this report. Studies involving the single extruded grain have not been completed. The results of that phase will be described in a subsequent report.

Test firings of the various propellant systems were conducted by assembling the M91 cartridge in an M27 initiator, to which was attached a 15-foot length of No. 4 rubber-lined aircraft hydraulic hose connected to an Aberdeen Proving Ground 1.0-cubic inch volume test fixture fitted with a piezoelectric gage. Ballistic requirements for this cartridge call for minimum individual pressures of 500, 575, and 625 psi at -65°, 70°, and 160° F (-54°, 21°, and 71° C), respectively, when fired in the standard test fixture.[4] While there is no requirement regarding the maximum gas pressure, a value less than 1500 psi is considered desirable. Standard M91 cartridges which contain the ammonium perchlorate-based HES 5808.7 propellant generally yield pressures of approximately 1000 psi at 21° C. In addition, it is required that the ignition delay of each cartridge should not exceed 65 milliseconds. This value is defined as the time between firing of the primer and the beginning of a continuous pressure rise on the pressure-time trace.

While the above specification calls for high temperature testing at 71° C, the Air Force has evidenced a desire to test at 200° F (93° C). Consequently, the high temperature firings were conducted at 93° C. Test firings of the various experimental propellant systems were first conducted at 21° C. Those charges which yielded satisfactory performance (i. e., performance levels similar to those obtained with standard M91 cartridges) were then evaluated at the extreme temperatures. Prior to the -54° C firings, the complete M27 initiators were conditioned for a minimum of three and a maximum of 24 hours. At 93° C, the initiators were conditioned for a minimum of three and a maximum of five hours.

EXPERIMENTAL

Preliminary Tests with Loose RDX-CA Propellant

Preliminary firings were conducted at 21° C with several fine granulation RDX-CA propellants loaded into the M91 cartridge as loose propellant. The standard igniter charge of 6 grains A4 black powder was added on top of the loose propellant. The descriptions of the propellants tested, all of which were graphite coated, are presented in Table I, and the ballistic results are shown in Table II.

TABLE I. Description of Experimental RDX-CA Propellants

	HES 5811.3	EX 7805	EX 7806
		Composition (%)	
RDX	82	77	77
Cellulose acetate	13.5	23	23
Methyl phthalyl ethyl glycolate	4.5	-	-
		Die Dimensions	
Diameter, in.	0.041	0.125	0.125
Length, in.	0.033	0.099	0.023
Number of perforations	0	0	0

TABLE II. Ballistic Results with Experimental RDX-CA Propellants

Propellant	Charge (gm)	Peak Pressure (psi)	Ignition Delay (msec)	Rise Time (msec)
EX 7805	2.0	1110	9	8
	2.0	1020	8	8
	2.0	1060	8	10
	1.8	990	9	11
	1.8	1040	10	12
	1.6	900	10	11
	1.6	930	10	12
EX 7806	2.0	1220	8	10
	2.0	1250	8	8
	2.0	1080	8	8
	1.8	1180	7	7
	1.8	950	9	7
	1.6	870	8	12
	1.6	870	9	10
HES 5811.3	2.0	1290	8	10
	2.0	1240	8	10
	2.0	1210	8	8
	1.8	1180	10	10
	1.8	1180	10	10
	1.6	920	9	11
	1.6	840	8	10

Ballistic requirements were met with all systems tested. As would be expected, a decrease in charge weight produced a corresponding pressure decrease. Since all three fine granulation propellants yielded the desired performance, it was decided to prepare molded integrated charges with each propellant.

Molded Integrated Charges

The shaded area in Figure 1 indicates the available volume for an integrated charge.

The external dimensions of the charge should be slightly smaller than those of the case to prevent compression during assembly of the cartridge. To obtain the desired outer diameter, the charges were molded in M91 cases.

It was found that the relatively large EX 7805 grains could not be satisfactorily molded in the desired dimensions. As a result, further effort with this type was discontinued. Molded samples of HES 5811.3 and EX 7806 were prepared in different charge weights ranging from 2.0 to 2.9 grams.

Previous experience in the use of molded charges for small arms indicated that a slightly greater charge of molded propellant was required for a given performance level than corresponding loose propellant.(3) These molded pieces were prepared using either manual pressure or a hydraulic press which permitted compression at approximately 1700 psi. The two compression methods were used to obtain differences in degree of consolidation. Charge weights of the molded pieces (which have a considerably higher bulk density than corresponding loose propellant) were controlled by the diameter of the longitudinal perforation. With the lighter weight molded pieces, which required thin case walls, one end of the perforation was partially closed (as shown in Figure 2A). This was required to ensure that the top surface of the molded charge had a perforation smaller than the base of the head, which is in the form of a truncated cone. If such were not the case, the molded piece would shift its position in the cartridge during vibration (refer Figure 2B).

In all the molded charges, the desired quantity of A4 black powder was placed within the perforation. Situating the black powder in this manner should result in more reproducible ignition than is obtained in the standard M91 cartridge loaded with loose HES 5808.7 propellant where the black powder charge is not centrally located.

The results of ballistic testing at 21° C are presented in Table III.

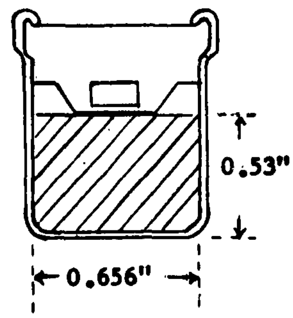

Figure 1. Schematic diagram of M91 Cartridge

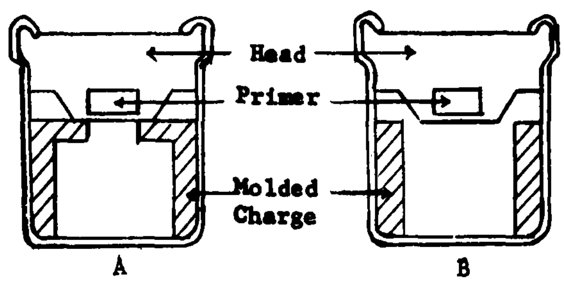

Figure 2. Schematic diagram of Experimental Cartridges

A - Double perforation. Perforation adjacent to head smaller than diameter of latter. (Charge is tightly contained in case and will not move significantly under vibration.)

B - Single perforation. Perforation larger than diameter of base of head. (Charge would move under vibration.)

TABLE III. Effect of RDX-CA Molded Charge Weight on Ballistic Performance

Propellant	Charge[a] (gm)	Pressure Used in Molding	Peak Pressure (psi)	Ignition Delay (msec)	Rise Time (msec)
HES 5811.3	2.1[b]	Manual	1380	10	12
			1340	10	10
	2.4[b]	Manual	1690	9	11
			1670	8	10
	2.4[b]	Hydraulic	1700	9	9
			1690	9	9
	2.7	Manual	1830	9	10
	2.9	Manual	c	-	-
EX 7806	2.0[b]	Manual	1180	11	9
	2.4	Manual	1530	10	10
			1490	10	10
	2.4[b]	Hydraulic	1600	9	9
			1590	9	9

[a] Six grains A4 black powder used in all cartridges.
[b] Double perforation required.
[c] Initiator body ruptured.

All the cartridges tested yielded higher pressures than the desired 1000 psi level, the pressure increasing with charge weight. With equal weight (2.4 grams), HES 5811.3 propellant yielded slightly higher pressures than did EX 7806. This is probably due to both the greater surface area exhibited by the former after fragmentation of the molded charge, as well as a higher RDX content. The results indicated a charge of approximately 2.0 grams molded EX 7806 (together with 6 grains A4 black powder) would be required, while that required for the

HES 5811.3 molded charge would be 1.8 grams or less. Since the lighter charge of HES 5811.3 would introduce processing problems (extremely thin walls of the molded charge) and since the desired ballistics could be met with the lower RDX content of EX 7806, it was decided to continue charge development studies solely with the EX 7806 propellant.

Initiator body rupture with the 2.9 gram HES 5811.3 charge (a weight considerably greater than the extrapolated required charge of 1.8 grams) was believed due to a rate of pressure build-up in the initiator so rapid that all of the propellant burned before any gas could vent through the filter to the 15-foot hose line. Thus, even though an open system was used, the test was conducted under essentially locked shut conditions. As such, the pressure generated by the excessive charge was sufficient to rupture the initiator body. However, since the RDX-CA propellants consist of a crystalline high explosive embedded in an inert binder, the possibility that this metal parts failure was due to detonation was considered. (It should be noted that most propellants, with the exception of single base formulations, can be detonated under certain conditions.) Studies were therefore conducted to determine the degree of hazard of the formulations used in this investigation.

To determine whether metal parts failure would also occur with a similar overcharge of an RDX-CA propellant of lower RDX content, a cartridge loaded with 2.8 grams molded EX 7806 (plus 6 grains A4 black powder) was fired in the standard test fixture. The initiator body failed in the same way as with the HES 5811.3 propellant. Since it was believed that these firings with excess charge weights were carried out under essentially locked shut conditions (due to the extremely rapid rate of pressure generation), two locked shut firings were conducted with an overcharge (2.4 grams) of the then standard single base nitrate ester propellant, PAE 4228, plus the regular 6 grains A4 black powder. The PAE 4228 charge loaded in the standard cartridge was 2.0 grams. (During the course of this investigation, the PAE 4228 propellant was replaced by the more thermally stable ammonium perchlorate-cellulose acetate HES 5808.7 propellant as the standard in the M91 cartridge.) As in all firings in this program, used initiators were employed, due to a scarcity of new components. Rupture of the initiator body occurred in both firings with the PAE 4228 overcharge. The pattern of metal parts failure in both firings was similar to that obtained with the RDX-based propellant, suggesting the initiator rupture produced by the latter was due to excess gas pressure and not detonation.

Tests were conducted with EX 7806 and EX 7954 (a propellant of identical composition and diameter but slightly greater disc thickness than EX 7806) to determine the sensitivity of this formulation to a detonating initiator. Charges of 39 grains of the propellant (containing 30 grains RDX) were pressed into 20 mm M97 HEI shells, an E77 blasting cap (3.2 grains PETN) was placed next to the charge, and the nose of the shell was then screwed tightly in place so as to offer maximum confinement. Detonation of the blasting cap did not produce detonation in either of two tests with EX 7806. However, high order detonation was obtained in three of ten EX 7954 charges. Thus, under these extreme conditions, detonation of the RDX-based propellants was induced in one-quarter of the tests.

The results were inconclusive. At best, the tests showed that the RDX composition can be detonated under extreme conditions. However, as mentioned above, many propellants now in use can be detonated. Perhaps the most satisfactory way of determining if a hazard exists, and the degree of same, lies in a complete evaluation of the functioning of M91 cartridges assembled with this propellant. In the course of the development described in this report, approximately 175 cartridges containing the established RDX-CA propellant charge were test fired (including locked shut firings) at temperatures ranging from -54° to 93° C. All cartridges functioned satisfactorily, with no damage to metal parts. Thus, it may be safely concluded that no detonation problem exists with respect to the use of these RDX-CA propellants in the M91 cartridge. It may also be noted that RDX based propellants (up to 50 percent RDX) have been successfully used in small arms applications.[5,6]

Development and Evaluation of EX 7806 Molded Charge

Since no evidence of a safety hazard with the RDX-CA propellants in PAD applications was obtained, investigations directed toward the development of a satisfactory molded charge were continued.

Molded charges having an average weight of 2.05 ± 0.06 grams EX 7806 propellant were prepared. As before, the external dimensions were such that the integrated charge fitted tightly in the case (height 0.530 in., diameter 0.640 in.). Two perforation diameters (0.450 in. and 0.0625 in.) were required to provide for the charge weight and to insure that the top surface of the charge had a perforation diameter smaller than the diameter of the metal head. The wall thickness of the molded charge, 0.095 inch, was believed to represent the minimum thickness which could be molded and still provide satisfactory physical properties. The charges were compressed at approximately 1700 psi, using a hydraulic press. Manual pressing was discontinued since the method was believed to yield a less reproducible product than did the use of the hydraulic press.

To improve further the vibration resistance of the tightly fitting molded piece, the bottom and lateral surfaces of the charge were bonded to the case wall with a solution of cellulose acetate in an equal volume mixture of acetone and ethyl alcohol. The charges so bonded adhered firmly to the case and could not be shaken loose by either hand or mechanical agitation. Bonding in this manner allows the molded charge to vibrate in unison with the case, and not be subjected to impact with the metal case.

Table IV lists the results obtained in the standard test system using a charge of 2.05 ± 0.06 grams molded EX 7806 propellant plus 6 grains A4 black powder. Conventional and modified locked shut tests were also conducted, since the rapid pressure build-up with the molded propellants might cause difficulty. In the modified tests, the initiator was fired into a small pressure station (approximately 0.062 cubic inch volume) which housed a piezoelectric gage. For comparison, average results obtained with M91 cartridges containing the previous standard PAE 4228 propellant (M10 composition) are included.

The experimental cartridges assembled with the molded charge thus met the ballistic requirements and passed the locked shut tests. However, the average pressure of 1252 psi was above the desired level of 1000 psi, and the pressures obtained at -54° C in the modified locked shut tests were higher than those obtained with the PAE 4228 (M10 composition) cartridge. In the modified locked shut tests, the rise time obtained with the experimental cartridge was approximately half that obtained with the standard, indicating the faster rate of gas generation of the molded charge.

Since a reduction in charge weight of the molded piece was required to reduce the pressure to approximately 1000 psi. In the

TABLE IV. Ballistic Performance of Cartridges Containing EX 7806 Molded Peopellant-A4 Black Powder and Standard Cartridges

	No. of Rounds	Temp (° C)	Peak Pressure (psi)	Ignition Delay (msec)	Rise Time (msec)
			Standard Test Fixture		
Experimental		21	1190	10	10
		21	1260	9	10
		21	1300	8	10
		21	1270	8	11
		21	1240	9	7
Avg			1252	9	10
Std Dev			37	1	1
			Conventional Locked Shut Tests		
Experimental	2	-54	No visible deformation or metal parts failure.		
	2	93	Ditto		
			Modified Locked Shut Tests		
Experimental		-54	29,700	1	3
		-54	29,600	2	3
		93	27,700	2	3
		93	29,400	2	2
Standard (PAE 4228)	4	-54	24,300[a]	4[a]	8[a]
	6	93	27,600[b]	3[b]	6[b]

[a] Average of four firings
[b] Average of six firings

standard test fixture, there arose a problem regarding the configuration of the molded charge. If the outer diameter and length were kept constant, it would be required to reduce the wall thickness below the 0.095 inch value used in the above tests. This reduction would result in an undesirably thin wall, adversely affecting the physical strength as well as introducing processing problems. Since the charge could be firmly bonded in the case, there was no longer a need for having a configuration such that the charge fitted tightly in the available volume. It was therefore decided to reduce the height of the molded charge, permitting use of a smaller, constant perforation diameter and a greater wall thickness. While this resulted in considerable air space between the top of the molded charge and the base of the head, movement of the former was prevented since the integrated piece was bonded to the case. (If desired, the M91 case could be shortened to permit minimum air space between the molded charge and the base of the head.)

Molded charges of EX 7806 were prepared having average charge weights of 1.80 and 1.90 grams. These had a perforation diameter of 0.25 inch and an 0.20 inch wall thickness, believed to be sufficient for satisfactory physical characteristics. The A4 black powder, used as an ignition booster, was placed within the perforation as before. In view of the air space between the charge and the head of the case, a disc of cellophane tape, 0.003 inch thick and having a diameter equal to that of the molded charge, was placed over the top of the molded piece. This served to contain the loose black powder in the perforation; otherwise, the black powder would flow from the perforation if the cartridge were inverted. The molded charges were bonded to the case with cellulose acetate in the manner previously described.

Since the object of these firings was to determine the charge yielding performance similar to that obtained with the standard M91 cartridge, a survey was made of the results obtained in acceptance testing of 24 recent lots of M91 cartridges assembled with the PAE 4228 (M10) multiperforated propellant. These acceptance tests were conducted at -54°, 21°, and 71° C, with the results determined on the basis of five firings at each temperature. The average of all these firings (120 rounds at each temperature) was taken to be representative of the performance of the standard cartridge.

Table V lists the results of firings at -54°, 21°, and 93° C in the standard test fixture with 1.80 and 1.90 grams of EX 7806 molded charges plus 5 grains A4 black powder. For comparison, the performances obtained with the acceptance tests of M91 cartridges (PAE 4228 propellant) are also presented.

While both experimental charges met the ballistic requirements, the mean pressures were below the averages obtained with the standard cartridge. Pressure reproducibility appeared to be slightly poorer with the molded charges; however, uniformity was within the range of that yielded by the standard cartridge. Ignition times were slightly less with the experimental cartridges, indicating the absence of any ignition problem with the molded charges.

Development and Evaluation of EX 7953 and EX 7954 Molded Charges

At this point in the development, use of EX 7806 propellant was discontinued, and two other RDX-CA propellants of identical composition but having slightly slower relative quickness (thicker web) were employed. All were disc shaped and graphite coated. A comparison of the three propellants is presented in Table VI. The decision to use these new propellants was prompted by the consideration that their greater disc thickness might serve to decrease the rate of gas generation of the molded charges (which was faster than that of the standard cartridge).

In view of the pressures previously obtained with the molded EX 7806 charges, it was believed that a charge of 2.0 grams of the two new propellants, coupled with variation in the A4 black powder quantity (to account for the slight difference in relative quickness of the two propellants) would yield the desired pressure levels. Consequently, molded charges having weights of approximately 2.0 grams were prepared with both propellants in the same cylindrical forms used previously (0.640 inch outer diameter). A longitudinal perforation, 0.30 inch diameter, was drilled into each molded charge, and the required amount of A4 black powder was placed within the perforation. The perforation was slightly larger than that previously used, to accommodate an increased amount of black powder.

TABLE V. Effect of Temperature on Ballistic Performance of Cartridges Containing Molded EX 7806 Propellant-A4 Black Powder Charges and Standard Cartridges

	-54° C			21° C			93° C		
	Peak Pressure (psi)	Ignition Delay (msec)	Rise Time (msec)	Peak Pressure (psi)	Ignition Delay (msec)	Rise Time (msec)	Peak Pressure (psi)	Ignition Delay (msec)	Rise Time (msec)
1.80 ± 0.02 gm EX 7806 Propellant + 5 gr A4 Black Powder									
	790	13	12	760	12	11	790	10	15
	780	11	9	880	10	9	910	11	10
	840	12	9	780	10	10	840	9	10
	840	11	10	770	10	8	900	9	8
	780	13	8	880	9	10	920	9	8
Avg	806	12	10	814	10	10	872	10	10
Std dev	28	1	1	54	1	1	50	1	3
1.90 ± 0.01 gm EX 7806 Propellant + 5 gr A4 Black Powder									
	830	14	12	970	10	8	870	8	8
	850	11	9	830	10	11	790	10	13
	880	11	10	980	10	9	880	9	10
	940	13	9	960	10	8	940	10	10
	920	12	9	930	11	8	870	9	11
Avg	884	12	10	934	10	9	870	9	10
Std dev	41	1	1	55	1	1	48	1	2
Standard Cartridge (PAE 4228)									
Avg									
24 lots	921	17	-	1020	14	-	1050[a]	13[a]	-
Highest	972	19	-	1074	16	-	1160	16	-
Lowest	730	15	-	874	13	-	948	12	-
Avg std dev									
24 lots	31	1	-	41	1	-	38	1	-
Highest	53	2	-	82	1	-	65	1	-
Lowest	12	1	-	15	1	-	15	1	-

[a] High temperature acceptance firings conducted at 71° C.

TABLE VI. Dimensions and Composition of RDX-CA Propellants

	EX 7806	EX 7953	EX 7954
Diameter, in.	0.125	0.125	0.125
Thickness, in.	0.023	0.045	0.030
Composition	77 RDX/23 CA	77 RDX/23 CA	77 RDX/23 CA

A photograph of the molded charge is presented in Figure 3. As before, the bottom and lateral surfaces of the molded charge were bonded to the case with cellulose acetate. A disc of cellophane tape (0.003 inch thick) was placed over the top of the molded charge to prevent the loose black powder from flowing into the air space between the top of the molded charge and the base of the head. The results obtained at 21° C in the standard test fixture using EX 7953 and EX 7954 molded propellant and various charge weights of A4 black powder are presented in Table VII.

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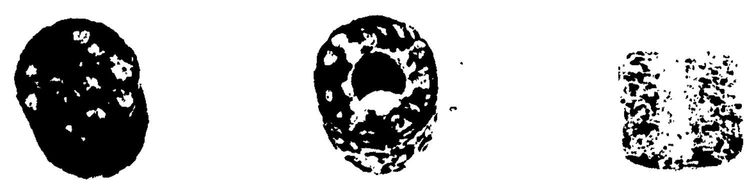

Figure 3. Molded RDX-CA Propellant Charge

TABLE VII. Effect of A4 Black Powder Charge Weight Upon Performance of Molded EX 7953 and EX 7954 Propellant

	Peak Pressure (psi)	Ignition Delay (msec)	Rise Time (msec)
1.97 ± 0.02 gm EX 7953 Propellant + 5 gr A4 Black Powder			
	1090	11	10
	1020	11	8
	1040	10	8
	1090	10	9
	1100	8	9
Avg	1068	10	9
Std dev	32	1	1
1.96 ± 0.02 gm EX 7953 Propellant + 6 gr A4 Black Powder			
	1080	11	9
	1130	11	8
	1140	10	8
	1040	9	8
	1080	9	8
Avg	1094	10	8
Std dev	37	1	1
1.97 ± 0.01 gm EX 7954 Propellant + 5 gr A4 Black Powder			
	1040	12	9
	1040	11	9
	1100	10	9
	1080	10	8
	1100	11	7
Avg	1072	11	8
Std dev	27	1	1

TABLE VII. (Cont'd)

	Peak Pressure (psi)	Ignition Delay (msec)	Rise Time (msec)
1.95 ± 0.02 gm EX 7954 Propellant + 6 gr A4 Black Powder			
	1140	9	9
	1120	10	8
	1150	11	8
	1120	11	8
	1130	10	8
Avg	1132	10	8
Std dev	12	1	1

All four combinations yielded acceptable pressures. It was desirable, however, to narrow the choice of possible combinations. Consequently, the systems selected for further evaluation were EX 7954 and EX 7953 plus 5 and 6 grains A4 black powder, respectively. Extreme temperature firings with these systems were conducted at -54°, 21°, and 93° C. The results of these firings are presented in Table VIII. For comparison, results obtained in acceptance testing of standard M91 cartridges (PAE 4228 propellant, M10 composition) are included.

Both experimental systems yielded mean pressures and pressure uniformity similar to those obtained with the standard cartridge. Ignition delays were slightly less with the experimental cartridges, indicating fragmentation of the molded charge readily occurred over the complete temperature range.

Locked shut firing tests were conducted in the M27 initiator to determine if M91 cartridges loaded with the experimental charges could function under locked shut conditions without producing metal parts failure. Initiators containing standard cartridges (Lot FA-2-10 assembled with PAE 4228 propellant) were fired for comparison. The results are summarized in Table IX.

TABLE VIII. Effect of Temperature on Ballistics of Cartridges Containing Molded EX 7953 and EX 7954 Propellants with A4 Black Powder and Standard Cartridges

	-54° C			21° C			93° C		
	Peak Pressure (psi)	Ignition Delay (msec)	Rise Time (msec)	Peak Pressure (psi)	Ignition Delay (msec)	Rise Time (msec)	Peak Pressure (psi)	Ignition Delay (msec)	Rise Time (msec)
				1.98 ± 0.01 gm EX 7954 Propellant + 5 gr A4 Black Powder					
	820	10	10	980	8	10	1070	8	9
	880	10	10	960	10	10	1030	9	8
	910	11	10	1030	10	10	1040	9	10
	890	12	8	910	11	10	1040	9	8
	950	10	10	930	11	9	1060	9	9
	900	12	8	970	10	11	1070	9	7
	1010	12	9	960	8	7	1030	10	9
	960	11	10	900	13	10	1070	9	10
	910	10	9	990	9	10	1060	9	8
	970	11	9	990	8	8	1020	9	8
Avg	920	11	9	962	10	10	1049	9	9
Std dev	51	1	1	38	2	1	18	1	1
				1.98 ± 0.02 gm EX 7953 Propellant + 6 gr A4 Black Powder					
	880	13	10	990	10	10	1160	11	8
	930	11	10	1090	12	8	1020	10	10
	870	14	9	1020	11	8	1100	10	10
	910	12	10	1070	11	8	1070	8	8
	880	12	11	1100	12	9	1080	10	11
	900	10	9	990	12	9	1170	10	9
	930	12	11	1060	12	10	1170	10	9
	910	11	8	1080	12	9	1040	8	8
	890	11	8	1050	11	9	1180	11	8
	900	12	11	1080	12	8	1130	10	8
Avg	900	12	10	1053	12	9	1122	10	9
Std dev	19	1	1	38	1	1	56	1	1
				Standard Cartridge (PAE 4228)					
Average									
24 Lots	921	17	-	1020	14	-	1050[a]	13[a]	-
Highest	972	19	-	1074	16	-	1160	16	-
Lowest	730	15	-	874	13	-	948	2	-
Avg Std dev									
24 Lots	31	1	-	41	1	-	38	1	-
Highest	53	2	-	82	1	-	65	1	-
Lowest	12	1	-	15	1	-	15	1	-

[a]High temperature acceptance firings conducted at 71° C.

TABLE IX. Conventional Locked Shut Tests

No. of Rounds	Temp (° C)	Results
		1.98 gm EX 7954 Propellant + 5 gr A4 Black Powder
2	-54	No visible deformation or metal parts failure
2	93	Ditto
		1.98 gm EX 7953 Propellant + 6 gr A4 Black Powder
3	-54	No visible deformation or metal parts failure
3	93	Ditto
		Standard Cartridge (PAE 4228)
3	-54	No visible deformation or metal parts failure
3	93	Ditto

Initiators loaded with both experimental cartridges successfully passed the conventional locked shut test.

Modified locked shut tests were conducted wherein the initiator was fired into a small pressure station (approximately 0.062 cubic inch volume) which housed a piezoelectric gage. While this is not a true locked shut test, it closely approximates the condition and, at the same time, permits measurement of the peak pressure obtained. The pressures yielded by experimental and standard cartridges (Lot FA-2-10) are presented in Table X.

The experimental cartridges yielded pressures equal to or slightly greater than those obtained with the standard. Since the M27 initiator can withstand at least 30,000 psi, the slightly higher pressures obtained with the experimental cartridges do not constitute a serious objection.

Rise times were significantly less with the experimental cartridge, indicating the molded charge is consumed more rapidly than the nitrate ester PAE 4228 propellant contained in the standard cartridge.

TABLE X. Pressures Developed in Modified Locked Shut Tests

Temp (° C)	Peak Pressure (psi)	Ignition Delay (msec)	Rise Time (msec)
	1.98 gm EX 7954 Propellant + 5 gr A4 Black Powder		
-54	23,200	4	4
	23,600	4	3
93	27,000	2	2
	26,600	2	2
	1.98 gm EX 7953 Propellant + 6 gr A4 Black Powder		
-54	25,900	4	3
	25,400	3	3
	25,800	3	3
93	26,100	2	2
	26,700	2	2
	25,700	2	2
	Standard Cartridge (PAE 4228)		
-54	23,700	4	8
	23,700	10	9
	23,400	6	8
93	23,800	2	4
	24,000	2	5
	23,200	3	7

Thermal Stability of EX 7953 and EX 7954 Molded Charges

Tests were conducted to define the maximum temperatures which the experimental cartridges could safely withstand for short periods. Unprimed M91 cartridges, containing the experimental RDX-CA charges, were exposed to temperatures 149° or 163° C (300° or 325° F) for four hours, conditioned to 21° C, primed with the standard M29A1 (styphnate) primer, and tested for ballistic performance at 21° C in the standard fixture. The cartridges were primed after the high temperature exposure to eliminate the possible detrimental effects of the high temperature upon the primer. Because of its scarcity, only two firings with EX 7954 were conducted at each exposure temperature. The results are presented in Table XI. For comparison, results previously reported with unheated experimental cartridges are included.

TABLE XI. Effect of High Temperature Exposure upon Performance of Experimental Cartridges

Exposure Conditions Temp (° C)	Time (hr)		Peak Pressure (psi)	Ignition Delay (msec)	Rise Time (msec)
1.98 gm EX 7953 Propellant + 6 gr A4 Black Powder					
149	4		1030	9	15
			1130	9	14
			1190	12	10
			1140	9	8
			1160	9	8
		Avg	1130	10	11
		Std dev	54	1	3
163	4		1100	10	10
			1060	12	9
			1060	10	11
			1190	9	10
			1080	11	9
		Avg	1098	10	10
		Std dev	48	1	1
Unheated		Avg of 10	1053	12	9
		Std dev	38	1	1
1.98 gm EX 7954 Propellant + 5 gr A4 Black Powder					
149	4		980	15	10
			1080	11	9
163	4		1020	11	9
			1070	8	10
Unheated		Avg of 10	962	10	10

The performance of the experimental cartridges was not detrimentally affected by four hours' exposure at 149° or 163° C. (The slightly higher peak pressures yielded by the heated cartridges, statistically significant at the 0.05 level with the EX 7953 charge, probably reflect day-to-day variation in pressure measurement instrumentation rather than real differences in cartridge behavior.) Cartridges subjected to these exposure conditions were disassembled and examined. No change in the physical appearance of EX 7953 or EX 7954 molded charge was observed, the individual grains of the charge retaining their identity. The bond between the molded piece and the case and that between the adhesive cellophane disc (0.003 inch thick) and the top of the molded piece were also uneffected. The originally transparent disc had developed a brownish coloration.

At 177° C (350° F), considerable pressure was generated in the experimental cartridges, resulting in bulging of the case bottoms and causing the heads to be blown off after approximately 1 hour and 45 minutes of exposure. The propellant did not autoignite; however, its physical form was substantially changed by the high temperature exposure.

The substantial increase in thermal stability offered by the experimental propellants over the nitrate ester propellants is evident in comparison with similar tests in the M38 CAD cartridge. In these, the nitrate ester PAE 4228 propellant (previous standard in the M91 cartridge) underwent autoignition in approximately 19, 8, and 4 minutes at 149°, 163°, and 177° C, respectively.(7)

The experimental propellants offer the same high level of thermal stability provided by the HES 5808.7 ammonium perchlorate-cellulose acetate propellant (current standard for both the M73 and M91 cartridge). In the M73 cartridge, the ballistic performance obtained with the HES 5808 type propellant was not affected by four hours' exposure at 149° C. At 163° C, however, one of five cartridges tested underwent autoignition during the four-hour exposure.(2)

Vibration Tests with Molded Charges

Four M91 cartridges assembled with each of the two integrated, case bonded, RDX-cellulose acetate charges were subjected to a modified, more rigorous vibration schedule than that required for USAF testing.[8] For comparison, four standard cartridges assembled with loose, multiperforated HES 5808.7 propellant plus A4 black powder were included. In these tests, cartridges were subjected to a vibration frequency cycled between 5 and 74 cps at an applied double amplitude of 0.036 inch and to an applied acceleration of ± 10 g cycled between 75 and 500 cps. The following schedule was employed.

	Time (hr) at		
Direction	-54 C	21° C	93° C
Vertical	15	15	15
Horizontal	15	15	15

While the standard requirements call for a total vibration time of nine hours, the cartridges were subjected to 90 hours' vibration in these tests.

Before and after the vibration tests, X-ray photographs were taken of the twelve cartridges. These photographs, prior and subsequent to vibration, are presented in Figures 4 and 5, respectively. The vibration did not break up or dislodge the case bonded integrated charges, nor did it dislodge the black powder in the perforation.

One cartridge from each of the three types (two experimental and the standard) were disassembled after vibration. Examination of these cartridges revealed no change in physical appearance of either of the experimental charges. Both molded pieces remained securely bonded to the case and the black powder was retained in the perforation by the adhesive cellophane disc. In the standard cartridge, however, a portion of the originally loose flowing black powder deposited on the surface of the multiperforated HES 5808.7 propellant grains, while most of the balance agglomerated into several large pieces. The appearance of the black powder suggested that it had first been pulverized (probably by impact with both the loose propellant grains and the metal case). This was followed by deposition of the finely divided black powder on the surface of the propellant grains and agglomeration. The grains were not affected by the vibration, none exhibiting splintering or chipping.

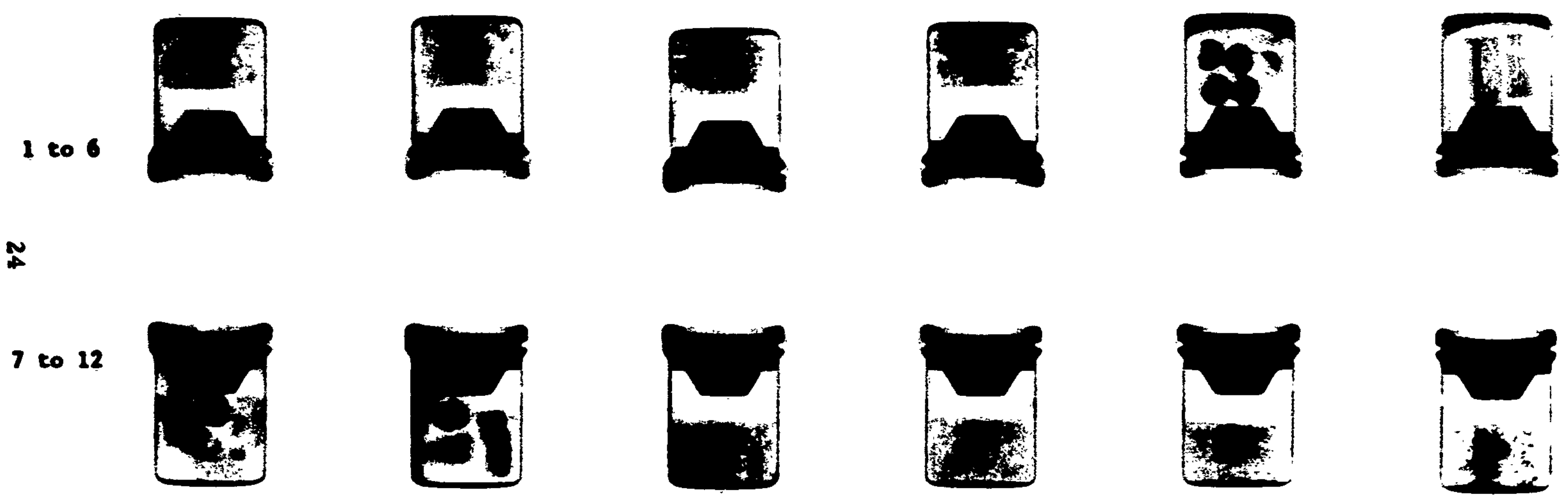

Figure 4. X-ray Photographs of Cartridges before Vibration

Nos 1 to 4, EX 7953 and Black Powder
Nos 5 to 8, HES 5808.7 and Black Powder
Nos 9 to 12, EX 7954 and Black Powder

1 to 12

36.231.S1374/ORD.63

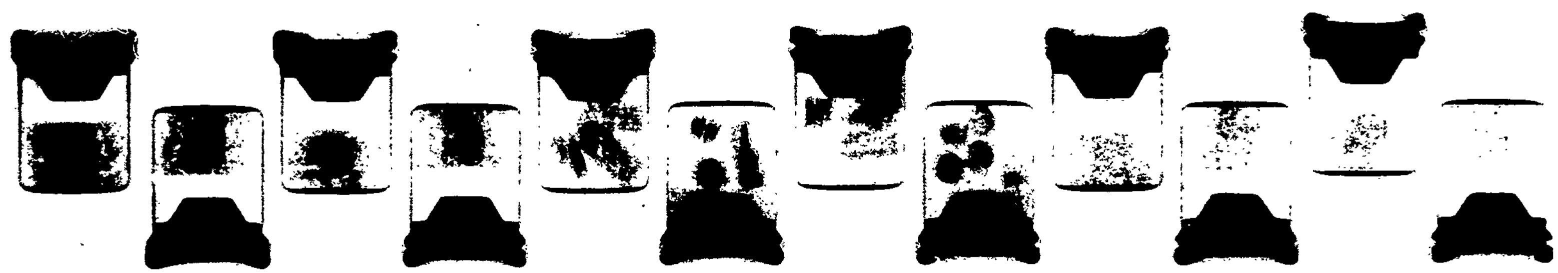

Figure 5. X-ray Photographs of Cartridges after Vibration

Nos 1 to 4, EX 7953 and Black Powder
Nos 5 to 8, HES 5808.7 and Black Powder
Nos 9 to 12, EX 7954 and Black Powder

The remaining three cartridges of each type were fired at 21° C in the standard test fixture. The ballistic results obtained with the vibrated cartridges are presented in Table XII. For comparison, those for the (unvibrated) experimental cartridges are repeated from Table VIII. The values for the standard cartridges (containing HES 5808.7) are based upon the average values obtained in acceptance testing of lots containing this propellant.

TABLE XII. Effect of Vibration upon Ballistic Performance of Cartridges

Condition	Peak Pressure (psi)	Ignition Delay (msec)	Rise Time (msec)
1.98 gm EX 7953 Propellant + 6 gr A4 Black Powder			
Vibrated	990	9	7
	1040	8	8
	1030	8	8
Not vibrated			
Avg of 10	1053	12	9
1.98 gm EX 7954 Propellant + 5 gr A4 Black Powder			
Vibrated	910	10	12
	990	8	9
	950	10	9
Not vibrated			
Avg of 10	962	10	10
Standard Cartridge (HES 5808.7)			
Vibrated	1200	12	10
	1140	11	10
	970	11	10
Not vibrated	1050	14	-

It is seen that none of the three lots exhibited any change in ballistic performance as a result of the vibration.

DISCUSSION

While the ballistic performance of the experimental and standard cartridges was unaffected by vibration, the absence of any changes in physical appearance of the former indicated the case bonded integrated molded charge concept should have greater vibration resistance than that offered by the standard cartridge. This is to be expected since the propellant and confined black powder will vibrate in unison with the metal case rather than being subjected to case impact, as are the loose explosive constituents of the standard cartridge. This concept of case bonded integrated molded charges thus offers application to PAD systems which require both rapid rates of gas evolution as well as high vibration resistance.

In regard to improved thermal stability, the RDX-cellulose acetate molded charge is substantially superior to the nitrate ester single base PAE 4228 propellant previously used as the standard in the M91 cartridge. It offers the same high level of thermal stability as does the HES 5808 type propellant currently used as the standard in this cartridge.

CONCLUSIONS

1. A case bonded integrated molded propellant charge, consisting of RDX-cellulose acetate, has been developed which meets the ballistic requirements for the M91 cartridge and which provides high resistance to both vibration and temperature. The charge consists of small granulation propellant molded into a monoperforated cylinder, which is bonded to the case. The required black powder is sealed in the perforation by means of an adhesive cellophane disc affixed to the top surface of the molded charge.

2. Thermal stability tests reveal these cartridges to be substantially superior to cartridges containing the nitrate ester single base propellant (PAE 4228), previously used in this cartridge, and similar to the ammonium perchlorate-cellulose acetate (HES 5808.7) propellant, currently used as the standard.

3. Neither the physical nor ballistic properties of the experimental cartridges were affected by severe vibration. While the same vibration caused no change in ballistic performance of the standard cartridge, pulverization and subsequent deposition of the black powder on the surface of the loose propellant grains was found to occur.

RECOMMENDATION

It is recommended that the case bonded molded charge concept be used in those PAD initiators requiring high vibration resistance.

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by M. E. Levy, J. B. Quinlan, W. White, and E. F. Van Artsdalen
FA Report R-1663, Dec 62; 31 pp incl tables and illus
OMS Code 4110.16.8100.1.33 Unclassified Report

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Thermal stability tests revealed the cartridge to be substantially superior to cartridges containing the nitrate ester single base propellant previously used in this cartridge and similar to the ammonium perchlorate-cellulose acetate (HES 5808.7) propellant currently used as the standard. Neither the physical nor ballistic

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