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MEASUREMENT OF HEAT INPUT INTO THE 105MM M68 TANK CANNON FIRING--ETC(U)
APR 78 T L BROSSEAU, J R WARD

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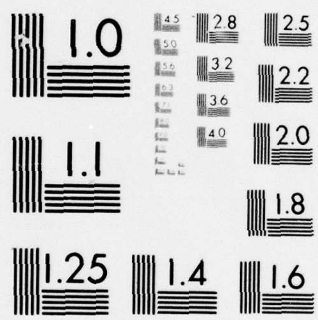

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MEASUREMENT OF HEAT INPUT INTO THE 105mm M68 TANK CANNON FIRING ROUNDS EQUIPPED WITH WEAR-REDUCING ADDITIVES.

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(10) Timothy L. Brosseau
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
Four in-wall thermocouples were used to measure the total heat input to an M68 tank cannon at 641.4mm from the rear face of the tube. This is the distance where vertical land diameter is measured to judge remaining tube life.

Heat inputs were measured for 105mm ammunition with known life in order to assess probable wear life for a developmental 105mm projectile that is lighter than the M392A2 APDS round. In addition, attempts were made to modify the → next page
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20. Abstract (Cont'd)

liner in the M456A1 and M490 TP-T rounds to try to reduce the erosiveness of these projectiles. It was found that replacing the existing 24.1cm-long TiO_2/wax liner with a 30.5cm-long talc/wax liner significantly reduced heat input to the barrel. It was estimated that the use of the talc/wax liner on the lightweight 105mm round would put the wear life in excess of the fatigue life.

Serial firings of the rounds with TiO_2/wax additive showed that at least ten rounds had to be fired before the heat input reached a stable value. This heat input was much lower for the M392A2 APDS round with a folded TiO_2/wax liner than it was for the M456A1 HEAT round. This is consistent with the ten-fold higher wear life for the APDS round of 10,000 rounds.

An insert with the external configuration of a Kistler gauge was used to measure temperature. If this proved feasible, a common hole could be drilled into a barrel that could accomodate pressure, temperature, or erosion sensors. The insert, however, wore faster than the surrounding steel. The temperature readings for the thermocouple in the insert were twenty to thirty percent higher than those measured by an equivalent in-wall thermocouple. The insert also failed to record the lower temperatures when the TiO_2/wax-lined rounds were fired in series.

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per 7-19-78 telecon w/Vernon Wyatt (ARRADCOM) the Classified Reference can remain in this report.

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INTRODUCTION

Wear-reducing additives such as polyurethane foam and TiO_2/wax have markedly extended the useful life of high-velocity cannon[1]. The TiO_2/wax liner in the 105mm M392A2 APDS round extended barrel life of the M68 cannon from 100 rounds to 10,000 rounds[2], well in excess of the current fatigue life of 1,000 rounds[3]. The TiO_2/wax liner was also adopted for the Army's HEAT and HEAT training round[4], and a decision was made to use the same high-force, high-flame temperature M30 propellant developed for these antitank rounds in a family of propelling charges being developed for the new extended range howitzers. The high-force M30 propellant allowed designers to keep system weight low and to keep the chamber volume small, so that the howitzers could fire both high zone and low zone charges.

By placement of the TiO_2/wax liner in the charges with M30 propellant, it was assumed the cannon would still be condemned for metal fatigue. During engineering development of the new charges, it was evident that the TiO_2/wax liner did not afford the anticipated protection[5,6]. In addition, the TiO_2/wax liner in the fin-stabilized projectiles altered the wear profile. This alteration led to a lower condemnation limit for the M68 cannon[7,8]. This observation is of concern

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1 *A. C. Alkidas, M. Summerfield, and J. R. Ward, "A Survey of Wear-Reducing Additives and of the Mechanisms Proposed to Explain Their Wear-Reducing Action", BRL Memorandum Report No. 2603, March 1976, AD # B010280L.*

2 *T. E. Davidson, J. M. Giesey, M. Kraut, and A. N. Reiner, "Test Program to Establish Condemnation Limits for Gun Tubes, Part I (U)," Watervliet Arsenal Technical Report WVT-RI-6408, April 1964 (Confidential).*

3 *"Evaluation of Cannon Tubes", Department of the Army Technical Manual TM-9-1000-202-35, November 1969.*

4 *R. O. Wolff, "Reduction of Gun Erosion, Part II. Barrel Wear-Reducing Additive", Picatinny Arsenal Technical Report No. 3096, August 1963.*

5 *"DT II of the XM198, 155mm Howitzer-XM199E9 Tube Wear Investigation", Yuma Proving Ground Firing Report No. 13701, 1976.*

6 *J. A. Demaree, "155mm M185 Tube Wear Test of Charge Propelling XM201 Interim Report", JPG Test Report No. JPG-76-601, June 1976.*

7 *A. A. Albright and G. S. Friar, "Analysis of Wear Data from 105mm M68 Gun Tubes in Field Service", Watervliet Arsenal Technical Report WVT-TR-75047, July 1975.*

8 *A. A. Albright, E. E. Coppola and G. S. Friar, "The Influence of Late Wear Life 105mm M68 Gun Tubes on Discarding Sabot Ammunition Flight Stability", Benet Weapons Laboratory Technical Report ARLCB-TR-77034, July 1977.*

not only because HEAT rounds are still the main training rounds, but also because future service rounds, such as the M735 and XM774, have fin-stabilized projectiles and use the same liner as the HEAT rounds[9].

In order to understand how wear-reducing additives promote increased barrel life, particularly for firings of M392 APDS rounds, a series of experiments was conducted[10-12] using 37mm, 105mm, and 155mm guns, in which the heat transferred to the barrel was measured in a manner developed by Brosseau in 1974[13]. These experiments showed that the placement of wear-reducing additive around the propellant and the composition of the additive were critical to heat transfer reduction. The additive was most effective when placed along the chamber wall as close as possible to the projectile base. It was learned that flaps folded over the forward end of the propelling charge further enhanced the heat transfer reduction. The TiO_2/wax additive was shown to be superior to polyurethane foam because an insulating layer composed of TiO_2 and condensed wax formed on the barrel. It was also demonstrated that rounds with similar barrel wear rates yielded similar heat inputs; hence, the erosivity of a given round could be inferred from comparison with temperature measurements of rounds with known wear rates.

In the UPGUN Program, temperature measurements are being made on an M68 tank cannon to try to predict the erosivity of a new fin-stabilized projectile, denoted as the 105mm APFSDS growth potential projectile, by comparing heat input of the new round with heat inputs measured for standard 105mm rounds with known wear rates. In addition, measurements are

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9 *"Artillery Ammunition Master and Reference Calibration Chart", TECOM Report No. 1375, Eighteenth Revision, May 1977.*

10 *T. L. Brosseau and J. R. Ward, "Reduction of Heat Transfer to Gun Barrels by Wear-Reducing Additives", BRL Memorandum Report No. 2464, March 1975, AD #B003850L.*

11 *T. L. Brosseau and J. R. Ward, "Reduction of Heat Transfer in 105mm Tank Gun by Wear-Reducing Additives", BRL Memorandum Report No. 2698, November 1976, AD #B015308L.*

12 *J. R. Ward and T. L. Brosseau, "Effect of Wear-Reducing Additives on Heat Transfer into the 155mm M185 Cannon", BRL Memorandum Report No. 2730, February 1977, AD #A037374.*

13 *T. L. Brosseau, "An Experimental Method for Accurately Determining the Temperature Distribution and the Heat Transferred in Gun Barrels", BRL Report No. 1740, September 1974, AD #000171L.*

being made for fin-stabilized rounds with wear reducing liners in different configurations to see if the erosivity of the present fin-stabilized rounds can be reduced. Sequential firings were made with rounds with the TiO_2/wax liner to determine how many rounds must be fired to achieve stable heat input to the barrel. Such determination is needed to correlate observed wear from wear tests with heat input and to judge the efficiency of new metal oxide/wax additives. A final portion of the test series consisted of temperature measurements made with an insert that contained a thermocouple. If such an insert proved successful, the insert could be used to measure heat input in a number of guns, and this would eliminate the need to weld thermocouples for each gun tested.

EXPERIMENTAL PROCEDURES

Heat transfer measurements were taken in a new M68 cannon (SN 24849) manufactured at Watervliet Arsenal. Four constantan wires, 0.13mm diameter, were welded with a capacitive discharge to the gun steel to form the thermocouple junctions. Each junction was over a groove, and each junction was 641.4mm from the rear face of the tube (RFT). This location is where the vertical land diameter is measured in order to assess the remaining barrel life[3]. The thermocouples were placed at different distances from the bore surface as denoted below:

Thermocouple No.	Position	Distance from Bore Surface, mm	Barrel Wall Thickness, mm
1	3 o'clock	0.87	59.49
2	9 o'clock	1.12	59.77
3	6 o'clock	1.50	59.33
4	12 o'clock	2.64	59.64

Table I summarizes pertinent characteristics of the standard ammunition fired in the test series. The M392A2 APDS round contains either polyurethane foam glued to the cartridge case wall[14] or a loose TiO_2/wax liner. The TiO_2/wax liner has flaps that fold over the top of the propelling charge to keep the liner from slipping during storage and handling[4]. The M456A1 HEAT and M490 TP-T rounds have a TiO_2/wax liner glued to the cartridge case wall some ten centimeters from the neck of the case[4]. The standard TiO_2/wax liner in the HEAT round is shorter than the serrated liner in the APDS round (24.1 cm vs 30.5 cm).

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14 *R. Wolff, "Reduction of Gun Erosion - Part I. Laminar Coolant", Picatinny Arsenal Technical Report No. 3096, May 1963.*

Table I. Pertinent Ammunition Characteristics[a]

Round	Propellant			Projectile		Primer	Muzzle Velocity, m/s	Chamber Pressure MPa
	Type	Web, mm	Mass, kg	Type	Mass, kg			
M392A2 APDS-T	M30	1.16 MP	5.602	M392E3	5.874	M80A1	1485.9	414.4
M467 TP-T	M1	0.86 MP	2.744	M468	11.25	M86	731.9	165.5
M456A1 HEAT-T	M30	1.35 MP	5.205	M456A1	10.31	M83	1173.5	419.2
M490 TP-T	M30	1.35 MP	5.188	M489	10.14	M83	1173.5	410.2
M735 APFSDS-T	M30	1.17 MP	5.670	M735	5.788	M120	1501.1	417.2

[a] Taken from Reference 9.

For test purposes some of the standard ammunition was modified before test firing. The modifications are discussed below, and a correlation between lot numbers of standard and modified ammunition together with a listing of the modifications are presented in Table II. Wear-reducing liners were removed from both HEAT and APDS rounds and the cartridges reassembled and crimped. Talc/wax liners with the same dimensions were substituted for the standard HEAT-type liners. In another set of HEAT rounds, the standard HEAT-type liners were replaced by the longer APDS-type liners. M735 APFSDS rounds were used to see if flaps have an effect in fin-stabilized rounds. The fins on the HEAT projectiles are full-bore diameter which precludes moving the liner closer to the cartridge case neck. The six M735 cartridges were assembled with the M148A1B1 steel case used with the HEAT rounds. This case comes with the HEAT-size liner already glued to the side. These liners were removed for the shots without additive; for the shots with the APDS liner, the HEAT liner was taken out and longer APDS liner placed in the case as if one were loading APDS rounds. The fins of the M735 projectile were put into the propellant, then the flaps were folded over the propellant bed and around the projectile. These rounds were uncrimped.

The 105mm APFSDS growth-potential projectile was simulated with a 105mm APDS slug that was lightened to 5.33kg. An APDS wear-reducing liner was placed in the case as if loading an APDS round except the liner was glued to the cartridge case and flaps were not folded over the propellant bed. The brass M115 cartridge case was crimped to the APDS slug. The growth potential round has a nominal muzzle velocity of 1565 m/s and a chamber pressure of 414 MPa.

The thermocouple plug has the external configuration of a Kistler 607A gauge. The thermocouple junction in the plug was placed the same distance from the bore surface as thermocouple No. 2. The plug was inserted 15.9 mm closer to the muzzle than the four in-bore thermocouples. The plug was placed in the same groove over which thermocouple No. 2 had been welded.

DISCUSSION OF TEST RESULTS

The firing sequence is reported in Table III. The HEP rounds were used as either warmer rounds to check instrumentation at the start of firing or to clean the residue on the barrel left by previously fired rounds with TiO_2/wax or talc/wax liners.

Heat inputs were computed from the temperature rise of each thermocouple 100ms after propellant ignition. Three-round replicates were fired for most modifications; temperature variations were similar to those reported earlier[11,13]. The greatest range in temperature for any thermocouple was 5 K. This range was seen in the thermocouple

Table II. Lot Numbers and Modifications of Ammunition Fired in the Test Series

Ammunition	Lot NO.	Modification
M392A2 APDS (no liner)	MA-12-1	removed TiO_2/wax liner
M392A2 APDS (polyurethane liner)	MA-9-4	none
M392A2 APDS (TiO_2/wax liner)	MA-12-1	none
M467 HEP	MA-30-10	none
M490 HEAT (no liner)	PB-30-38	removed TiO_2/wax liner
M456A1 (inert loaded) HEAT	MA-94-17	none
M490 HEAT-TP	MA-102-34	none
M490 HEAT-TP (talc liner)	PB-30-38	removed TiO_2/wax liner. substituted talc/wax liner with same dimensions.
M490 HEAT-TP (long liner)	PB-30-83	removed TiO_2/wax liner substituted TiO_2/wax liner from M392.
M735 APFSDS (no liner)	Delta Model 23 projectile	M83 primer; uncrimped case
M735 APFSDS (flaps)	Delta Model 23 projectile	M83 primer; uncrimped case; TiO_2/wax liner folded over fins.
M735 APFSDS (standard liner).	Delta Model 23 projectile	M83 primer; TiO_2/wax glued on M148A1B1 case. This is the same as HEAT rounds.

Table III. Test Firing Sequence

Round no.	Round Description	Purpose/Remarks
	20 September 1977	
1	HEP	warmer
2	HEP	warmer
3-5	HEAT TP-T w/o liner	
6-8	APDS w/o liner	
	22 September 1977	
9	HEP	warmer
10-12	APDS polyurethane	
13	HEAT TP-T	
14	HEP	clean-out
15	HEAT TP-T	
16	HEP	clean-out
17	HEAT TP-T	
18	HEP	clean-out
19	APDS TiO_2/wax	
20	HEP	clean-out
21	APDS TiO_2/wax	
22	HEP	clean-out
23-25	APDS TiO_2/wax	
	23 September 1977	
36-42	APDS TiO_2/wax	
43	HEAT TP-T w/o liner	clean-out
44-46	HEP	clean-out
47	HEAT (inert loaded)	
48	HEP	clean-out
49	HEAT (inert loaded)	
50	HEP	clean-out
51	HEAT (inert loaded)	
52	HEP	clean-out
53	HEAT TP-T talc/wax	
54	HEP	clean-out
55	HEAT TP-T talc/wax	
56	HEP	clean-out
57	HEAT TP-T talc/wax	
58	HEP	clean-out
59	HEAT TP-T long liner	
60	HEP	clean-out
61	HEAT TP-T long liner	
62	HEP	clean-out
63	HEAT TP-T long liner	
64	HEP	clean-out
65-66	APFSDS w/o liner	

Table III. Test Firing Sequence
(Continued)

Round No.	Round Description	Purpose/Remarks
	26 September 1977	
67	HEP	clean-out
68-76	HEAT (inert loaded)	
	27 September 1977	
77-80	HEAT (inert loaded)	
81-83	HEP	clean-out
84	APFSDS standard liner	
85	HEP	clean-out
86	APFSDS standard liner	
87	HEP	clean-out
88	APFSDS flaps	
89	HEP	clean-out
90	APFSDS flaps	
91	HEP	clean-out
92-96	APDS TiO_2/wax	no cooling between shots; firing rate approximately a round/minute
97-98	APDS partially removed polyurethane	expenditure; no cooling between shots
99-123	HEP	expenditure; no cooling between shots
	10 November 1977	
124-127	HEP	clean-out
128	APDS (light slug)	
129	HEP	clean-out
130	APDS (light slug)	
131	HEP	clean-out
132	APDS (light slug)	
133	HEP	clean-out
134	HEAT (inert loaded)	recheck with 27 Sep results
135	HEP	clean-out
136	HEAT (inert loaded)	
137	HEP	clean-out
138	HEAT (inert loaded)	

nearest the bore surface. The mean temperature of each thermocouple was used in plots of the product of temperature rise and radial distance to the thermocouple vs distance to bore surface to compute heat input. Heat inputs for inert-loaded M456A1 HEAT and M490 TP-T rounds were the same, so no attempt to distinguish between these rounds is made.

Table IV summarizes the heat input, Q, measured for each standard round and each modified round, and the lowest heat input recorded during sequential firings of rounds with the TiO_2/wax liners. The corresponding wear rate is listed if it is available.

Table IV. Summary of Heat Input Measured 641.4mm RFT

Round	Modification	Q, J/mm	Wear, mm/rd, x 10^4
APDS	no liner	449	180
APDS	polyurethane foam	416	41
APDS	TiO_2/wax, flaps	381	
APDS	TiO_2/wax, flaps, minimum	348	1.8
HEAT	no liner	471	~200
HEAT	TiO_2/wax	421	
HEAT	TiO_2/wax, minimum	412	18
HEAT	talc/wax liner	383	
HEAT	APDS liner	394	
APFSDS	no liner	451	
APFSDS	TiO_2/wax	405	
APFSDS	TiO_2/wax, flaps over fins	402	
APDS	TiO_2/wax with 5.23kg slug	406	
HEP		312	~0.9

One goal of this series of firings was to estimate the erosivity of the light APDS slug fired with 19-perforated M30 propellant. Table V contains single-shot heat input data for APFSDS and APDS rounds. The similar results for the APFSDS and APDS projectiles without additive shows that the presence of the fins may not be significant in determining erosivity. Hence, the use of a slug to simulate the 105mm APFSDS growth-potential projectile is valid. The heat input results also predict that the growth-potential round and the M735 cartridge will have similar wear rates.

Table V. Comparison of Single-Shot Heat Transfer Data for 105mm Discarding Sabot Rounds

Round	Q, J/mm
APDS no liner	449
APFSDS (M735, no liner)	451
APDS (polyurethane foam)	416
APDS (TiO_2/wax, flaps)	381
APFSDS (M735; TiO_2/wax)	405
APFSDS (5.23kg slug)	406

The data in Table V also demonstrate the superiority of the TiO_2/wax liner with flaps over the polyurethane foam liner, even before one includes the insulating effect from repeated firings with rounds with TiO_2/wax liners.

A second area of interest was to modify the configuration of the additive in present fin-stabilized rounds. Secondary wear from the HEAT training round has led to reduction of the condemnation criterion for the M68 cannon from 1.90mm land diameter increase at 641.4mm RFT to 1.42mm[7,8]. By modifying the liner in the fin-stabilized rounds to imitate placement of the TiO_2/wax liner in the APDS round, it is hoped both primary and secondary wear rates may be reduced significantly.

The present HEAT round has full-bore diameter fins, hence the TiO_2/wax liner cannot be moved closer to the neck of the cartridge case. This left two other modifications available, namely replacement of TiO_2/wax with a talc/wax liner, and replacement of the short TiO_2/wax liner in the HEAT round with the longer TiO_2/wax liner used in the M392 APDS round. The M735 projectile has sufficient space between the fins and cartridge case wall to permit moving the liner, hence the liner in the M735 was replaced with a TiO_2/wax liner from the APDS round. The liner was placed at the neck of the case and the flaps were folded over the fins after the fins had been loaded into the propellant bed. This appeared as close as one could come to imitating the configuration of the TiO_2/wax liner in the APDS round in a fin-stabilized round. The results for these rounds are listed in Table VI.

Table VI. Heat Transfer Measurements with Fin-Stabilized Projectiles

Round	Q, J/mm	Percent Reduction
HEAT (w/o liner)	471	-
HEAT (std TiO_2/wax liner)	421	11
HEAT (longer TiO_2/wax liner)	394	16
HEAT (talc/wax)	383	19
M735	451	-
M735 (std TiO_2/wax liner)	405	11
M735 (TiO_2/wax, flaps)	402	12

The results suggest that substitution of the longer APDS liner or substitution of talc/wax will significantly decrease heat input to the barrel for the present HEAT rounds.

Talc was proposed as a substitute for TiO_2 by Picatinny Arsenal investigators based on experiments performed with a vented-chamber apparatus[15,16]. Some limited firings were done in the M68 tank cannon[17]. Fifty-round groups of M456A1 HEAT rounds were fired with their standard TiO_2/wax liner and with talc/wax liners. Fifty-round groups of M392 APDS rounds were also fired with a short, HEAT-type, TiO_2/wax liner and with talc/wax liners. The results of these tests taken from reference 17 are given in Table VII. The limited data support the contention that substitution of talc/wax for TiO_2/wax will lower the erosivity of the 105mm HEAT rounds. The data also demonstrate the efficiency of the flaps on the standard APDS liner, since the M392 with its standard liner would have produced no wear in fifty rounds[2]. This trend is also seen in the heat transfer measurements. The lowest heat input for any TiO_2/wax liner was with the APDS liner with flaps.

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15 *J. P. Picard, R. G. Wetton, and R. L. Trask, "A New Additive for Reducing Gun Barrel Erosion", Picatinny Arsenal Technical Memorandum Report No. 1781, May 1967.*

16 *J. P. Picard and R. L. Trask, "A New Gun Barrel Erosion Reducer", J. Spacecraft and Rockets, 5, 1487 (1968).*

17 *D. H. Fletcher, "Final Engineering Report on Engineering Design Test of Ammunition Additive for 105mm Gun, M68 (Improvement of Additive Effect)", DPS Report No. 2368, May 1967.*

The results in Table VI also show that the APDS liner with flaps yielded no improvement over the standard HEAT liner. Apparently, the fins of the M735 slug preclude the functioning of the flaps. One would predict however, that substitution of a 30.5cm long talc/wax liner for the 24.1cm long TiO_2/wax liner would offer improvement in barrel life for the M735 projectile based on the results with the fin-stabilized HEAT rounds.

Table VII. Tube Wear Data for Talc/Wax Liners Fired in 105mm Ammunition

Round	Number Fired	Pullover Measurement[a], mm (inches) Vertical	Horizontal
M456A1 (std TiO_2)/ wax	54	0.08 (0.003)	0.15 (0.006)
M456A1 (talc/wax)	50	none	none
M392 (HEAT-type liner)	50	0.10 (0.004)	0.10 (0.004)
M392 (talc/wax)	50	none	none

[a] Pullover measurements made at 641.4mm (25.25") RFT.

Another objective of the test series was to see how the heat input changed when repeated firings were made with APDS and HEAT rounds loaded with TiO_2/wax liners. Previous results[11,18] showed the heat input was reduced by firing repeated rounds with TiO_2/wax additive. Presumably, an insulating layer of TiO_2 and condensed wax is building on the bore surface. In this series, sufficient rounds were fired to determine the maximum heat reduction achieved for both HEAT and APDS rounds. Marked differences in heat input could explain why the barrel wear life with the APDS round is ten times greater than the 1,000 rounds for the HEAT projectiles. Table VIII summarizes the results of these test firings and gives the number of rounds needed to achieve stable heat input to the barrel.

[18] *F. A. Vassalo, "Heating and Erosion Techniques Applied to the Eight-Inch Howitzer", Vol. I, 12th JANNAF Combustion Meeting, CPIA Publication 273, December 1975.*

Table VIII. Heat Input Data for Serial Firing of APDS and HEAT Rounds

Round	Q, J/mm	Percent Reduction
APDS (no liner)	449	-
APDS (polyurethane)	416	8
APDS (single-shot with TiO_2/wax)	381	18
APDS (minimum with TiO_2/wax)[a]	348	29
HEAT (no liner)	471	-
HEAT (single-shot with TiO_2/wax)	421	11
HEAT (minimum with TiO_2/wax)[b]	412	12

[a] Thirteen rounds to establish minimum heat input.

[b] Ten rounds to establish minimum heat input.

Table VIII clearly demonstrates the superiority of the TiO_2/wax liner in the M392A2 round. It is also noteworthy that repeated firings with the HEAT round provide little extra protection.

The last objective of this test series was to see if a plug that fit flush to the bore surface could be used to house a thermocouple. As mentioned previously the advantage of this technique is a hole could be drilled into the barrel that could be used to measure pressure, temperature, or erosion[19]. In addition, the plugs could be fabricated with thermocouples at different distances from the bore surface. In the plug-housing experiment, the thermocouple plug had the external configuration of a Kistler gauge with the thermocouple 1.12mm from the bore surface. From the start of the test series, the thermocouple plug measured temperatures twenty percent higher than thermocouple No. 2; the difference grew larger as the firing progressed reaching thirty percent at the end of the firing series. When the plug was removed from the barrel, the reason for the diverging temperature readings was apparent. Over two millimeters had been eroded from the surface of the thermocouple plug. Reference 17 reports an attempt to measure bore surface temperatures in an M68 tank cannon with a Namac Corp. commercial thermocouple. The surface of this thermocouple eroded in a similar fashion. The high temperatures recorded by the thermocouple plug at the start of firing presumably resulted from gas leaking around the side of the insert. The thermocouple then sensed heat from the side of the probe as well as from the surface. An interesting note was that the thermocouple probe failed to detect the decreasing heat input when the APDS and HEAT rounds with TiO_2/wax liners were fired in series.

[19] *S. E. Caldwell and A. Niiler, "The Measurement of Wear from Steel Using the Radioisotope ^{56}Co", BRL Report No. 1923, September 1976.* (AD #A030262)

CONCLUSIONS

a. The 105mm growth-potential round should have a 30.5cm-long, talc/wax liner. This liner should be glued to the cartridge case and placed as close as possible to the projectile's base. Such a liner should keep the wear rate of the growth-potential round below the 0.0018 mm/round for the M456A1 cartridge. The M68 cannon is now condemned for wear when origin wear exceeds 1.42mm before 1,000 full-charge rounds are fired. If the wear rate of the growth potential round is less than 0.0014 mm/round, the M68 cannon would be condemned for metal fatigue rather than excessive wear when the growth-potential round is fired through it.

b. The 30.5 cm-long, talc/wax liner should also reduce the wear rate of the fin-stabilized M456A1, M490, M735, and XM774 cartridges.

c. The present M735 projectile with a TiO_2/wax liner should wear near the origin of rifling similar to the M456A1 or M490 rounds.

d. Folding flaps over the fins of the M735 projectile did not reduce heat input any more than the standard, HEAT-size TiO_2/wax liner glued to the cartridge-case wall. This is in contrast to the ten-fold improvement in wear life for the M392A2 APDS round with a folded TiO_2/wax liner over the M456A1 round with a TiO_2/wax liner without flaps.

e. At least ten rounds with TiO_2/wax liners must be fired in sequence to achieve the minimum heat input to the barrel. Following this series of rounds, the heat input stabilizes.

f. A Thermocouple insert with the external shape of a Kistler gauge eroded faster than the surrounding steel. Temperatures measured with the insert were twenty to thirty percent higher than temperatures recorded by an in-wall thermocouple originally at the same distance from the bore surface as the thermocouple in the insert.

g. Full-scale wear tests should be conducted with talc/wax liners in the M456A1 and M490 cartridges. Attention should also be paid to whether the talc/wax liners decrease secondary wear as well as primary wear.

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