AD-A122 294 ROLE OF SURFACE OXIDE ON GUN BARREL WEAR(U) ARMY 1/1
ARMAMENT RESEARCH AND DEVELOPMENT COMMAND ABERDEEN
PROVI.. J R WARD ET AL. NOV 82 ARBRL-TR-02437
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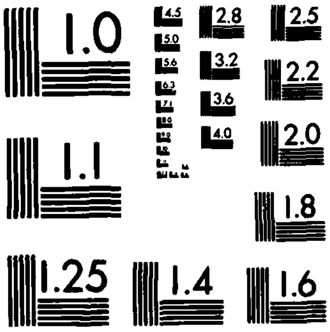

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TECHNICAL REPORT ARBRL-TR-02437

ROLE OF SURFACE OXIDE ON GUN BARREL WEAR

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November 1982

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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REPORT DOCUMENTATION PAGE		**READ INSTRUCTIONS BEFORE COMPLETING FORM**
1. REPORT NUMBER Technical Report ARBRL-TR-02437	2. GOVT ACCESSION NO. AD-A122294	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ROLE OF SURFACE OXIDE ON GUN BARREL WEAR		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J.R. Ward, R.P. Kaste, I.C. Stobie, and B.D. Bensinger		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS USA Ballistic Research Laboratory ATTN: DRDAR-BLI Aberdeen Proving Ground, MD 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS RDT&E 1L161102AH43
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Armament Research & Development Command US Army Ballistic Research Laboratory (DRDAR-BL) Aberdeen Proving Ground, MD 21005		12. REPORT DATE November 1982
		13. NUMBER OF PAGES 26
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Iron Oxide
Gun Barrel Wear
Gun Propellant
Blowout Gun

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) raj

Earlier analysis of gun tubes and steel nozzles exposed to propellant combustion gases showed that a tenacious oxide layer is left on the surface after firing. The thickness of the oxide layer was inversely proportional to the flame temperature of the propellant. Experiments were performed in a 37-mm blowout gun to determine whether the oxide layer influences wear. The experiments were performed with a nozzle that had been conditioned with M1, M30, M5, or M8 propellant. The results showed the oxide layer insulates the

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Abstract (Cont'd):

20. steel and reduces erosion. The wear with M8 propellant decreased as the flame temperature of the propellant used for the previous shot decreased. Conversely, the wear with M1 propellant increased as the flame temperature of the propellant from the previous shot increased.

These results show the Effective Full Charge (EFC) factors determined from standard wear tests may not predict total wear when rounds with different propellants are fired in combination. These results also suggest that if propellants with comparable flame temperatures produce different oxide thicknesses, the wear could be significantly greater for the propellant with the thinner oxide layer.

The oxide layer effect was shown in imbedded thermocouple tests in a 105-mm tank gun. The heat transfer was higher in an M392A2 round preceded by an M490 without a liner than a M392A2 preceded by an M467. The M467 conditions the barrel with a thicker oxide layer. A similar trend was shown with M490 rounds with conditioning rounds that had different oxide thicknesses.

The oxide layer effect was used to explain abnormally high wear in a study where M392A2 rounds and M467 rounds were fired alternately. The total wear was twice as great as predicted by the correlation of heat transfer from the M392A2 and the wear from a wear test of M467 TP-T rounds.

TABLE OF CONTENTS

LIST OF TABLES

I. INTRODUCTION

Earlier analysis[1,2] of steel nozzles exposed to propellant combustion gases showed that a tenacious oxide layer is left on the surface. The thickness of the oxide layer was inversely proportional to the propellant's flame temperature as illustrated in Table 1. If this oxide layer affects the subsequent round, it is conceivable that wear produced from firing rounds with different propellants will be much different than that expected from EFC factors determined from wear tests where rounds with a given propellant are fired continuously.

TABLE 1. OXYGEN CONCENTRATION PROFILES ON STEEL EXPOSED TO PROPELLANTS WITH DIFFERENT FLAME TEMPERATURES

Propellant	Flame Temperature, K	Oxygen, atoms/cm^2, x 10^{-16}
M2	3,375	9
M30	2,994	17
M1	2,480	34

In order to determine if wear was influenced by firing combinations of propellants with different flame temperatures, tests were run in a 37-mm blowout gun with M1, M30, M5 and M8 propellants. In one set of tests, M8 was fired alternately with another propellant to see the effect when the nozzle had a thin oxide coating. A second set of tests was run with M1 propellant to see the effect when the nozzle had a thick oxide deposit. The wear in these sets of tests was compared with wear from repeated shots with M8 or M1 propellant.

II. EXPERIMENTAL

The compositions of the four propellants used in the wear tests are listed in Table 2. Thermochemical properties computed by the BLAKE code[3] are listed in Table 3 where

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[1] *A. Niiler, J.E. Youngblood, S.E. Caldwell, and T.J. Rock, "An Accelerator Technique for the Study of Ballistic Surfaces," BRL Report No. 1815, August 1975.*

[2] *A. Niiler and R. Birkmire, "Composition Changes in Gun Steel Surfaces Due to Erosive Propellant Burn," Proceedings of the Tri-Service Gun Tube Wear and Erosion Symposium, Dover, NJ, March 1977.*

[3] *E. Freedman, "BLAKE - A Ballistic Thermodynamic Code Based on TIGER," Proceedings of the International Symposium on Gun Propellants, Picatinny Arsenal, Dover, NJ, October 1973.*

T = flame temperature,
F = impetus,
η = co-volume,
M = molecular weight,
C_p = specific heat,
γ = ratio of specific heats.

The wear measurements were done with a 37-mm blowout gun described earlier.[4] Wear was determined by weighing a contoured steel nozzle after each shot. In these experiments, the nozzle's throat diameter was 12.5 mm which gave a rupture pressure of 262 MPa (38 kpsi) with two 1.6 mm thick shear disks. Propellant charge masses were adjusted to give a closed bomb pressure of 306 MPa (44.4 kpsi) to insure shear disk rupture.

Baseline wear was determined by repetitive firings in which each propellant was fired alternately with M8, and then each propellant was fired alternately with M1 to test the effect of oxide layer on wear.

III. RESULTS AND DISCUSSION

The individual mass losses for all tests are listed in the Appendix.

Table 4 summarizes the effect on wear of M8 propellant as the propellants with progressively lower flame temperatures and thicker oxide coatings are fired alternately. One can see that the oxide acts as an insulator with the greatest difference in M8 when M1 propellant is the conditioning round.

Table 5 summarizes the reverse experiment in which one examines the effect on M1 wear as propellants leaving thinner oxide coatings are fired alternately. Again, the trend shows that the oxide insulates the steel, the difference in wear being greatest with M8. These results are plotted in Figures 1 and 2.

Tables 6 and 7 show the results for M5 propellant and M30 propellant, illustrating that there is no significant difference in wear regardless of the propellant used on the previous round. This suggests that there is a threshold thickness in the oxide which must be exceeded before measurable differences in wear are obtained, and the thicker the oxide the more protection provided. This is entirely analogous to the role TiO_2 plays in wear-reducing additives[5].

---

[4] *J.R. Ward and R.W. Geene, "Erosivity of a Nitramine Propellant with a Flame Temperature Comparable to M30 Propellant," BRL Memorandum Report No. 02926, June 1979.*

[5] *J.R. Ward and T.L. Brosseau, "Role of the Insulating Layer from TiO_2-Wax Liner in Reducing Gun Tube Wear," Proceedings of the 1980 JANNAF Propulsion Meeting, CPIA Publication 315, March 1980.*

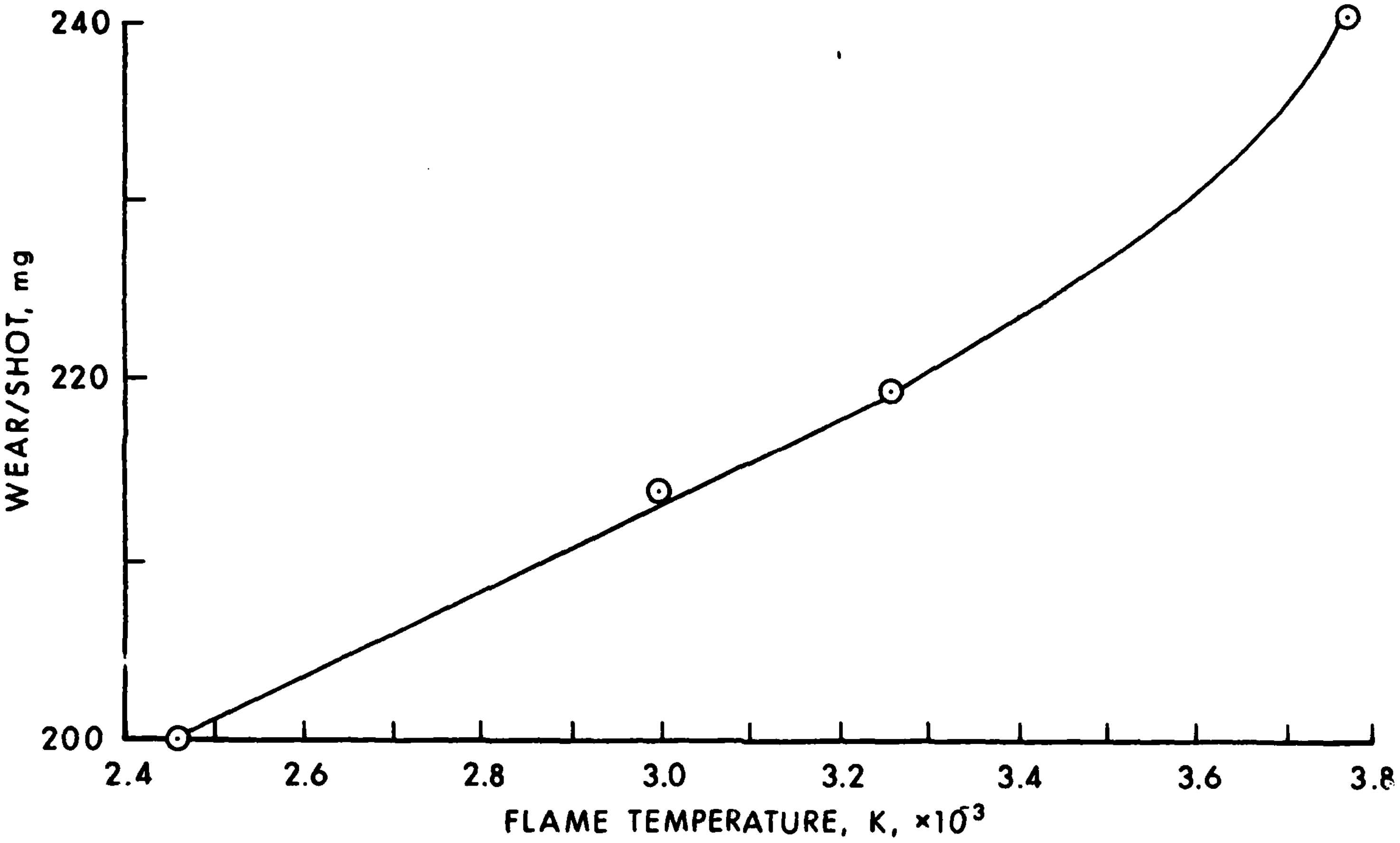

Figure 1. M8 Propellant Wear vs The Flame Temperature Of The Preceding Round.

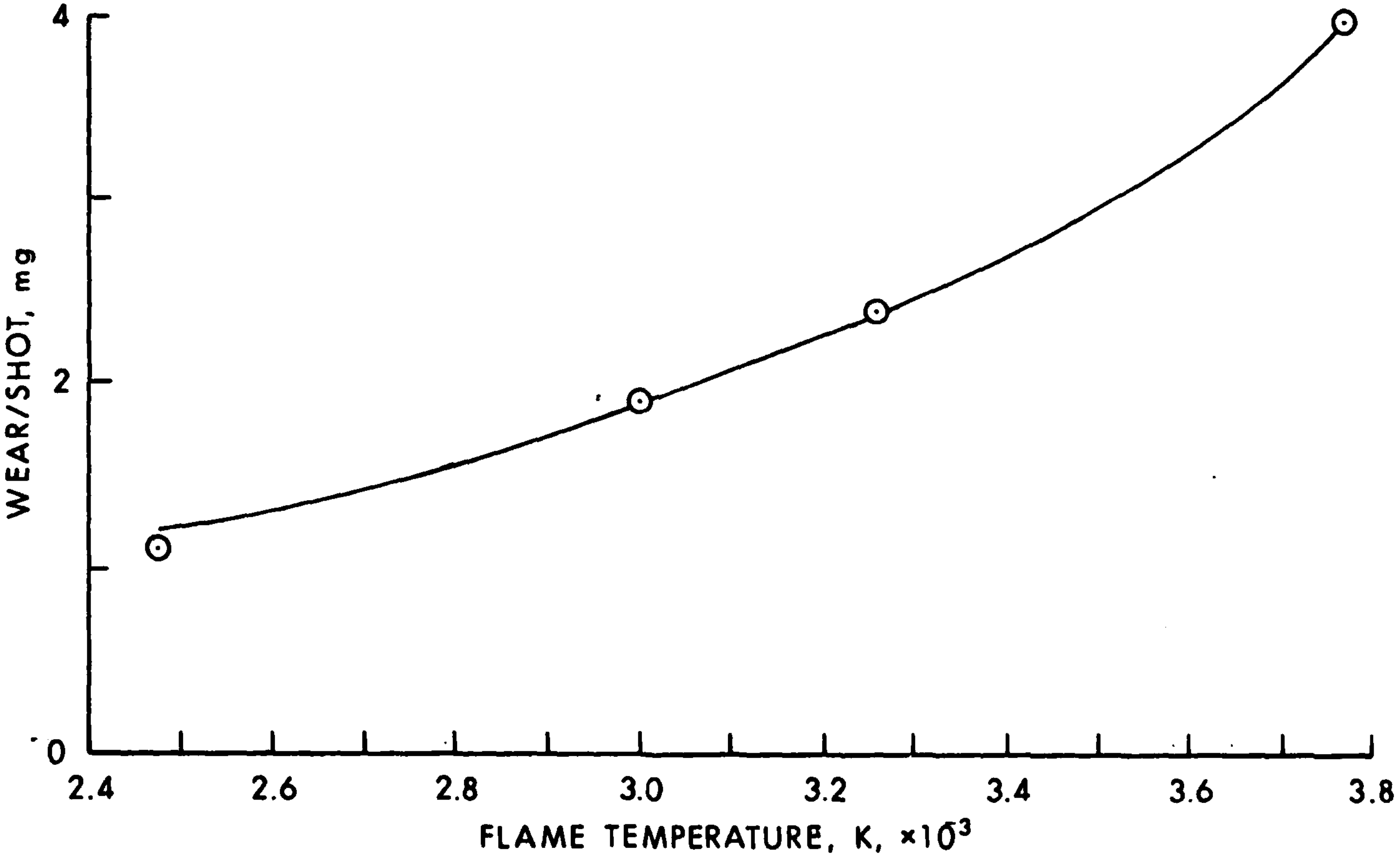

Figure 2. M1 Propellant Wear vs The Flame Temperature Of The Preceding Round.

TABLE 2. COMPOSITIONS OF PROPELLANTS
(weight percent)

	M5	M8	M1	M30
Nitrocellulose (Percent Nitrogen)	81.95 (13.25)	52.15 (13.25)	85.00 (13.25)	28.0 (12.6)
Nitroglycerine	15.00	43.00	-----	22.5
Nitroguanidine	-----	-----	-----	47.7
Ethyl Centralite	0.60	0.60	-----	1.5
Barium Nitrate	1.40	-----	-----	-----
Potassium Nitrate	0.75	1.25	-----	-----
Diethylphthalate	-----	3.00	-----	-----
Dinitrotoluene	-----	-----	10.0	-----
Dibutylphthalate	-----	-----	5.00	-----
Cryolite	-----	-----	-----	0.3
Diphenylamine, Added	-----	-----	1.00	-----
Ethyl Alcohol, Residual	2.30	0.40	0.75	0.2
Water, Residual	0.70	-----	0.50	-----
Graphite	0.30	-----	-----	-----

TABLE 3. SUMMARY OF THERMOCHEMICAL PROPERTIES AND COMBUSTION GASES OF PROPELLANTS

Prop	Temp K	Force J/g	η cm^3/g	M g/mole	CO*	CO_2*	H_2O*	H_2*	N_2*	C_p J/mole	γ
M8	3,716	1,178	0.970	26.2	13.0	6.4	10.2	2.4	5.4	47.7	1.22
M5	3,264	1,079	1.003	25.1	16.5	4.9	9.3	4.0	4.9	45.5	1.23
M30	3,021	1,078	1.050	23.3	11.8	3.0	10.5	5.5	11.9	41.1	1.24
M1	2,480	928	1.108	22.2	22.8	2.4	6.1	9.1	4.5	41.0	1.27

**Moles of gas/kg of propellant.*

TABLE 4. EFFECT OF SURFACE OXIDE ON WEAR WITH M8 PROPELLANT

Conditioning Propellant	Flame Temp K	Charge Mass, g	No. Shots	M8 Mass Loss mg/shot*
M8	3,716	68.4	6	240.5 ± 15.0
M5	3,264	72.8	3	219.3 ± 5.0
M30	3,021	72.2	2	219.5 ± 8.1
M1	2,480	80.09	3	199.6 ± 14.4

**Error expressed as sample standard deviation.*

TABLE 5. EFFECT OF SURFACE OXIDE ON WEAR WITH M1 PROPELLANT

Conditioning Propellant	Flame Temp K	Charge Mass, g	No. Shots	M1 Mass Loss mg/shot*
M1	2,480	80.09	5	1.1 ± 0.4
M30	3,021	72.2	4	1.9 ± 1.7
M5	3,264	72.8	4	2.4 ± 1.7
M8	3,716	68.4	4	4.0 ± 0.8

**Error expressed as sample standard deviation.*

TABLE 6. EFFECT OF OXIDE COATING ON WEAR WITH M5 PROPELLANT

Conditioning Propellant	Flame Temp, K	No. Shots	M5 Mass Loss, mg/shot*
M8	3,716	3	48.6 ± 3.7
M5	3,264	5	50.7 ± 6.0
M1	2,480	3	44.2 ± 3.1

**Error expressed as sample standard deviation.*

TABLE 7. EFFECT OF SURFACE OXIDE ON WEAR WITH M30 PROPELLANT

Conditioning Propellant	Flame Temp, K	No. Shots	M30 Mass Loss, mg/shot*
M8	3,716	3	12.3 ± 5.8
M30**	3,021	7	10.8 ± 3.1
M30**	3,021	6	3.9 ± 1.1
M1	2,480	4	5.5 ± 1.3

Error expressed as sample standard deviation.

***Different M30 lots used in alternate firings with M1 and M8.*

Some evidence for the insulation by low-flame temperature propellants in guns may be found by examining heat input with different "cleanout" rounds. If the heat input for the M392 round (M30 propellant) with an M467 cartridge (M1 propellant) as cleanout round reflects the contribution from the oxide deposit left by the M467 round, then the M392 cartridge should have higher heat input if the cleanout round were an M392 round without additive or an M392 round with polyurethane foam. Each of these rounds is more erosive than the M467 cartridge, hence each should leave a thinner oxide. The first experiments to measure heat input of 105-mm tank rounds did use M392 rounds minus TiO_2-wax additive as cleanout rounds, but the thermocouples were not in the same axial location as in the second test.[6] One can use data from rounds common to both tests to estimate heat input. Table 8 summarizes the heat transfer results where one first notes that total heat input decreases as one goes downbore. One would expect the heat input from an M392A2 round following an M392 round (no additive) to be higher than an M392A2 following an M467. The heat input for the M392 cleanout round is higher at 641mm RFT.

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

TABLE 8. EFFECT OF CLEANOUT ROUND ON HEAT INPUT FROM M392 CARTRIDGE*

Cartridge	Additive	Cleanout Round	Heat Input, J/mm 641mm**	667mm***	1,010mm***
M392A1	none	none	449	426	359
M392A2	polyurethane foam	none	416	401	342
M392A2	TiO_2-wax	M392 no additive	---	380	321
M392A2	TiO_2-wax	M467TP-T	381	---	---

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* *Axial distances measured from rear face of tube*
** *Reference 3*
*** *Reference 5*

Another opportunity to test the effect of previous rounds on heat input was in the evaluation of wear-reducing additives for the 105-mm tank cannon[7] where rounds without wear-reducing liners were used as "cleanout" rounds along with M467 TP-T cartridges. The pertinent data are listed in Table 9 where the heat input effect is reflected as the peak temperature of the thermocouple nearest the bore surface. The peak temperature for the M392A2 and the M490 cartridges, both with M30 propellant, was higher following a "no liner" cleanout round vs. the M467 TP-T (M1 propellant) cartridge.

TABLE 9. EFFECT OF CLEANOUT ROUND ON HEAT INPUT

Round	Temperature Rise, K	Cleanout Round, Propellant
M392A2	157	M490 (no liner), M30
M392A2	150	M467, M1
M490	182	M490 (no liner), M30
M490	174	M490 (no liner), M30
M490	167	M467, M1

The failure to see any change in wear for M5 and M30 propellants in the blow out gun, regardless of the propellant used on the previous shot, implies the difference in oxide thickness is not sufficiently thick to change the heat transfer rate to affect wear. An analogous situation illustrating this point

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[7] *I.C. Stobie, T.L. Brosseau, and R.P. Kaste, "Heat Transfer Measurements in 105 mm Tank Gun with M735 Rounds," Technical Report ARBRL-TR-02265, September 1980.*

involved a Navy experiment in which rounds were shot with three propellants having flame temperatures ranging from 2,100 to 3,000 K.[8] Charge weights were adjusted to give equivalent interior ballistics. Rounds were fired without wear-reducing additive and repeated with additive. Presumably, the oxide layer deposited was equivalent for each propellant, yet the change in wear was most dramatic for the 3,000 K propellant and not even measureable for the 2,100 K propellant.

Heat input could be used to determine which combination of rounds produces the most wear. For rounds with a wear-reducing additive depositing an insulating residue, the insulating residue from repeated firings of either TiO_2-wax additive of M1 propellant is not formed. Niiler, et al[9], recently showed the oxide from M1 propellant builds on repeated firing much like the residue from the TiO_2-wax liner.

IV. CONCLUSIONS

1. Gun barrel wear from propellant combustion gases is affected by the oxide left on the surface by the previous shot. The oxide acts as an insulator. Since the oxide thickness varies inversely with propellant flame temperature, wear increases following a shot with a higher flame-temperature propellant and decreases following a shot with a lower flame-temperature propellant.

2. The EFC factors determined from conventional gun wear tests where a given round is fired repeatedly will not predict wear when rounds with different flame temperatures are fired in combination.

3. Limited analysis of heat transfer results in the M68 tank cannon suggests the heat input is sensitive to the previous round. This suggests that the oxide layer influences wear in guns and heat input measurements can be used to determine what combination of rounds produces the worst wear.

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[8] *M.C. Shamblen, "Overview of Erosion in US Naval Guns," Proceedings of the Tri-Service Gun Tube Wear and Erosion Symposium, Dover, NJ, March 1977.*

[9] *A. Niiler, et al, report in preparation.*

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3. E. Freedman, "BLAKE-A Ballistic Thermodynamic Code Based on TIGER," Proceedings of the International Symposium on Gun Propellants, Picatinny Arsenal Dover, NJ, October 1973.

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

7. I.C. Stobie, T.L. Brosseau, and R.P. Kaste, "Heat Transfer Measurements in 105-mm Tank Gun With M735 Rounds," Technical Report ARBRL-TR-02265, September 1980.

8. M.C. Shamblen, "Overview of Erosion in US Naval Guns," Proceedings of the Tri-Service Gun Tube Wear and Erosion Symposium, Dover, NJ, March 1977.

9. A. Niiler, et al, report in preparation.

APPENDIX A

COMPILATION OF WEAR DATA

TABLE A-1. MASS LOSS FOR M8 (REPETITIVE FIRE)

ID	Nozzle	Charge Mass, g	Pressure, MPa	Mass Loss, mg
11	8*	68.4	**	236.1
14	8	68.4	228	230.1
16	8	68.4	234	228.8
19	8	68.4	234	253.0
22	8	68.4	228	265.0
24	8	68.4	228	230.0

---

* *New Nozzle*

***Not recorded*

TABLE A-2. MASS LOSS FOR M30 PROPELLANT (REPETITIVE FIRE)*

ID	Nozzle	Charge Mass, g	Pressure, MPa	Mass Loss, mg
25	T	72.2	241	7.6
28	T	72.2	248	16.5
31	T	72.2	241	12.3
34	T	72.2	241	8.1
37	T	72.2	241	11.9
39	T	72.2	241	9.1
41	T	72.2	241	9.9
75	58	72.2	**	4.6
78	58	72.2	**	3.0
81	58	72.2	**	4.7
84	58	72.2	**	2.3
86	58	72.2	**	5.3
89	58	72.2	**	3.7

---

* *ID 24-41 is M30 propellant used with M8 tests. ID 75-89 is M30 propellant used with M1 tests.*

** *Maximum chamber pressures not recorded.*

TABLE A-3. MASS LOSS FOR M1 PROPELLANT (REPETITIVE FIRE)

ID	Nozzle	Charge Mass, g	Pressure, MPa	Mass Loss, mg
71	5	80.09	234	1.5
74	5	80.09	*	1.1
77	5	80.09	228	1.5
80	5	80.09	*	0.8
83	5	80.09	*	0.6

**Chamber pressure not recorded.*

TABLE A-4. MASS LOSS ALTERNATING M8 WITH M30, M5, OR M1 PROPELLANT

ID	Nozzle	Propellant	Charge Mass, g	Pressure, MPa	Mass Loss, mg
12	58*	M8	68.4	**	299.2
15	58	M5	72.8	234	52.5
18	58	M8	68.4	234	221.1
21	58	M5	72.8	234	45.2
23	58	M8	68.4	228	222.8
26	58	M5	72.8	234	48.2
30	58	M8	68.4	**	214.0
33	58	M30	72.2	**	18.8
36	58	M8	68.4	221	213.8
28	8	M30	72.2	228	7.4
31	8	M8	68.4	234	225.2
34	8	M30	72.2	221	10.8
51	8	M1	80.09	234	1.6
54	8	M8	68.4	228	207.0
57	8	M1	80.09	228	4.3
60	8	M8	68.4	228	208.9
63	8	M1	80.09	234	4.4
66	8	M8	68.4	228	183.0
69	8	M1	80.09	228	2.8

---

* *New nozzle*

** *Not recorded*

TABLE A-5. MASS LOSS ALTERNATING M1, M5, OR M30 PROPELLANT

ID	Nozzle	Propellant	Charge Mass, g	Pressure, MPa	Mass Loss, mg
50*	5	M1	80.09	234	4.9
53	5	M5	72.8	248	40.7
56	5	M1	80.09	234	1.9
59	5	M5	72.8	234	46.6
62	5	M1	80.09	234	1.3
65	5	M5	72.8	234	45.2
68	5	M1	80.09	234	1.5
51**	8	M1	80.09	234	1.6
52***	58	M1	80.09	228	4.4
55	58	M30	72.2	228	5.4
58	58	M1	80.09	214	1.2
61	58	M30	72.2	221	5.6
64	58	M1	80.09	228	0.4
67	58	M30	72.2	****	4.0
70	58	M1	80.09	234	1.5
72	58	M30	72.2	****	7.1

---

* *Previous shot on nozzle 5 was M5 propellant (ID 35)*
** *Previous shot on nozzle 8 was M30 propellant (ID 34)*
*** *Previous shot on nozzle 58 was M8 propellant (ID 36)*
**** *Not recorded*

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