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LABORATORY STUDY OF PROPELLING CHARGE FOR 60 MM LIGHTWEIGHT MORTAR

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Picatinny Arsenal
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Renewed interest in the 60 mm lightweight mortar (LWM) resulted in the development of the XM720 cartridge. During development of the cartridge, questions arose relative to the effects of certain ammunition characteristics on the ballistics of the weapon. The ammunition characteristics considered most likely to affect ballistics were propellant weight, moisture, and the felted fiber increment container. Closed bomb studies were designed to determine if these characteristics affected ballistic results. It was concluded that the felted fiber increment container is hygroscopic

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and does not act as a barrier to moisture, which results in a significant change in ballistic characteristics of the weapon. Based on this laboratory study, a proving ground firing program is recommended.

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INTRODUCTION

Renewed interest in the 60 mm mortar as a lightweight mortar (LWM) system has led to a proposal for a new family of ammunition for that weapon. Technological advances made in the 81 mm mortar system were applied to the 60 mm program, culminating in the development of the XM720 cartridge.

M10 flake propellant (9 mils) in a horseshoe shaped high-density felted fiber container is used as the propelling charge for the 60 mm LWM. In the development of this round, there was some question as to the effect of various characteristics of the propelling charge on the ballistics of the weapon. The characteristics considered most likely to affect ballistic results were the propellant weight, the felted fiber container, and moisture. Therefore, a closed bomb laboratory experiment simulating actual firing conditions was designed to determine whether or not these characteristics affect a significant change in the ballistic performance of the weapon. The results of the experiment are documented in this memorandum.

DISCUSSION

Experimental Design

The experiment was designed as a 2^3 factorial in which there were three variables at two levels each. The variables and their levels are:

Variable	Level 1	Level 2
Propellant	Without increment	With increment
Humidity	Low	High
Charge weight of M10	Low (5 grams)	High (8 grams)

The closed bomb measurements reflected maximum pressure and burning time. The matrix of the experiment is shown in Tables 1 and 2. Three replications were made for each of the maximum pressure and burning time measurements.

Table 1

Maximum pressure (psi)

	Propellant (A_1) (8 grams)		Propellant + increment (A_2) (8 grams)	
	Low humidity (H_1)	High humidity (H_2)	Low humidity (H_1)	High humidity (H_2)
	6310	6170	7280	7060
	6240	6180	7290	7250
	6270	6190	7460	7330
$\bar{x}$ =	6273	6180	7343	7213

	Propellant (A_1) (5 grams)		Propellant + increment (A_2) (5 grams)	
	Low humidity (H_1)	High humidity (H_2)	Low humidity (H_1)	High humidity (H_2)
	3910	3770	4850	4740
	3850	3770	4830	4840
	3940	3800	4960	4820
$\bar{x}$ =	3900	3780	4880	4800

Table 2

Burning time (milliseconds) between 500 and 3,000 psi

	Propellant (A_1) (8 grams)		Propellant + increment (A_2) (8 grams)	
	Low humidity (H_1)	High humidity (H_2)	Low humidity (H_1)	High humidity (H_2)
	2.720	3.936	3.936	9.504
	3.104	4.128	4.064	9.472
	2.752	4.448	4.128	9.024
$\bar{x}$ =	2.859	4.171	4.043	9.333

	Propellant (A_1) (5 grams)		Propellant + increment (A_2) (5 grams)	
	Low humidity (H_1)	High humidity (H_2)	Low humidity (H_1)	High humidity (H_2)
	4.096	7.520	5.408	13.376
	4.288	5.952	5.984	10.784
	3.872	6.272	5.504	10.816
$\bar{x}$ =	4.085	6.581	5.632	11.659

Experimental Procedure

The tests were conducted by the Ballistics and Combustion Research Branch of FRL in a standard 190-cubic centimeter closed bomb at +70°F. The samples were ignited with a Hercules M100 match and one gram (g) of black powder. The combustion characteristics used to evaluate each test were maximum pressure and burning times between 500 and 3,000 psi. A Kistler 701H transducer was used to monitor the pressures. The output voltages were sampled at 32 microsecond intervals and stored in a Honeywell data acquisition system. The data was then printed out by an ASR 33 teletype unit for analysis.

Discussion

The felted increments evaluated in this experiment were high-density increments, manufactured by the Brunswick Corporation, Sugar Grove, Virginia, for propelling charge XM204, Mod 2, for 60 mm ammunition. The increments were loaded with M10 propellant (Lot PE 178-63, 9 mil).

The samples used to study the high humidity effect were conditioned in a 100 percent relative humidity desiccator at +70°F for one week. The gain in weight of the samples, thus exposed, is shown in Table 3. It can be seen that the percent gain in weight of the propellant is approximately the same whether it is conditioned in or out of the increment container. This indicates that the increment container is hygroscopic and does not act as a barrier to the moisture.

Table 3

Gain in weight of samples exposed to 100 percent RH and +70°F

Sample	Initial weight (grams)	Percent gain in weight
Propellant RAD PE 178-63	8.0	4.8
Propellant RAD PE 178-63	5.0	5.1
8g propellant + increment container	10.5	4.5
5g propellant + increment container	7.5	4.3
Empty increment container	2.5	3.2

Data from the closed bomb study is shown in Tables 1 and 2. Table 1 shows the maximum pressures obtained on the propellant and propellant-plus-increment at both high and low humidity levels. The high humidity level was achieved by conditioning the samples at 100 percent RH, while the low humidity level represents the samples as received without conditioning. Table 2 shows the burning time data for the same samples. The closed bomb data were collected in a random manner according to the factorial design mentioned previously. The increments weighed 2.5 grams (g). Some of them were loaded with 8 g of propellant to simulate the propelling charge for the weapon. These charges produced maximum pressures of approximately 7200 psi and constituted the high pressure level of the experiment. The other increments were loaded with 5 g of propellant. These produced pressures of approximately 4800 psi and represent the low pressure level of the experiment.

Table 4 shows the analysis of variance (ANOVA) of the factorial experiment for the maximum pressure measurements. Three parameters or variables were studied in this experiment. The loaded increments versus the propellant by itself, two levels of humidity (conditioned to 100 percent RH and nonconditioned), and two levels of pressure or charge weight. The high pressure was represented by the increment loaded with 8 g of propellant simulating the actual propelling charge of the weapon. The lower pressure was achieved by using a smaller (5 g) propellant charge with the increment container. This design was employed to determine if there would be any significant interactions between humidity, pressure, and propellant with and without increment.

Since the ANOVA was conducted to obtain the variation in the means, the variances were first confirmed as being homogeneous so the resultant variation could be properly attributable to the means. A preliminary test of significance (Bartlett's Test) was applied to the data to determine if the variances were homogeneous. Homogeneity having been established, an analysis of variance was then conducted on the data (Ref 1). In this analysis, that portion of the variance (sum of squares) attributed to each effect or assignable cause, is calculated. The sum of squares, for each, is then divided by the degrees of freedom to obtain the mean squares. Dividing the mean square by the error mean square, the F-test value for each is obtained. When the calculated F-test value exceeds the critical F-test value obtained from the literature (Ref 1), significance is assumed.

As shown in Table 4, the main effects, A (with or without increments), H (humidity), and P (pressure), all tested highly significant, the level of significance being considerably less than 1 percent.

The interactions evidenced no significant difference. There was not enough evidence to determine whether or not the increments, humidity, or pressure interacted in a way as to mutually affect each other.

The blocking effect was significant at 5 percent, but not at 1 percent. Therefore, it is not considered to be highly significant.

The absence of interaction implies that each of the main effects significantly affected the results, regardless of the other two effects.

Table 2 shows the burning time data for the samples in the experiment. The values shown represent the burning time, in milliseconds, between 500 and 3,000 psi of the

Table 4

Analysis of variance
(Max pressure measurements)

Source	Sum of squares	Degrees of freedom	Mean square	F-test
Main effects:				
A (w + w/o increment)	6,314,004.17	1	6,314,004.17	1,760.9[a]
H (humidity)	67,204.17	1	67,204.17	18.7[a]
P (charge weight)	34,920,937.5	1	34,920,937.5	9,738.9[a]
Interaction:				
AH	4.16	1	4.16	0.001
AP	4,004.163	1	4,004.163	1.12
HP	204.163	1	204.163	0.06
AHP	2,204.174	1	2,204.173	0.61
Residual error	(81,800.0)	(16)	(5,112.5)	
Blocking	31,600.0	2	15,800.0	4.41[b]
Corrected error	50,200.0	14	3,585.7	
Total	41,390,362.5	23		

Critical value of F^{1}_{14} = 4.60 (5%); 8.86 (1%)

F^{2}_{14} = 3.74 (5%); 6.51 (1%)

[a] Highly significant

[b] Significant

pressure curve. An inspection of the data shows that high humidity adversely affects the burning time of both the propellant with increment and the propellant by itself. This effect, however, seems to be greater with the propellant with increment than with the propellant alone.

To verify the validity of this assumption and to determine if any significant interactions had occurred, a nonparametric test was performed on the data. A nonparametric test was used for the burning time data, rather than an analysis of variance, because the variances were found to be nonhomogeneous (Barlett's Test). Therefore, a nonparametric analysis was applied to the data (Ref 2). The test used was the "Sign Test" in which the observations are paired and differenced, the number of plus and minus differences are counted, and the results are referenced into a special table of significant values. This test was done for all the main effects and the results were checked by the statistical H-Test according to the formula:

$$H = \frac{12}{N(N+1)} \sum \frac{(R_i)^2}{n_i} - 3\,(N+1)$$

where:

$N = \sum n_i$

R_i = sum of ranks of the ith sample.

The Sign Test was also computed for the interactions. The results of these tests are shown in Table 5.

Table 5

Nonparametric test analysis (Burning time measurements)

Main effects	
A (increment)	Highly significant (1%)
H (humidity)	Highly significant (1%)
P (weight)	Highly significant (1%)
Interactions	
AH	Significant (5%)
AP	Not significant (5%)
HP	Not significant (5%)

Table 5 shows that all three variables, propellant with and without increments (A), humidity (H), and pressure and charge weight (P), are all highly significant on the burning time data at the 1 percent level.

Table 5 also shows that there was one significant interaction at the 5 percent level. This occurred at AH [propellant with and without increments(A) and humidity (H)]. This interaction can be interpreted as follows:

AH: Subjecting the sample to 100 percent humidity significantly affects the results, but the effect is considerably greater on the propellant with increment than on the propellant without increment. The interaction HP [humidity (H) and pressure (P)] is not significant. The humidity does not affect one pressure level more so than the other at 100 percent RH. The interaction AP [propellant with and without increment (A) and pressure (P)] is not significant. There was not enough evidence to say that changing the charge weight had more effect on the propellant with increment than on the propellant without increment.

Thus, it can be seen that high humidity environmental conditions can seriously increase the burning time of the propelling system for the LWM. This can have a deleterious effect on the ballistics of the weapon.

Heat-of-explosion tests were conducted on both the felted increments and the propellant to determine how much energy each contributes to the total propelling system. Two determinations were made on each and are shown in Table 6. The heat of explosion of the propellant and increment is 967 calories per gram (cal/g) and 646 cal/g respectively. Based on these values, the heat of explosion of the loaded increment was calculated to be 891 cal/g. The increment contributes approximately 18 percent of the energy of the total system. It is suggested that the heat-of-explosion test be included as an acceptance criterion for the propelling charge of the 60 mm LWM. In the event of ballistic failure, this test will determine if the failure is due to the felted increments or the propellant. Otherwise, this differentiation could not be made.

Table 6

Heat-of-explosion tests

	Heat of explosion (cal/g)		
Sample	**Run 1**	**Run 2**	**Avg**
Propellant M10 (RAD 178-63)	966	968	967
Increments (Brunswick Hi-Dens)	645	646	646
Increment + propellant (calculated value)	–	–	891

CONCLUSIONS

1. Felted increments are hygroscopic and highly porous, causing transmittal of moisture to the propellant contained in the increment.

2. The high moisture content affects the maximum pressure of the propelling charge significantly.

3. The burning time between 500 and 3,000 psi is drastically affected by high moisture. In the case of the loaded increments, the burning time is increased by approximately 50 percent.

4. The increment contributes approximately 18 percent to the total energy of the propelling charge.

5. The moisture in the propellant can result in serious changes in the ballistic characteristics of the weapon.

RECOMMENDATIONS

Based on this laboratory study, it is recommended that a proving ground firing program be initiated for the 60 mm LWM to determine the effect of moisture on the ballistic characteristics of the weapon. If the increase in moisture seriously affects the ballistics, as is indicated in this laboratory study, an effort should be made to apply a coating to the increment to prevent the moisture from reaching the propellant.

A heat-of-explosion test should be included as an acceptance test for the propelling charge of the 60 mm LWM. This is advised so that in the event of ballistic failure, a determination can be made as to whether the failure is caused by the felted increment or the propellant.

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