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PREDICTION OF WEAR CHARACTERISTICS OF ARTILLERY PROPELLING CHARGES

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MARCH 1981

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Tube wear characteristics were assessed for modifications to propelling charges M119A1 and M203 (for 155-mm howitzer) and to propelling charge M188E1 (for 8-inch howitzer). The modifications involved a change in the ignition system for the M119A1, a change in wax type in the wear reducing liner of the M203, and a change in propellant (from M30A2 to M31A1) and change of amount of wear additive in the M188E1.

Comparison of relative total heat input to the gun tube is used to predict the effect on wear characteristics when charges of similar ballistics

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20. ABSTRACT - Continued

characteristics are compared. The modifications for the M119A1 and for the M203 did not affect tube wear characteristics of the charges. However, the modifications to the M188E1 (M188A1) are expected to double the wear life of the M201 gun tube observed with the M188E1 charge.

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INTRODUCTION

Tube wear and erosion caused by high performance propelling charges is a major problem, and considerable time and expense have been required to evaluate wear. In the past, such evaluation has involved the firing of several thousand rounds of each new charge, and the evaluation usually occurred at the end of a development cycle. If tube wear life was discovered to be unsatisfactory at this stage, a crash program had to be established to improve the wear and to avoid the rejection of the propelling charge.

Recently techniques have been development which allow an estimation of tube wear from measurements of total heat input and erosion taken on a group of five to ten firings. These techniques were successfully applied to testing of the high zone 155-mm propelling charge M203 (ref 1) and of the 105-mm high explosive antitank (HEAT) projectile M490-TP-T (ref 2). In these tests different configurations, types, and quantities of wear reducing additives were evaluated. It was found that, if a silicone ablator was properly placed in either the M203 charge or the M490-TP-T projectile, heat input was reduced by one third, which may translate into a wear life improvement of a factor of two or three. The same technique was also used to predict that a change in the wax used in the TiO_2/wax wear reducing liner of the M203 charge would not adversely affect the wear life in the 155-mm M199 cannon (ref 1).

During the past year modifications have been made to the propelling charges M119A1 (zone 8) and M203 (zone 8S) for the 155-mm howitzer and to propelling charge M188E1 (increaments 8 and 9) for the 8 inch howitzer. These unmodified charges are shown in figures 1 through 3. Several tests were performed to assess the effects on the tube wear characteristics of the charge. Wear testing of these modifications, testing methods, and analysis of the results are included below.

For the M119A1 the ignition system was changed from a basepad-and-center-core to a basepad-only system, and the effects of this change on the tube wear characteristics of the charge were determined. This modification is designated as the M119A2 charge.

The first residue problem with the M203 propelling charge was observed during safety testing, with charges preconditioned to 336 K. The residue consisted of large pieces of uncombusted cloth. During subsequent testing no residue occurred when the TiO_2/wax wear reducing liner was removed. Also, a change in wax to one having a melting point of 355 K instead of 344 K resulted in elimination of the residue in charges preconditioned to 336 K. However, heat inputs measured with the new wax indicated no change in tube wear characteristics (ref 1).

In subsequent firings of the M203 with the new wax, residue occurred periodically in charges preconditioned to 294 K. Again, the problem did not occur in charges without the wear reducing liner. The occurrence of residue was found to depend on the initial propelling charge temperature, tube temperature, and residence time of the M203 in the firing chamber before firing. All of these parameters affect the softening of the TiO_2/wax liner. Again a change in the wax in the wear reducing liner was found to solve the residue problem (ref 3).

To evaluate the effect of this change on the wear characteristics of the charge, the total heat input to the tube was measured for many different tube temperatures.

The M188E1 had a significant flash and blast overpressure problem, a wear problem, and a residue problem. To solve these problems, the M30A2 propellant in the M188E1 was replaced with the cooler burning M31A1 propellant. This modification is designated as the M188A1 charge. Calculations predicted that because of the lower flame temperature of the M30A2 propellant, flash and blast overpressure would be reduced and wear characteristics of the - charge would improve — even if less wear additive (liner) was used.

In residue tests on the M188E1, no residue occurred when the wear reducing liner was removed from the charge. Consequently, a need existed to evaluate the effect of removing the wear reducing liner from increments 8 and 9 of the charge and to determine if the wear reducing liner could be placed differently in the charge to eliminate residue and to maintain wear reducing performance.

EXPERIMENTAL

The wear reducing liner variations for the M203 and M188E1 were evaluated by the determination of the average values of the total heat input to the gun tube for several different test groups and by the comparison of these average values. Relative heat input values for charges of a similar basic type (e.g., for a group of M203 charges) provide a basis for judging the effectiveness of the variations in reducing tube wear. In one series of tests on the M188E1, erosion sensors were also used. The experimental work required the instrumentation of M185, M199, and M201 gun tubes with heat sensors and erosion sensors.

Tubes

Heat input data were obtained from tests using the four gun tubes listed below:

M185 tube no. 26787 (steel) M119A1/A2 tests (155-mm)
M199 tube no. 87 (chrome), M203 tests (155-mm)
M201 tube no. 9464 (chrome), M188A1 tests (8-inch)
M201 tube no. 25 (chrome), M188E1/A1 tests (8-inch)

Internal Heat Sensors

In all tubes except no. 25, thermocouple wells were installed near the origin of rifling to receive a thermocouple (internal heat sensor). Each well was flat-bottom-drilled to a measured distance from the inner bore surface at the center of the groove. A distance of approximately 1-mm from the bore surface was specified in order that the entire heating cycle be completed prior to achievement of maximum temperature at this depth. The internal heat sensor installation is shown in figure 4.

Wires of stainless sheathed 40 gauge chromel-alumel are forced into contact with the flat bottomed hole by the action of a compression spring. When contact is maintained, a thermocouple junction is formed at the contact points of the wires with the bottom of the well. If contact is lost for any reason no output will be present. Thus, when an output is generated, it directly represents the change in temperature at the contact point. Subsequent analysis yields the total local amount of heat input per unit area at the interior bore surface. As shown in figure 4, a small amount of silicone grease is placed in the thermocouple well prior to insertion of the thermocouple to fill void spaces and to decrease the small thermal resistance introduced by the presence of the hole. The thermocouple assembly is held in place by use of a 10-32 machine screw, which also imposes the required spring load on the thermocouple.

Tube 25 was instrumented with the same type of heat sensor as described above; however, the installation was different in that the initial hole was drilled all the way through and then plugged. The heat sensor was then placed in the plug approximately 1 mm from the bore surface. Thus, the heat sensor sensed the heat input to the plug. This arrangement could lead to higher heat inputs because of the discontinuity between the plug and the tube wall on the inner bore surface. The heat sensor in tube 25 (for M188E1/A1 tests) was placed about 0.120 m further from the rear face of the tube than in tube 9464 (for M188A1). This location could also lead to a different value for the total heat input.

The exact positions of the heat sensors with respect to the rear face of the tubes were:

Tube 26787 - 1.003 m (39.5 in.),
Tube 87 - 1.06 m (41.7 in.),
Tube 9464 - 1.136 m (44.716 in.),
Tube 25 - 1.25 m (49.4 in.).

Erosion Sensor

Tube 25 was also instrumented with two contoured erosion sensors at the origin of rifling (fig. 5). Because significant erosion per shot was anticipated at this location, accurate placement of the erosion sensors required the fabrication of special removable erosion sensor holders. The sensor holders were made from chrome-moly-vanadium steel and provided a means for adjusting surface match between sensor and holder, as well as a means for firmly fixing the sensors into position after adjustment. After fabrication each holder was inserted into its respective location in the tube and honed to produce an excellent fit to the bore curvature. Gas seals were provided by use of conventional O-rings.

The erosion sensors were machined in the shape of cylinders having a single O-ring groove at the approximate mid point. (See fig. 5). The inner face of the sensors was contoured to match the bore curvature. This face, after polishing, was fitted with a series of impressions made with a microhardness tester.

A diamond indenter of the Knoop type was employed for all erosion sensors. This indenter produces a sharp impression with a constant length-to-depth ratio of 30:1, independent of load, as illustrated in figure 6. Variation in impression depth could be obtained by changing the load on the microhardness tester. The impressions served as a gage by which erosion or wear could be measured after firing. The approximate depths of the Knoop impressions on each sensor range from 0.254 to 10.2 μm. After forming the surface impressions, the surface of each sensor was characterized prior to test by photomicrographs (SEM) at 275X magnification. The smallest impression was further photographed at 900X. Finally each sensor was weighed by means of an analytical balance.

Post test examination of the erosion sensor can indicate the amount of erosion in several ways. First, when gross erosion occurs, eliminating all impressions, total weight loss gives a direct measure of material loss. Second, when severe erosion occurs one or several impressions may be completely removed, thus indicating surface loss. Third, when minor erosion occurs, the impression lengths will shorten in direct proportion to depth change. Finally, very minor erosion is indicated by removal of surface polishing marks which are about 25 micrometers deep.

External Thermometer

A thermocouple thermometer was also attached to the external surface of the M199 tube at approximately 0.89 m (35 in.) from the rear face of the tube. This position was chosen so that the tube temperature could be correlated to previous residue test conditions where the temperature was measured at the same position.

PROCEDURE

Test Firings

The tests were conducted by ARRADCOM, Calspan Corporation, and proving ground personnel. The M119A1, M119A2, and M203 charges were tested at Jefferson Proving Ground, Madison, Indiana, and the M188E1 and M188A1 charges were tested at Dahlgren, Virginia, and Yuma Proving Ground, Yuma, Arizonia. The charges were preconditioned at the desired temperatures for at least 24 hours prior to firing. Ballistic data were obtained for all firings. Both copper crusher and piezoelectric gauges were used for pressure measurements and either coils or radar was used for velocity measurements. These data were obtained and corrected by proving ground personnel.

Two variations were compared in the M119 tests: (1) the M119A1, which has a basepad containing clean-burning igniter (CBI) and a benite center-core igniter, and (2) the M119A2, which has only a basepad with CBI. The A1 and A2 variations were fired alternately, both with the M107 projectile. A group of M119A2 charges was also used to fire the M483 projectile, and another group was then used to fire the M549 simulator (modified M107) projectile.

For the residue tests with the M203 charge an artificial method was developed for pre-heating the gun tube. The output of an oil fired heater was directed into the breech end of the tube until the external surface of the M199 tube reached the desired temperature. Two types of heaters were used at different times: one, a space heater unit and the other, a burner similar to the type used in a home heating unit. The external tube temperature and the residence time in the firing chamber before firing were recorded. Inert M107 projectiles were used for all residue test firings.

In the M203 residue tests, the only variable was the type of wax used in the wear reducing liner. Two types of charges were compared. One was fabricated with Indramic 170C wax, with a melting point of approximately 335 K (180 F), and the other was fabricated with Bareco 655 Polywax, which melts at 372 K (210 F).

Test firings of charges preconditioned at 222 K (-60 F), 294 K (70 F), and 336 K (145 F) were carried out over a range of gun tube temperatures. The tube temperature was measured by the external thermometer. This temperature was generally not equal to the inner chamber temperature. On one occasion the inside wall of the chamber was probed with a thermometer. The temperature was not uniform axially, and the external reading was approximately 14 K (24 F) higher than the inside reading at the same axial location. Groups with the two wax variations were fired at various tube temperatures.

A total of 500 rounds were fired during the Yuma Proving Grounds test with the M188A1 propelling charge and the M106 projectile in order to determine the tube wear characteristics. Half of these rounds were fired with the zone 9 increment and the other half without. Between the firing of the two groups, 50 zone 8 increments were fired alternately with M106 and M650 projectiles. Since the zone 8 increment contained no wear reducing liner, these 50 rounds served as cleaning rounds. Heat sensors were used to measure the total heat input to the gun tube during the firing of 120 rounds only (60 zone 8 increments and 60 zones 8 and 9) M106 projectiles were used for these 120 rounds. Pullover readings were taken prior to each day's firings. The tube was stargaged before and after firing of each group. Muzzle velocities and pressure were recorded on all rounds. Rounds were fired during 5- to 15-minute intervals; thus the external tube temperature remained essentially at ambient temperature.

A total of nine groups of tests were conducted in the Dahlgren wear evaluation. Heat sensors were used to determine the average of the total heat inputs during the firing of five shots, and erosion sensors were used to measure the total erosion during the five-shot firings. The number and variation in the series of shots can be seen in table 4. Further descriptions of charge variations in table 4 are shown below.

The listing for zone 9 of the M188A1 charge with 1/2 liner and flaps in zone 8 means that this charge contains in the zone increment, 1/2 the total length and weight of the TiO_2/wax wear reducing liner normally used in the M188E1 standard charge. In addition, the liner is moved forward and slit at the top, similar to the TiO_2/wax wear reducing liner in the M392A2 tank round. The resulting flaps are folded over the top of the zone 8 increment. This charge also contains a full length liner in increment 9. The term "flaps" in the rest of the descriptions shown in table 4 has a similar meaning. The dimensions of the liner in the M188E1 are 0.606 m (23 7/8 in.) x 0.373 m (14 11/16 in.) in the zone 8 increment and 0.593 m (23 3/8 in.) x 0.082 m (3 1/4 in.) in the zone 9 increment charge. The weight is 0.68 kg (24 oz).

Data Reduction for Heat Input and Erosion Sensors

The major data reduction in this investigation involved conversion of in-wall thermocouple outputs to total bore heat input per unit area and assessment of the amount of erosion by examination of appropriate erosion sensors. Conversion of in-wall temperature to heat input was based upon the theory (ref 5) that bore heat input per unit area is given by the expression

$$Q = \sqrt{\pi K c\rho_m \theta}\,(T(\theta) - T_o)$$

where Q is the local heat input per unit area at the heat sensor location

T_o is the initial in-wall temperature

θ is the time after firing

K is the thermal conductivity

$c\rho_m$ is the heat capacity per unit volume

θ is the time after firing.

Q is evaluated at successive time intervals of 0.1, 0.2, 0.3 seconds, etc., resulting in a plot of Q vs θ. The curve produced approached the desired heat input asymptotically.

The amount of erosion experienced by each erosion sensor was determined by comparison of the pretest and posttest scanning electron microscope (SEM) photographs. This comparison was made after careful ultrasonic cleaning (as confirmed by use of the SEM in the x-ray mode) and included visual study of the surface condition and measurement of impression depth change.

RESULTS

Test data for the M119 charge variations are summarized in table 1, including initial temperature of charge and average heat inputs. Average values and standard deviations were calculated for each test group. Test data are shown in tables 2 and 3 for the M203 charge, including ranges of external tube temperatures and average heat inputs. Heat input at two heat sensor stations are reported. Both stations were at the same axial position and were positioned radially between 11 and 1 o'clock. Table 4 shows the M188E1/A1 test data, including initial temperature of charge and average heat input; and table 5 indicates the tube wear produced during testing of the M188A1 propelling charge.

No erosion sensor data are given because the indentations made with the Knoop indenter were consistently filled with metal and the change in depth could not be accurately determined.

DISCUSSION

The purpose for comparing the heat input values for the M119A1 and M119A2 Charges was based on previous experience during the development of propelling charge XM201E2 (zones 6 and 7). The XM201E2 contained a TiO_2/wax wear reducing liner and originally had clean burning igniter (CBI) in the basepad ignition system. When a spot of black powder was added to the CBI, the total heat input to the tube was greatly reduced and the ignition delay was reduced to that obtained for charges with only black powder in the igniter. With this modified basepad containing CBI and with a doubling of the TiO_2/wax liner in the XM201E2 propelling charge, the tube life of the 155-mm howitzer increased to 3500 rounds from the 1000-round life previously achieved.

Ward and White (ref 4) observed considerable heating of the gun tube by the CBI igniter during simulator experiments conducted to ascertain why both the heat input and wear rate were so unexpectly high. Their results showed that the hot gases did not damage the TiO_2/wax liner. Therefore degradation of the wear reducing liner by hot gases with the CBI basepad was apparently not the cause of the increased heat input. Also, although Ward and White observed that an inert-loaded XM201E2 charge moved 5 cm towards the projectile base when fired with a black powder basepad vs a 2.5-cm movement toward the base when fired with a CBI basepad, no mechanism could be inferred from this observation. Thus a significant increase in heat input was effected by changing the ignition system, but the mechanism has not been determined.

Neither the M119A1 nor the M119A2 charges have a wear reducing liner. However, in view of the XM201E2 results, a question arose as to whether modification of the ignition system by the removal of the center core might influence the heat input to the gun tube and alter the wear characteristics. No significant difference was measured in heat input between the M119A1 and M119A2 propelling charges when fired with the M107 projectiles. The average values of the heat input for the M119A2 charges fired with the other projectile types are slightly lower (although within the standard deviations) there is again no significant difference compared to the M119A1. Thus, eliminating the benite center core does not appear to influence the heat transfer characteristics for the M119A2 charge.

A more recent modification of the M119A2 charge has a different configuration for the flash reducer package, and a small amount, (a spot) of black powder has been added to the CBI basepad. This modification is similar to that made to the XM201E2 propelling charge. In view of the XM201E2 results, it would be advisable to compare the heat inputs and wear characteristics of this modification with the M119A1 and the -A2 version containing only CBI in the basepad.

Wear reducing liners for the M203 propelling charge contain approximately 53.5% wax, 46% titanium dioxide, and 0.5% dacron fiber. The liners are approximately 2 mm thick. The dacron fiber helps to hold the liner together if it cracks during handling.

As a part of the M203 residue investigation, the melting characteristics of several waxes were determined from differential scanning calorimetry measurements (ref 3). Figure 7 shows the relative fractional heat absorbed by four different waxes as their temperature was increased at a constant rate. Shell 300 is representative of the wax originally used in the M203 charge. Indramic 170C and Polywax 655 are the waxes used in the charges compared in this study. The curves in figure 7, which reflect the fraction of the wax melted at any given temperature, can be used to compare the melting characteristics of the waxes. For example, Indramic 170C wax has a higher fraction of wax melted, up to 341 K (155°F), than the other waxes tested. These different characteristics occur because of the distribution of molecular weights in a particular type of wax.

The occurrence of residue could be almost completely eliminated by using Polywax 655. Although no direct evidence exists, the suggested mechanism is the enhanced liner breakup that a more brittle wax provides, which results in a decrease in cloth residue. It is inferred that a softened liner does not readily break up and disperse and that some of the cloth (which may be shielded from the hot propellant gases by the melting liner material) is not consumed and thus remains in the chamber after the firing. Polywax 655 is the most brittle of the waxes surveyed. More brittle and higher-melting-point waxes than the Polywax 655 are not amenable to the current manufacturing process for the wear reducing liner, because the temperature is limited by the available steam pressure.

Several parameters contribute to the softening of the wear liner prior to firing: (1) the initial charge temperature, (2) the gun chamber temperature, and (3) the time the charge spends in the chamber prior to firing. Consequently, all of these parameters were varied as a part of the residue testing. During these tests the heat inputs were monitored as well. The TiO_2 content was held constant with all wax variations. Thus, the tests compared heat inputs from M203 charges with wear reducing liners containing either Indramic 170C wax or Polywax 655.

As seen from tables 2 and 3, for a given charge type and preconditioning temperature there is a trend toward lower heat inputs as the tube temperature increases. This lower heat input is expected, since there will be less heat transferred to the bore surface as the temperature increases. According to the analysis the total heat input depends linearly on the initial temperature T_o. Figure 8 shows the decrease in measured heat input as a function of external tube temperature for a series of charges preconditioned to 336 K. A linear regression yields a coefficient of $-2.8\ kJ/m^2/K$ for this case and is representative of the values obtained for other groups in the series.

Heat sensor 2 gave slightly higher average values than heat sensor 1 in all cases but one; however, all results are consistently within the standard deviation.

When the baseline charges were compared with the modified charges, all of which were pre-conditioned to 294 K and fired at similar tube temperature, no significant differences in heat input to the tube were observed. Averaging over all available heat input values gives 108 ± 8 J/m^2 for the baseline and 112 ± 9 J/m^2 for the modified charges. Again, the averages are within the standard deviation. Similarly, where comparisons can be made with the 336 K charges, a significant difference does not exist. In the tube temperature range of 350 to 400 K the combined averages yield 105 ± 5 J/m^2 for the baseline charge and 104 ± 5 J/m^2 for the modified version. Thus we can conclude that the melting characteristic of the wax has little or no effect on the heat input to the gun tube. This fact is further substantiated by previous results reported for the first wax change (ref 1).

At the elevated tube temperatures used during these studies, the initial charge temperature (which determines the maximum pressure) has almost no effect on the heat input values. Previous results (ref 1) obtained in the range of 330 to 350 K indicated a much stronger pressure dependence. In general, the average heat inputs tended to be proportional to average peak pressure. The current data do not indicate higher values for the 336 K charge, which has the highest pressure; in fact, the average values are slightly lower than for the 294 K charges in both the baseline and modified charges. Likewise the 222 K charge, which has the lowest pressure, has heat input values comparable to the other groups fired at the same tube temperature range.

The wear rate in a gun tube is probably influenced more by the peak bore surface temperature than the total heat input. This bore surface temperature can be affected by a number of factors other than the total heat input to the tube:

1. The ignition portion of the ballistic cycle can contribute to the heat input since the hot gases from the igniter will produce a temperature rise which is integrated with that due to the convective heating during the later stages of the cycle. The low temperature conditioned charges, for example, have considerably longer ignition delay times. These longer ignition delays mean that the bore surface temperature of the gun tube will be increased before the propellant ignites. This heating could lead to a higher bore surface temperature.

2. The rate of heating also has an effect on the maximum temperature of the bore surface. The heating rate will depend on the pressure-time characteristics of the ballistic cycle. Faster heat input rates produce higher bore surface temperatures because the thermal conductivity of the steel, which determines the rate at

which heat is transferred away from the inner bore surface, is essentially constant with temperature. Wear probably depends more strongly on the rate of heat input than on total heat input since it is the rate that will determine the maximum temperature of the bore surface for comparable total heat inputs. Heat input values for the M119A1/A2 charges are higher than those observed with the M203 charge, however, the M203 charge has a higher wear rate than the M119A1/A2. Both factors 1 and 2 would influence these observed differences.

3. Another factor which will influence the wear difference in these charges is the pressure of the charge, which is much higher for the M203 than for the M119A1/A2. If the heat inputs are similar and are such that the bore surface temperature is below the melting point of the steel but is high enough to soften the steel, then the higher pressure will induce a much higher shear force, which causes a greater wear rate.

4. The melting characteristics of the TiO_2/wax wear reducing liner would be expected to influence both the peak bore surface temperature and the total heat input, especially at high tube temperatures. The gun tube heat input measurements for the M203 charge were obtained for tube temperatures which included values above and below the wax melting point (355 K for Indramic 170C and 372 K for Polywax 655). One might expect differing heat input values and corresponding peak bore surface temperatures depending on whether the bore surface is above or below the melting point of the wear additive. The effectiveness of the wear reducing liner may depend on the degree of softening of the wax prior to firing. The fact that it is dispersed differently when soft is evidenced by the cloth residue produced when the charge is preconditioned to higher temperature or by long residence times in the hot chamber prior to firing.

Brosseau et al. (ref 6) have proposed an empirical expression which relates wear rate of a gun tube to heat input and muzzle velocity. The relation predicts a constant wear rate for low values of the heat input and a rapid rise in wear rate above some threshold value of the heat input. This threshold value is not known for the 155-mm systems; however, it is expected to be in the range of 1 MJ/m^2. The wide range of heat input values measured within a given group of M203 charges (see table 3), which is exhibited by the large standard deviations, may mean that the

TiO_2/wax wear reducing liner places the M203 charge at the wear threshold. Thus, the wear rate would be very dependent on the method in which the liner is dispersed, and this dispersion could lead to a large shot to shot variation. Because of the various factors discussed above which can influence the heat inputs and wear rates, it is not obvious that the lower heat inputs observed at elevated tube temperatures necessarily correlate with lower wear rates. Further experiments are required to correlate the heat input to actual wear rates in the 155-mm system.

The wear life of the M188E1 charge in the M201 8-inch cannon was established as 1500 rounds for the zone 9 charge and 3000 rounds for the zone 8 charge, with 3.4 mm (0.135 in.) of wear measured at 1.17 m from the rear face of the tube representing the point of tube condemnation.

The M188E1 charge contains M30A2 propellant (i.e., M30 propellant containing about 2 to 3% KNO_3) and always a TiO_2/wax wear reducing liner. In contrast, the M188A1 charges listed in table 4 contain M31A1 propellant (i.e., M31 propellant containing about 1% K_2SO_4) with a wear reducing liner always in the zone 9 increment of the charge and with varying amounts of TiO_2/wax wear reducing liner in the zone 8 part of the charge. The M188E1 charge left large pieces of unburned cloth residue when fired under ambient conditions. If the wear reducing liner was removed from this charge, no residue was left in the chamber.

If the M188A1 charge is judged in terms of lowest heat input and least wear, the charge with the TiO_2/wax in the flap configuration in the zone 8 and also in zone 9 part of the charge would be selected. However, if the wear reducing liner is kept in both zones in this charge, large amounts of residue are observed. Consequently, the wear reducing liner was removed from the zone 8 increment of the charge, but, allowed to remain in the zone 9 increment. With this new configuration no residue has been observed in firings of this charge to date.

The heat input data in table 4 shows that the zone 8 part of the M188A1 charge without the wear reducing liner has a much lower heat input than the zone 8 part of the M188E1 with the TiO_2/wax wear reducing liner. These data also show that the total heat input from the 5-round test group is significantly different from that from the 60-round test group. This difference can be explained by the different experimental techniques used and different placements of the thermocouples in the gun tube.

The M188A1 charge which has the wear reducing liner only in the zone 9 part of the charge had a significantly lower heat input than the M188E1 charge which contained a full TiO_2/wax wear reducing liner. Also, the M188A1 charge with the wear reducing liner only in the zone 9 part of the charge did not leave any residue.

Erosion sensor data was also taken during the five-round test group firings. However, all the Knoop indentations in the sensors were filled with metal which, by use of the x-ray fluorescence attachment to the scanning electron microscope, was shown to be mostly lead with some steel.

From table 4 it is clear that the zone 8 increment of the M188A1 charge has a higher heat input than the corresponding zone 9 increment. One is tempted to say that this difference means that the wear in the zone 8 increment will be higher than that of the combined zone 8 and 9 increments. One explanation would be that although wear reducing liner has been removed from the zone 8 increment, the wear reducing liner in the zone 9 increment lowers the total heat input, with corresponding less wear. However, the total heat inputs for the zone 8 increment and zone 8 plus zone 9 increments should be compared with extreme care. The wear in the gun tube is dependent on the peak pressure generated during firing and on the temperature of the bore surface -- which temperature is directly related to the rate of heat transferred to the tube and only indirectly to the total heat input.

For charges of similar configuration and burning characteristics (which probably have equal rates of heat transfer and similar peak pressures), it is valid to compare total heat inputs. Thus, for charge variations of the zone 8 increment (where only the liner is varied), the rates of heat transfer and peak pressures are similar; and comparisons of total heat inputs can be made. This fact is equally true for the zone 9 increment. However, the zone 8 and zone 9 increments could have much different rates of heat transfer, with the zone 9 increment transferring heat to the tube at a much faster rate than that of the zone 8 increment.

From table 4 it is also clear that these charges have different maximum pressures. Heat which is put into the tube at such a rate that it can be dissipated before raising the bore surface temperature significantly will add to the total measured heat input to the tube but may not lead to high erosivity. If the bore surface temperature produced by the two charges is similar, but lower than the melting point of steel, then the charge with higher peak pressure will be more erosive, since higher pressure will create a greater shear force to remove metal.

Based on the results of this test, it was recommended that the M188A1 charge with the wear reducing liner only in the zone 9 increment of the charge be type-classified and that some firing of the initial production lot of charges be conducted for wear evaluation.

The M201 cannon is chrome plated with about a 0.13 mm thick coating. The change from the M30A2 propellant to the M31A1 propellant could influence the wear life of this cannon in two different ways: First, the propellant change could increase the number of rounds it takes to remove the chrome plating at the origin of rifling. This removal has been found to be a function of the propellant flame temperature (ref 7). Second, when the chrome plating is removed, the wear of the steel beneath the coating should be considerably slower for the cooler burning propellant. Because it would take several hundred, or perhaps even a 1000 rounds, to remove the chrome plating at the origin of rifling in a new tube, and since only 500 rounds were available for the wear test, it was decided to estimate the wear characteristics of the new M188A1 propelling charge in a M201 cannon in which the chrome plating had been removed from the origin of rifling. This estimation would give us the lower limit for the wear life of the gun tube since we could not estimate how many additional rounds would be added to the wear life by the increase in life of the chrome plating.

A comparison of the pullover gauge reading at 1.17 m from the rear face of the tube taken during the 500-round wear test can be made from table 5. The zone 9 increment of the M188A1 charge wore 0.3 mm per 250 rounds, whereas the corresponding zone 8 increment wore only 0.1 mm per 250 rounds. The previous wear test for the M188E1 had established that the zone 9 increment wore approximately 0.6 mm per 250 rounds and the corresponding zone 8 increment wore approximately 0.3 mm per 250 rounds.

From these data it is clear that the propellant change from M30A2 to M31A1 has greatly decreased the wear in the M201 cannon. Also the wear in the zone 8 increment of the charge is considerably less than that in the zone 9 increment of the charge. This result is the opposite of what would have been predicted from the total heat input measurements. Therefore, this observation should serve as a warning that total heat inputs should be compared only for charges which burn similarly and which have similar ballistic properties.

CONCLUSIONS

1. The measurement of the relative total heat input to the gun tube predicts the wear characteristics of 155-mm and 8-inch propelling charges if charges of similar ballistic characteristics are compared.

2. The M119A1 propelling charge with a benite center-core igniter and the M119A2 charge with only a CBI basepad have similar total heat inputs and are expected to have similar wear characteristics.

3. The change in wax in the wear reducing liner of the M203 propelling charge from Indramic 170C to the Polywax 655 did not affect the total heat input characteristics. Thus, it is predicted that the wear characteristics will be similar for the two waxes.

4. For a specified M203 charge variation and preconditioning temperature, a trend exists towards lower heat inputs as the tube temperature increases. This trend is predicted by theory and may also be due in part to a change in the functioning mechanism of the wear reducing liner as its initial temperature increases.

5. The M188A1 charge for the 8-inch system with no wear reducing liner in the zone 8 increment of the charge, and with a wear reducing liner in the zone 9 increment of the charge, gave lower heat inputs than the earlier M188E1 charge.

6. It is predicted that the 8-inch propelling charge M188A1 will at least double the wear life observed with M188E1 in the M201 gun tube -- primarily due to the cooler burning M31A1 propellant.

7. Although the total heat input to the tube from the zone 8 increment of the M188A1 propelling charge is greater than that of the zone 8 plus zone 9 increments, the observed tube wear is about one-third as much. This phenomenon is probably caused by higher heating rates and pressures with the zone 9 increment, which lead to greater erosivities.

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Table 1. Heat input and ballistic data for M119A1/A2 charge -- Jefferson Proving Ground (10/79)[a]

Propelling charge	Projectile	No. fired	Average heat input (10^4 J/m^2)	Average pressure (MPa)[b]	Average velocity (m/sec)
M119A1	M107	10	148 ± 4	221 ± 2	696.4 ± 1.7
M119A2	M107	10	146 ± 3	219 ± 2	696.1 ± 0
M119A2	M483	10	142 ± 5	229 ± 2	672.2 ± 0.8
M119A2	M549	9	143 ± 4	223 ± 2	694.0 ± 1.1
M119A2	M107 mod (M549 simulator)	9	142 ± 3	227 ± 3	693.8 ± 17

[a] Charge temperature = 294 K.
[b] Spindle pressure.

Table 2. Heat input and ballistic data for baseline M203 charge -- residue test, Jefferson Proving Ground (7/79)

Propelling charge[a]	Range of tube temp (K)	Rounds fired	Average heat input (10^4 J/m^2) Heat sensor 1	Heat sensor 2	Average pressure (MPa)[b]	Average velocity (m/sec)
Baseline charge 294 K (70°F)	325 - 336	10	118 ± 5	120 ± 4	320 ± 4	829.7 ± 1.9
	356 - 365	10	107 ± 6	110 ± 6	322 ± 3	830.0 ± 1.9
	380 - 381	5	105 ± 3	113 ± 2	313 ± 3	830.0 ± 2.2
	405 - 410	5	96 ± 3	98 ± 2	311 ± 4	826.5 ± 1.8
	417 - 418	5	106 ± 6	109 ± 4	323 ± 4	826.8 ± 2.3
Baseline charge 336 K (145°F)	355 - 356	5	98 ± 2	103 ± 5	376 ± 3	856.0 ± 2.4
	367 - 389	5	111 ± 1	107 ± 3	381 ± 3	859.9 ± 2.2

[a] All charges fired with M107 projectile.
[b] Pressure measured with copper crusher gauge.

Table 3. Heat input and ballistic data for modified M203 charge -- residue test, Jefferson Proving Ground (7/79)

Propelling charge[a]	Range of tube temp (K)	Rounds fired	Average Heat input (10^4 J/m^2) Heat sensor 1	Heat sensor 2	Average pressure (MPa)[b]	Average velocity (m/sec)
Modified M203 charge (655 Polywax/scrim); 336 K (145°F)	303 - 327	15	127 $\pm$ 8	137 $\pm$ 6	380 $\pm$ 7	868.1 $\pm$ 3.6
	356 - 360	15	103 $\pm$ 3	106 $\pm$ 3	378 $\pm$ 5	860.3 $\pm$ 1.7
	390 - 411	8	106 $\pm$ 5	105 $\pm$ 6	376 $\pm$ 6	860.8 $\pm$ 1.7
	397 - 399	7	106 $\pm$ 10	91 $\pm$ 8	372 $\pm$ 4	859.1 $\pm$ 1.9
	402 - 410	10	96 $\pm$ 3	92 $\pm$ 5	378 $\pm$ 5	861.9 $\pm$ 2.7
	413 - 422	5	91 $\pm$ 3	103 $\pm$ 7	380 $\pm$ 4	860.3 $\pm$ 2.6
Modified M203 charge (655 Polywax/scrim); 294 K (70°F)	303 - 324	15	122 $\pm$ 5	125 $\pm$ 7	311 $\pm$ 3	829.4 $\pm$ 1.4

[a]All charges fired with M107 projectile.
[b]Pressure measured with copper crusher gauge.

Table 3. (Cont)

Propelling charge[a]	Range of tube temp (K)	Rounds fired	Average Heat input (10^4 J/m^2) Heat sensor 1	Heat sensor 2	Average pressure (MPa)[b]	Average velocity (m/sec)
Modified M203 charge (655 Polywax/scrim); 294 K (70°F)	377 - 381	15	112 ± 6	118 ± 10	308 ± 5	826.1 ± 2.2
	380 - 398	12	97 ± 6	105 ± 10	308 ± 2	825.7 ± 1.8
	408 - 413	15	112 ± 6	112 ± 7	308 ± 4	824.6 ± 2.7
Modified M203 charge (655 Polywax/scrim); 222 K (-60°F)	315 - 332	15	119 ± 4	121 ± 4	291 ± 4	789.6 ± 2.2

[a]All charges fired with M107 projectile.
[b]Pressure measured with copper crusher gauge.

Table 4. Heat input and ballistic data for M188E1/A1 charge[a]

Propelling charge[b]	Rounds fired	Average Heat input (10^4 J/m^2)	Averags pressure (MPa)[c]	Average velocity (m/sec)
		DALGREN, VIRGINIA (11/78)		
M188E1: zone 9, std liner	5	214.5 ± 8.5	276.0 ± 2.7	773.2 ± 4.7
zone 8, std liner	5	201.8 ± 15.7	223.2 ± 9.0	712.7 ± 5.9
M188A1: zone 8, no liner	5	186.8 ± 3.7	215.6 ± 2.5	706.9 ± 2.8
zone 8, 1/2 liner with flaps	5	172.5 ± 7.0	214.0 ± 3.5	705.2 ± 2.7
zone 8, full liner with flaps	5	160.1 ± 7.4	219.2 ± 3.6	709.9 ± 2.7
zone 9, no liner in zone 8	5	167.5 ± 2.8	266.6 ± 5.9	765.7 ± 1.3

[a]Charge temperature = 294 K.
[b]All changes fired with M106 projectiles.
[c]Pressure measured with copper crusher gauge.

Table 4. (Cont)

Propelling charge[b]	Rounds fired	Average Heat input (10^4 J/m^2)	Average pressure (MPa)[c]	Average velocity (m/sec)
M188A1:				
zone 9, 1/2 liner with flaps in zone 8	5	162.6 ± 6.6	268.2 ± 4.0	765.1 ± 1.4
zone 9, full liner with flaps in zone 8	5	160.7 ± 5.1	269.5 ± 5.0	765.5 ± 1.5
zone 9, std charge with (5 oz) lead	2	178.8 ± 13.6	276.5 ± 5.0	773.2 ± 0.8
YUMA PROVING GROUND (5/79)				
zone 9, no liner in zone 8	60	122.1 ± 8.0	264.4 ± 3.6	765.6 ± 1.4
zone 8	60	133.4 ± 5.7	210.5 ± 3.3	704.1 ± 0.9

[a]Charge temperature = 294 K.
[b]All charges fired with M106 projectiles.
[c]Pressure measured with copper crusher gauge.

Table 5. Tube wear for M188E1 charge with M106 projectile

Tube round no.	Zone	Pullover gage measurements at 1.17 m (46 in.) from rear face of tube*
1161	9	1.6 mm (0.063 in.)
1299	9	1.78 mm (0.070 in.)
1401	9	1.91 mm (0.075 in.)
1411	9	1.91 mm (0.075 in.)
1461	8	1.96 mm (0.077 in.)
1536	8	2.01 mm (0.079 in.)
1626	8	2.06 mm (0.081 in.)
1711	8	2.06 mm (0.081 in.)

*Indicates increase in diameter over 203.2 mm (8.000 in.).

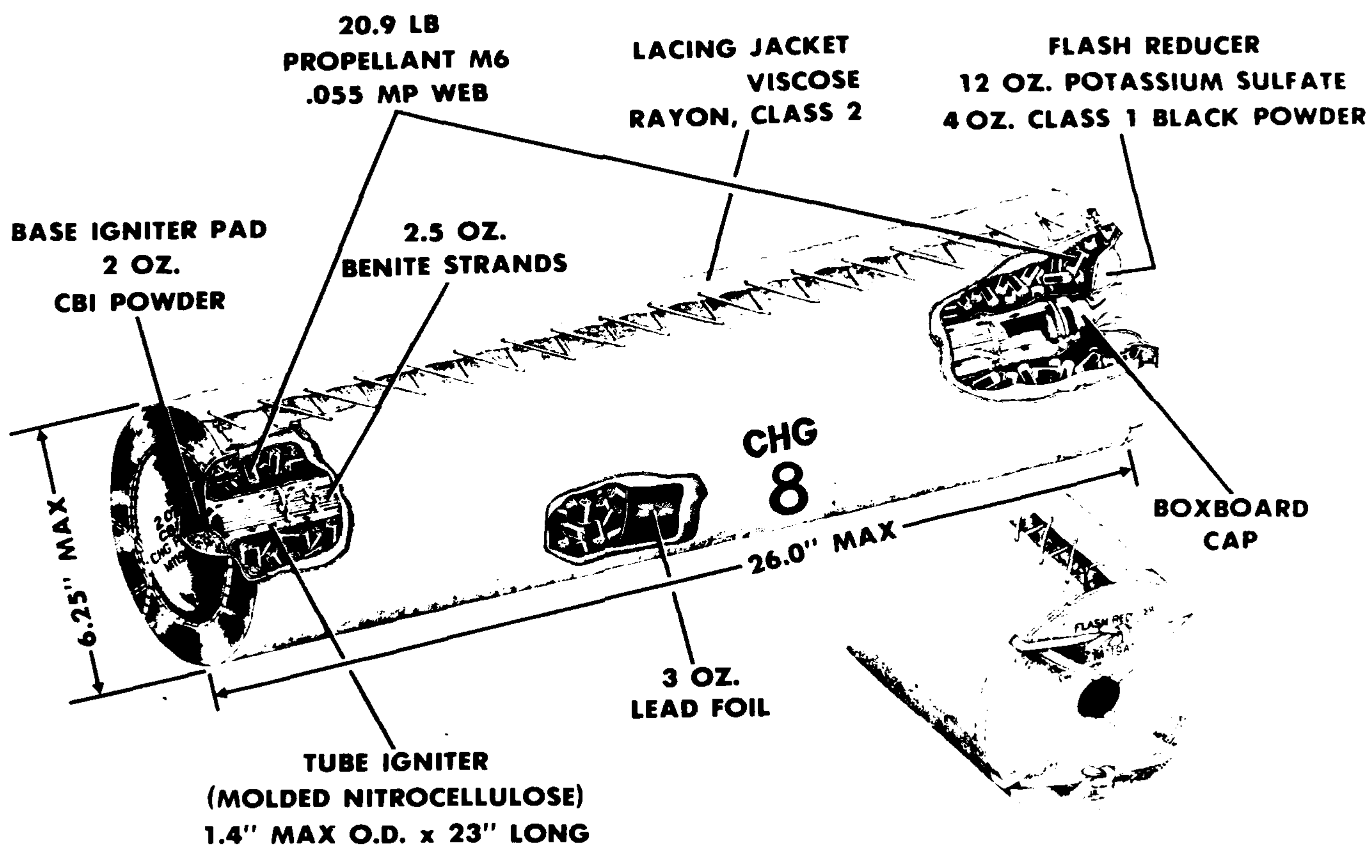


Figure 1. M119A1 propelling charge

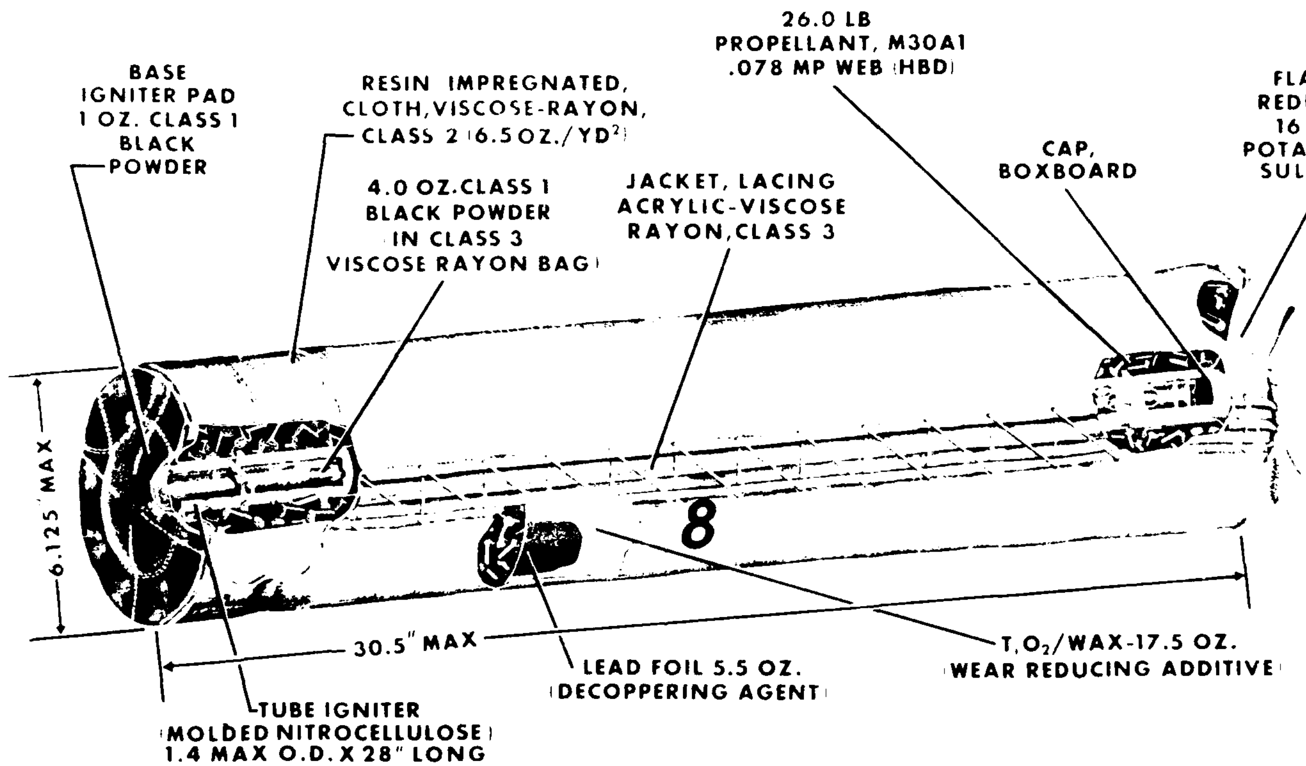


Figure 2. M203 propelling charge

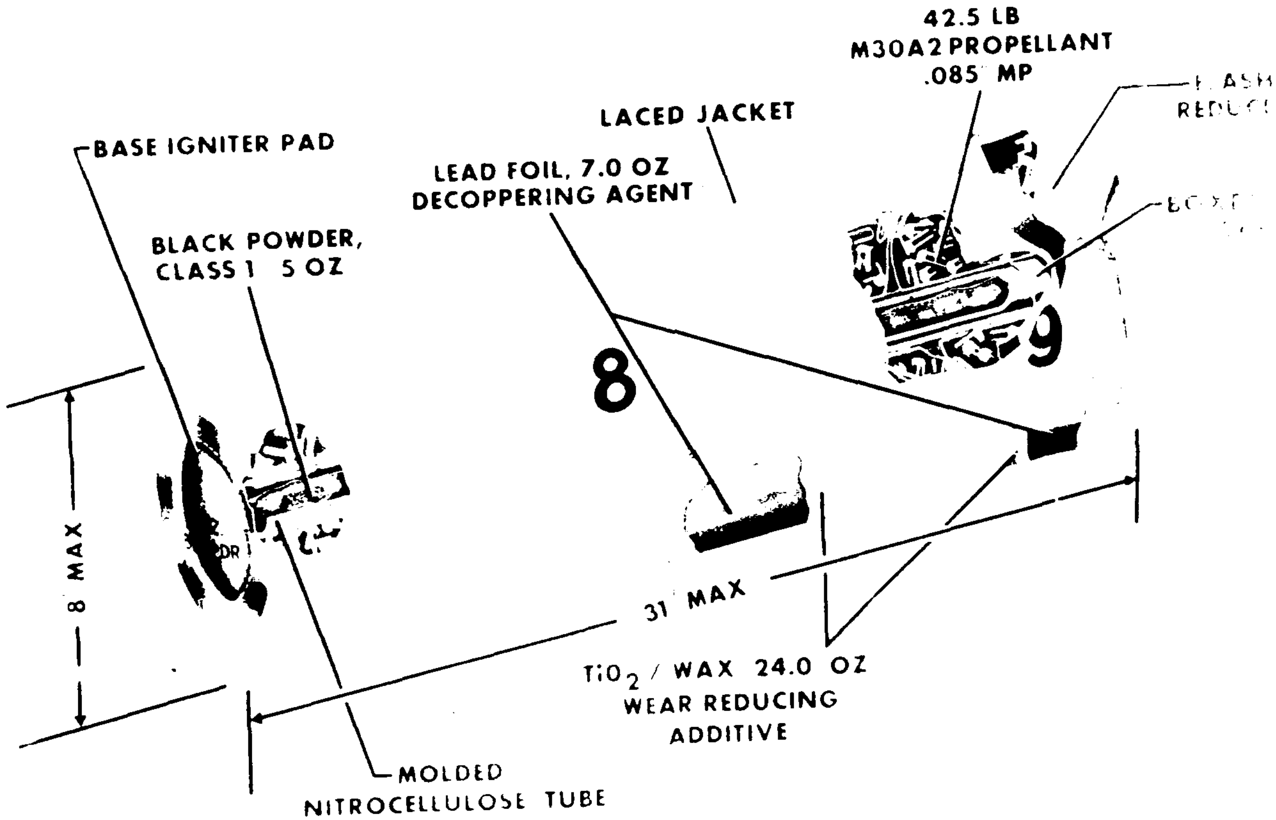


Figure 3. M188E1 propelling charge

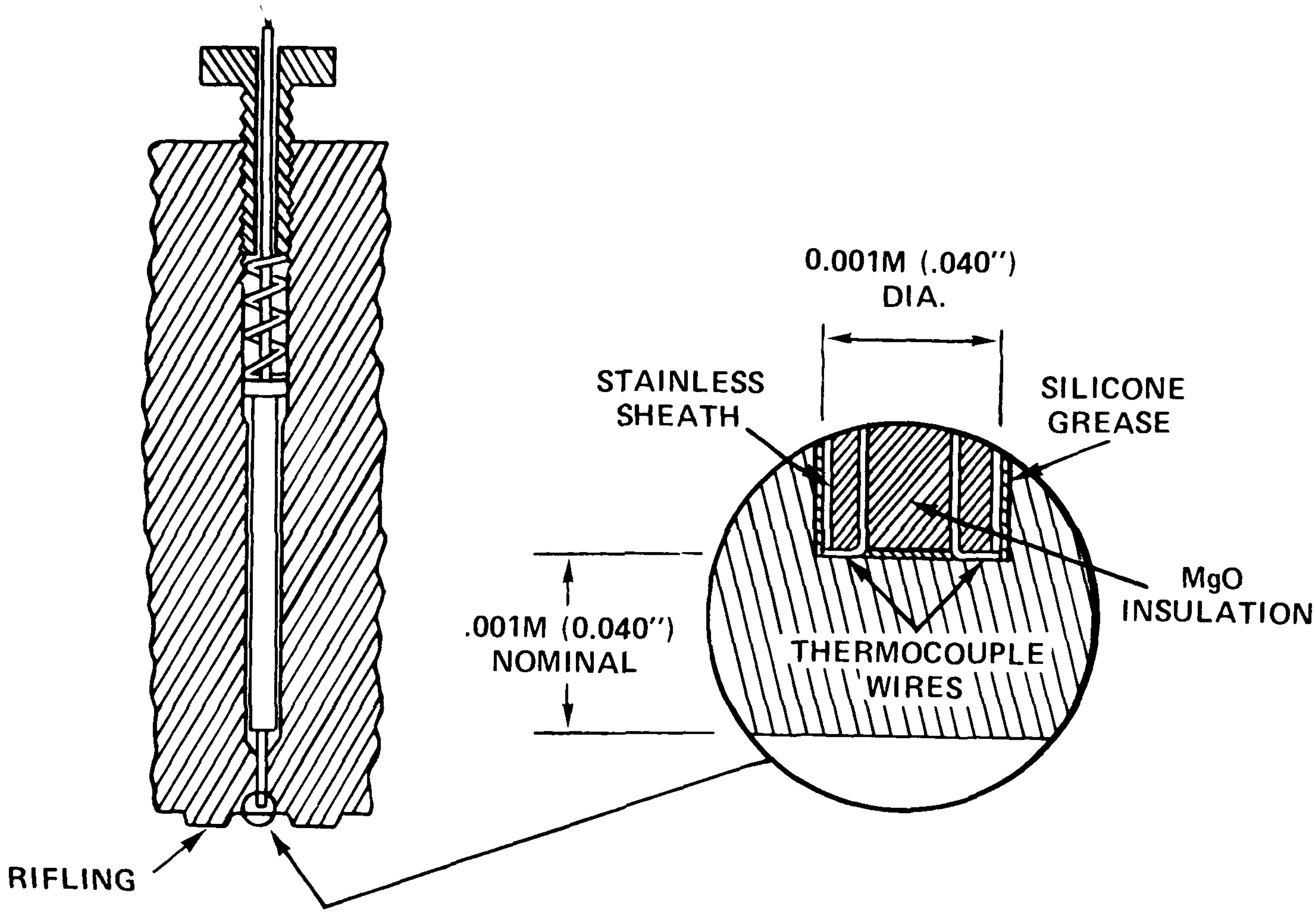


Figure 4. In-wall thermocouple (heat sensor) installation

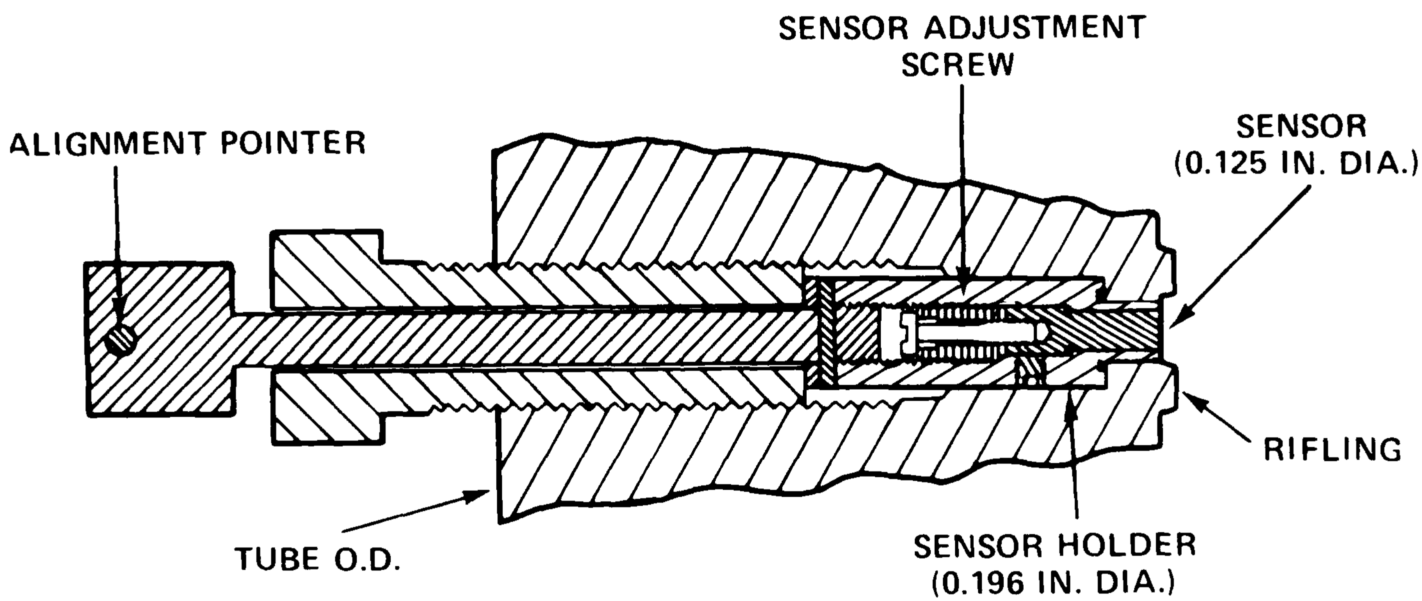
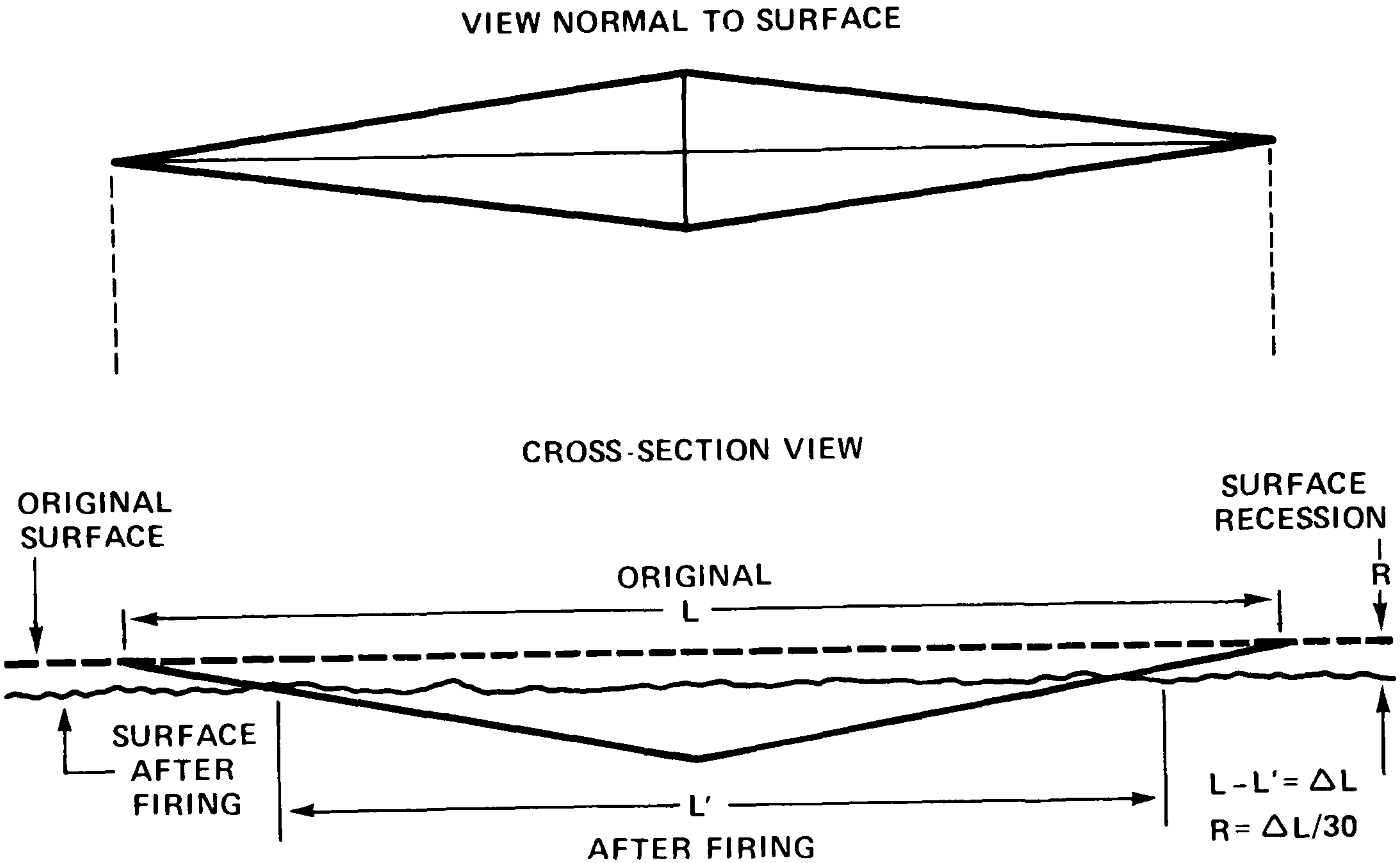


Figure 5. Erosion sensor installation



NOTE: In practice, actual length of indentation is from 10 to 400 micrometers.

Figure 6. Knoop microhardness indenter configuration

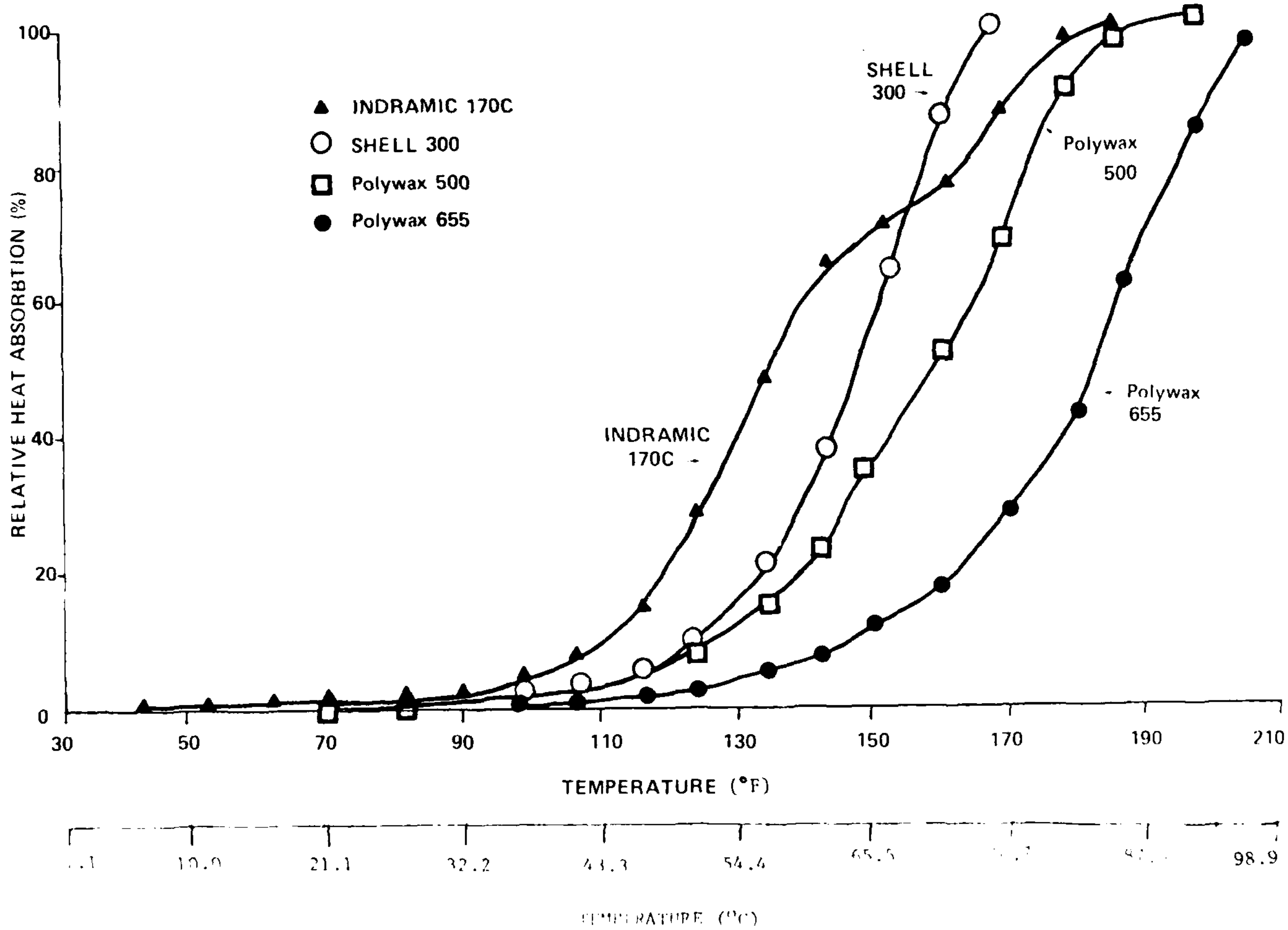


Figure 7. Relative heat absorption vs temperature for selected waxes

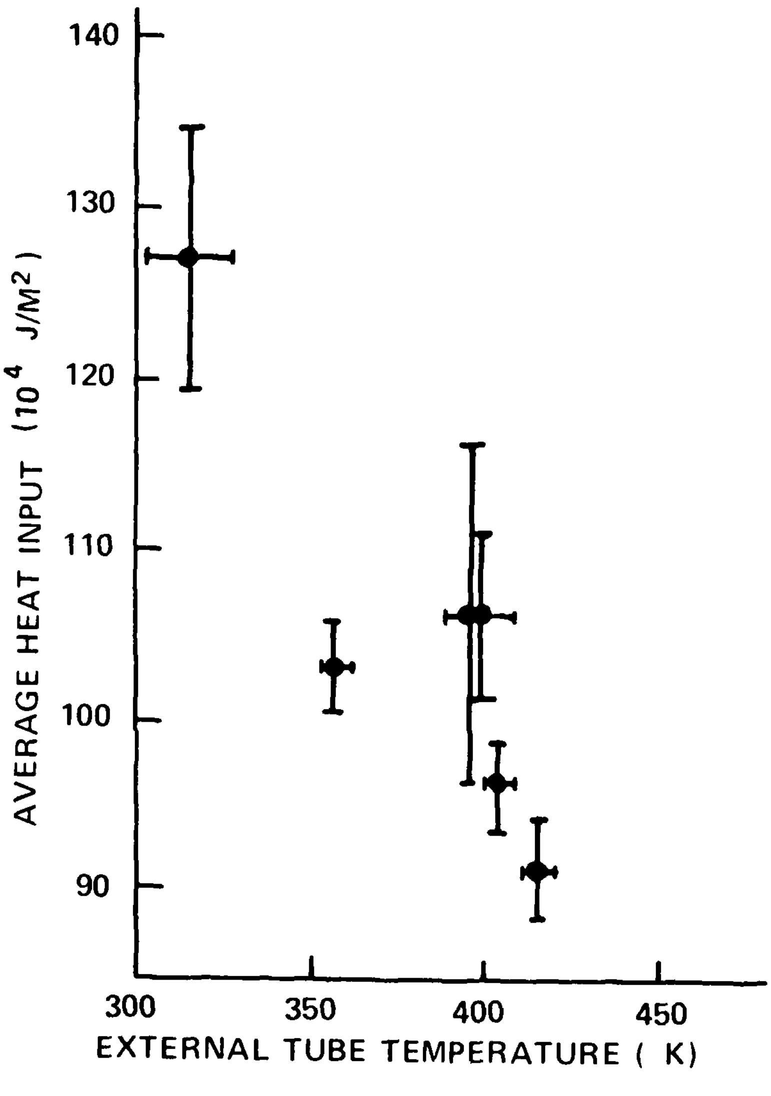


Figure 8. Variation in total heat input with increasing tube temperature -- liner with Polywax 655 (charges preconditioned to 336 K)

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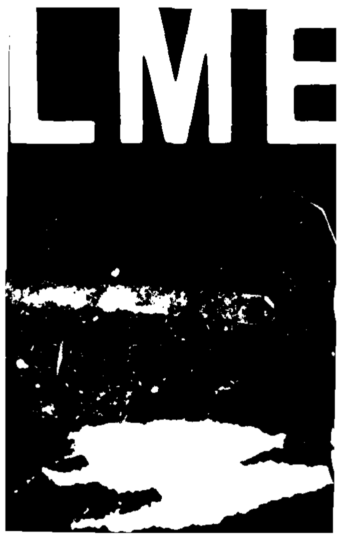
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