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Cobalt-base alloy gun barrel study

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ABSTRACT

Firing tests of a small caliber experimental gun barrel made of a cobalt-base alloy have been conducted with the purpose of determining the degree of wear and erosion due to excessive firing durations. The small amount of barrel material loss makes the cobalt-base alloy an excellent candidate for use as a gun liner. An unusual wear pattern resulting from this loss was observed near the muzzle. Elimination of chemical and thermal effects made a plausible explanation of the wear pattern possible.

1. Introduction

For over 50 years, the United States Army has used a short cobalt-chromium liner (Stellite 21®[1]) in its M2 machine gun to reduce barrel wear and erosion. Even though this approach is highly successful, it has not been adopted for use in other fielded weapons. This may be due to the problems faced with emplacing the liner in the barrel or the perceived cost/benefit of the approach. Alternatively, chromium coatings have also proven to be effective in reducing wear. However, the plating process used to apply the chromium to the bore of the tube involves hexavalent chromium, a known carcinogen. This has led to efforts to find ways to replace the chromium plating process.

Recently, advances have been made in explosive bonding of liners to gun tubes [1–3] and in using a pressurization technique to attach the liner [4,5]. This has prompted considerable interest in alternate materials that might be used as liners. The United States Army Research Laboratory (ARL) was able to obtain several 5.56 mm barrels made entirely from a cobalt-chromium alloy. These experimental barrels served as a test bed to determine how this particular alloy would wear under extreme firing conditions. The intent of the firing tests was to demonstrate that a gun tube liner made of this material would extend the service life of the gun tube to the extent that the soldier would not have to carry a second barrel, as is now the case. The next section presents the rationale and procedures for the firing tests as well as the equipment used to measure the bore diameter. The results section gives the experimental findings in terms of barrel wear as a function of shot number. An unusual wear pattern was observed, and this is discussed in the section following the results. Conclusions are presented in Section 5.

2. Materials and methods

The composition of the cobalt-base alloy (CBA) is presented in Table 1. The production of this alloy does not involve the use of hexavalent chromium. Consequently, the use of a liner made of this material would avoid that particular environmental issue.

Careful consideration was given to the firing cadence. In order to demonstrate the wear resistance of the CBA barrel, the plan was to test the barrels at increasing levels of firing durations. The baseline firing rate was that specified by the field manual appropriate for small caliber weapons [6]. The manual specifies two cadences: sustained and rapid. For sustained rate of fire, the manual calls for 3–5 round bursts, with 4–5 s between bursts. The barrel is changed every ten minutes. For rapid fire, the manual calls for 8–10 round bursts with 2–3 s between bursts, and the barrel must be changed every two minutes. The baseline cadence was denoted as the Phase 1 test. Thereafter, the firing tests were conducted with increasing durations. A separate barrel was used for each cadence. Barrel 1 was used for the sustained cadence, and Barrel 2 was used for the rapid cadence. Table 2 presents the complete firing sequence.

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[1] Stellite 21 is a registered trademark of Kennametal Stellite, Goshen, IN.

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Table 1
Chemical composition of chromium-cobalt alloy.

Element	Co	Cr	Ni	Mo	Fe	W	Mn	Si	N	C
%	54	26	9	5	3	2	0.8	0.3	0.08	0.06

Table 2
Firing durations for two cadences.

Firing cadence	Phase 1 time (min)	Phase 2 time (min)	Phase 3 time (min)	Phase 4 time (min)	Phase 5 time (min)
Sustained	10	15	20	25	30
Rapid	2	3	4	5	6

After each firing phase was completed, the gun barrels were cleaned and their bore diameters measured with a laser system. The instrument used to do this was a Bore Erosion Measurement and Inspection System (BEMIS™) made by Laser Techniques Company (LTC) of Redmond, WA. The BEMIS allows bore diameter measurements along the entire barrel length and measures the bore diameter at both the land and groove positions.

Each barrel was placed in a standard machine gun. A pneumatic device was attached to the trigger and used to fire the weapon. The pneumatic device was controlled by a custom-made timing device that allowed two inputs: the time of firing, and the time interval between bursts. The trigger device was calibrated in initial tests that established the time of fire and intervals between bursts that would achieve the average rate of fire for both sustained and rapid cadences. The firing device allowed a uniform sequence of shots that might not have been possible with a gunner operating the weapon.

The ammunition was the standard $5.56 \times 45\text{-mm}^2$ M855 round, along with the M856 tracer round. These rounds are fired in a ratio of 4–1, respectively. This ammunition was selected as it is the most prevalent in the inventory and is well characterized.

After the tests were completed, Barrel 1 was sectioned along its length and the bore surface examined with a light microscope.

3. Results

The bore diameter measurements for Barrel 1 (sustained cadence) are shown in Fig. 1. The plots are keyed to the baseline and five phases, shows the accumulated bullet count. These measurements were performed at the land location. The measurements start near the origin of rifling, and the initial spike in the data is due to bore diameter variations prior to that point. The barrel length is 463 mm, including the chamber. In order to relate the axial position shown in Fig. 1 to the distance from the rear face of the tube (RFT), 30 mm must be added to the axial position. That is, 400 mm axial position corresponds to 430 mm from the RFT.

There is no discernible wear for the first 200 mm of bullet travel for all phases. Increased barrel diameter is observed starting at about 200 mm (axial position). The diameter goes through a peak at about 340 mm and then decreases. There is a sharp decrease in bore diameter observed for Phases 4 and 5 at around 250 mm. This is attributed to the effects of the gas port at this location.

Fig. 2 shows a micrograph of the bore surface for Barrel 1 at 10 mm from the muzzle. The surface is relatively smooth and is colored red. An energy dispersive spectrometry (EDS) scan of the surface is shown at 450 mm from the RFT shown in Fig. 3. The primary element on the surface of the bore is copper, coming from the bullet jacket. There are also trace amounts of cobalt and

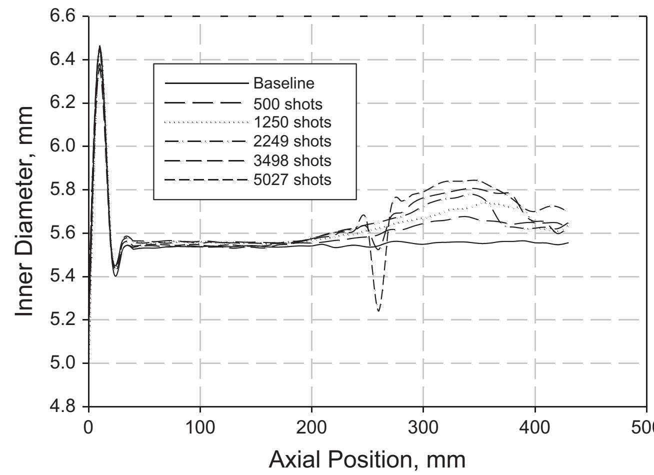

Fig. 1. Inner diameter as a function of axial position for Barrel 1.

Fig. 2. Bore surface of Barrel 1 at 450 mm from the RFT.

chromium. No metallurgical examination of the CBA was performed. However, no discernible cracks were observed in a micrograph of the CBA's cross section at 10 mm from the muzzle, as contrasted to the small cracks seen at 200 mm from the breech.

A sample of Barrel 1 was cut 6.5 mm from the end of the tube. The sample was mounted, polished, and observed under the eyepiece of a micro-hardness tester. The copper layer thickness varied from 0 to 15 μm ($0\text{–}1.5 \times 10^{-2}$ mm).

A micrograph of the surface 200 mm from the RFT is shown in Fig. 4. The dark lines at the upper and lower portion of the micrograph are the edges of the land. There appears to be a cross-hatch pattern of surface cracks in the CBA. Also, it appears that there are small deposits of copper on the edges of the land.

The bore diameter at the groove location for Barrel 1 begins to increase at about 290 mm. The exact location is obscured to some extent after Phases 4 and 5 by the anomalous behavior at the gas port location. Fig. 5 compares the measurements of the bore diameter at the land and groove positions taken after Phase 5.

Velocity measurements were performed during the tests of Barrel 1. The average muzzle velocity in each phase showed a 0.5% decrease for the 5027 shots. The average velocity in each phase for Barrel 2 showed a slight increase with phase number. In addition, yaw tests with Barrel 1 made after the Phase 4 tests indicated that the bullet yaw was very small.

Barrel 2 was fired at a higher rate than that for Barrel 1 but for a shorter period of time. As a result, fewer rounds were fired through Barrel 2. Inner diameter measurements at the land location are shown in Fig. 6. No discernible wear is observed for the first 200 mm of bullet travel. The bore diameter begins to increase at 200 mm axial position and then goes through a maximum at approximately 340 mm. The bore diameter decreases