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CANNON WEAR AND EROSION SCIENCE AND TECHNOLOGY OBJECTIVE PROGRAM (STO) 155-MM PROJECTILE ROTATING BAND/OBTURATION FOR EXTENDED RANGE

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14. ABSTRACT

The higher level of muzzle energy and longer tube travel have resulted in large down bore cannon wear with 52+ caliber 155-mm weapons. The down bore wear is primarily due to projectile body engraving that occurred after the copper rotating band has worn out. Inadequate obturation, lubrication, bore surface contamination, poor barrel plating, and other factors all contribute to accelerate rotating band wear. The large down bore cannon wear will adversely impact accuracy, munitions performance, and cannon wear life.

The U.S. Army Tank-Automotive and Armaments Command – Armaments Research, Development and Engineering Center, Picatinny Arsenal, NJ Cannon Projectile Compatibility program as part of the Cannon Wear and Erosion Science and Technology Objective effort addresses the problem by updating rotating band and obturator designs for the extended range environment. This technical base program investigated the use of alternate rotating band materials with high melting temperatures and improved wear characteristics. One dimensional finite element wear models and body engraving models have been developed to aid in the design of new bands. Welding techniques and parameters for soft iron, nickel, MONEL®, and stainless steel were developed to assure band integrity at all launch conditions. Test results for a new rotating band design with alternate band materials have been extremely encouraging. An investigation of using improved obturator designs incorporated with advanced materials has also proven beneficial in maximizing performance for extended range applications.

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INTRODUCTION

The primary function of the rotating band and obturator is to impart spin to the projectile and maintain a positive gas seal, the failure of which will adversely impact projectile and weapon performance. During the development of 155-mm extended range weapon systems, excessive wear of the rotating band, projectile body engraving, and origin wear are often the cause for cannon condemnation. More recently, for indirect fire and extended range ordinance (ERO), wear and erosion problems are attributed to muzzle wear. Rotating bands and obturators of 155-mm projectiles have been failing prematurely due to a number of factors not limited to increased barrel length, increased in-bore spin velocities, outdated band/obturation designs, and propellant residue. The loss of the rotating band and obturator causes in-bore projectile balloting and subsequent projectile engraving when contact is made with the barrel surface. The effect on the barrel is severe muzzle end wear resulting in increases in projectile dispersion. A major contributor to this problem is that the inventory of 155-mm projectiles were designed to 39 caliber system requirements (M198, Paladin, etc.). The ERO programs that develop new cannons introduce new problems for projectiles originally intended for 39 caliber systems. The U.S. Army Tank-Automotive and Armaments Command – Armaments Research, Development and Engineering Center, Picatinny Arsenal, NJ (TACOM-ARDEC) Technical Base Cannon Projectile Compatibility (CPC) program objective is to develop a rotating band/obturator combination that will perform satisfactorily in all extended range weapon systems.

BACKGROUND

To achieve higher muzzle velocities and longer ranges, weapon designers rely on larger quantities of high energetic propellant and longer cannons with larger chambers. During the ERO developmental program in the 1980's, the increased range came at the expense of rapid origin wear of steel cannons and worn projectile rotating bands with severe body engraving on projectiles. The steel 52 caliber cannons were often condemned in less than 100-round high zone firings. From the test results, the need for improved bore protection and an improvement in rotating band performance is evident.

The larger volume of propellant used for extended range and the increased combustion activities are responsible for the accelerated origin wear of steel cannons. High refractory metal coatings such as chrome plating have slowed the erosion at the origin but have not prevented down bore wear. Down bore wear is due primarily to projectile body engraving after the rotating band has worn out. Many factors contributed to the rapid band wear. A combination of higher muzzle velocity (increased spin and frictional heating), poor obturation, and bore surface effects caused rapid heating and melting of the copper band. The severely worn band and gas blowby will result in projectile body engraving, which will accelerate chrome chipping and stripping and finally unacceptable muzzle wear. This enlarged bore diameter will result in poor precision and higher balloting forces on the ammunition. The reliability of the fuze could also be affected because of the higher pitch and yaw motions at muzzle exit.

The TACOM-ARDEC Technical Base CPC program's goal is to develop the next generation rotating band/obturator for future projectiles.

PROGRAM OBJECTIVE

The objective of the CPC program is to provide an improved rotating band and obturator combination for future projectiles that will be compatible with the next generation extended range weapons. The band and obturator will function at a velocity of greater than 1,000 m/s and at a pressure of 60,000 PSI. The band will have no low zone sticker or projectile fallback problems. The requirement for the rotating band to perform at a very high muzzle velocity and not have a low zone sticker problem is contradictory. For high zone firing applications, a strong band is desirable, but a small band is desirable for the low zone firing application in order to minimize stickers. In order to achieve the goals of the CPC program, the proper selection of a suitable band material coupled with an optimum design configuration was employed to ensure adequate high zone performance while minimizing low zone sticker issues.

DISCUSSION

Current Rotating Band Design

There are three common band configurations used in the current projectile inventory: the M107, M864/M549A1, and the M483A1 types (fig. 1). The band material is either copper or a copper/zinc alloy. The swaged M107 band is compatible up to the M119A2 charge velocity (684 m/s) while the welded overlay bands such as the M864/M549A1 types are compatible up to the M203/M203A1 charge level (826 m/s). At the 950-m/s velocity range, all band designs performed poorly with anything greater than 52-caliber cannons.

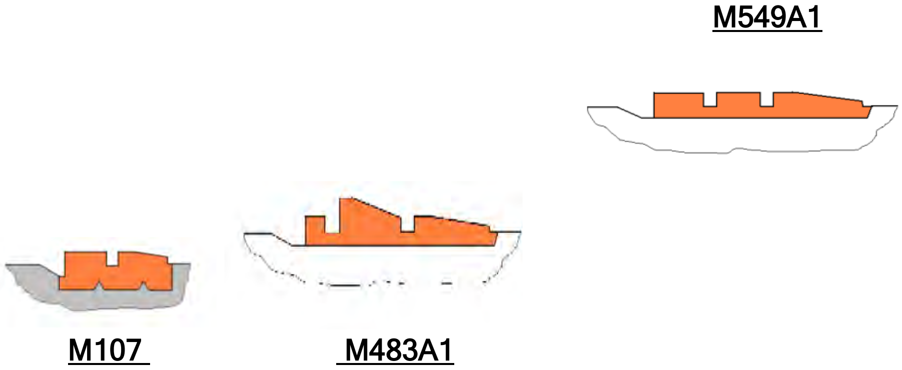
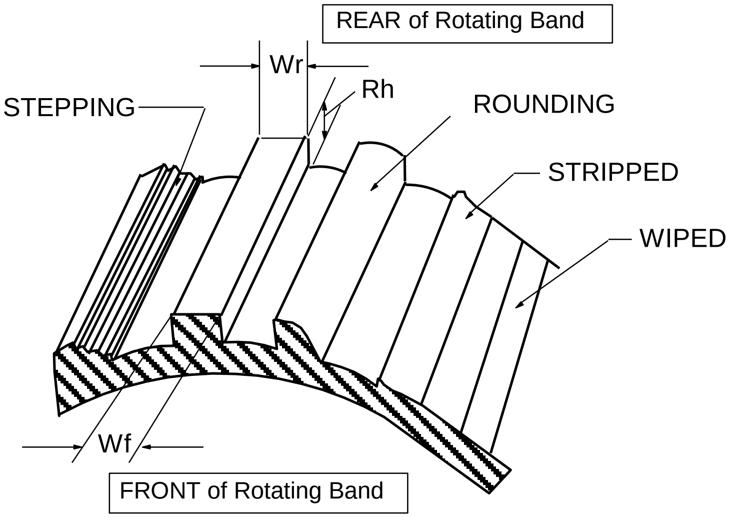


Figure 1
Existing rotating band design shapes

Rotating Band Criteria

The main requirements of rotating bands include that they be compatible with higher velocity limits, have improved performance with fourth quarter (wear) cannons, use existing manufacturing techniques, minimize torsional impulse, provide no increase in projectile drag, and produce no projectile fallbacks or stickers. In general, the rotating band should not wear out completely and cause projectile body engraving, which leads to gun tube wear and a decline in accuracy and loss of tube life. Historically, existing copper bands did a very good job of satisfying many of these requirements depending on the projectile and the rotating band shape or configuration used. In recent years however, results of 155-mm 52 caliber test firings have shown that many of the existing copper rotating bands wear excessively and cannot survive the longer tube travel. Because rotating band wear is one measure of a rotating band's performance, members of the CPC program developed criteria for inspecting and evaluating fired and recovered rotating band hardware. This inspection criterion is related to the observations made upon examining hundreds of recovered projectiles during the course of the CPC program. Some of the characteristics that are on recovered rotating bands are shown on figure 2.

RECOVERED ROTATING BAND OBSERVATIONS



Note: "Wf" is the dimension (width) of the front section of the recovered rotating band, "Wr" is the dimension (width) of the rear section of the recovered rotating band, and "Rh" is the height of the recovered rotating dimension.

Figure 2
Recovered rotating band characteristics

These characteristics were used to describe and evaluate various rotating band and obturator performance tests conducted under the CPC program as well as on other programs such as the Crusader Program where tube wear and rotating band performance is a concern. For an ideal rotating band, Wf and Wr would be equal to 0.25 in. and Rh would be equal to 0.05 in. As part of a complete recovered rotating band inspection, the CPC program used the following list of definitions and explanations to describe performance.

Explanation of Rotating Band Features and System Performance Implications

Band Driving Edge Width

This is the remaining width of the band land.

- Visual inspections:
  0 to 0.005 in. is "knife-edge."
  0.005 to 0.050 in. is "O.K."
  0.050 to 0.100 in. is "good."
  0.100 to 0.156 in. is "excellent."

- Measured inspections:
  Thickest band land on the projectile is measured with calipers recorded to the nearest five thousands of an inch.

There should always be some detectable remaining driving edge width. When there is none, the projectile may not be sufficiently spin-stabilized.

Extruded Band Material

When the band is engraved, material is extruded forward and aft out from the band groove.

Depending on the traction forces from the gun tube and speed of engraving, more material will be extruded aft than forward, and higher traction forces and slower engraving will favor this condition.

Since this material is generally unmolested throughout the rest of the projectile's life (except in the case of live ammunition), it can be easily seen where on the band it was initially engraved, even on a fully worn-out band.

There are no direct system performance implications from this feature.

Bourrelet Engraving

Widest parts of the projectile (excluding the rotating band) are called bourrelets (or bore-riders). There is a forward bourrelet and an aft bourrelet.

There is some amount of space between the gun tube and the bourrelets within which the projectile can move. If the projectile translates perpendicular to its direction of travel, it is termed "balloting." If it rotates about an axis perpendicular to its direction of travel, it is termed "cocking."

Balloting and cocking can be distinguished in recovered projectiles by noting the locations of the deepest engraving on the forward bourrelet relative to the aft bourrelet. If the deepest engraving is on the same side, the projectile is balloted, while if it is on opposite sides, the projectile is cocked.

- Body engraving:
  Just detectable (0.001 to 0.002 in. deep) is "very light."
  0.005 in. deep is "light."
  0.010 in. deep is "moderate."

Anything deeper than this can usually be measured. Full-depth bourrelet or body engraving would be the height of the gun tube lands, 0.050 in. for a new tube.

Because the projectile is spinning very rapidly, any off-axis imbalance will drive one side into the gun tube wall. This increases the imbalance further, which further drives the projectile into the gun tube. The result is increased gun tube wear, and the amount of wear increases towards the muzzle. This is the origin of muzzle wear. Any bourrelet engraving indicates loading of the projectile steel against the gun tube with concomitant increased gun tube wear.

Chromium Nodules and Thermal Gouging

Chromium nodules are present on the edges of the gun tube lands from the electroplating process. These nodules are of the order of 100 to 300 μm in diameter and are fairly spherical.

As the projectile slides over them, some of them embed in the rotating band. The rotating band is normally melt-lubricated in the gun tube and the embedded chromium nodules interfere with this. The melting point of copper is 1,084°C while chromium is 1,863°C, and they are virtually insoluble in each other. Thus, the nodules will rub on the gun tube and cause frictional heating.

They will not melt-lubricate because their melting point is so much higher than the copper matrix in which they are embedded. The surrounding copper being in intimate contact (heat transfer coefficient close to 1) removes the heat too quickly. Also, instead of submerging in the surrounding matrix, they tend to wear against the gun tube. They will, however, rotate in the matrix, exposing different faces to wear and giving rise to a faceted appearance.

The heat created from friction between the nodules and the gun tube is transmitted very rapidly to the surrounding copper matrix causing it to undergo gross melting. If this gross melting occurs near the driving edge of the rotating band, it will be worn off very quickly. Any metal that is molten when the projectile leaves the gun tube will be thrown off by centrifugal forces.

Chromium nodules have the following implications to gun system performance:

- They cause higher wear because they provide a rougher surface.
- Once nodules embed, there are two more deleterious effects.
  - Adhesive or abrasive wear of the gun tube (chromium nodules against chromium electroplate).
  - Gross melting of regions of the rotating band groove.

The rotating bands that have exhibited this feature most clearly have thermal gouge in the center of the groove. It is conceivable that gross melting of other bands occurred near the driving edge leading to rapid wear and worn-out bands. This rapid wear mechanism is difficult to detect in examining a worn-out band.

Wedge Shaped Depressions on Forward Area of Band Land

The leading edge of the rotating band is often machined with a taper.

As the band wears, the gun tube land tends to “bulldoze” rotating band material away from the driving edge. Where the band has this taper, there is a gap between the band and the gun tube groove. The bulldozing action will tend to fill this gap. It will be best filled next to the driving edge and least filled next to the trailing edge.

There are no system performance implications from this feature.

Stepped Band Grooves

This is sometimes called double engraving, and it can arise from several phenomena. It is always traceable to a discontinuity in the wear of the rotating band as it travels down the gun tube.

Because of the number of mechanisms that can cause this feature, it is difficult to give specific system performance implications. It does indicate a discontinuity during projectile travel, however, which should as a general rule be avoided.

Wavy Band

A wavy band is a band that no longer has any driving edge, but there is a thickness variation that corresponds to the periodicity of the gun tube land and grooves. Thus, there is some material remaining that may support some amount of rifling torque but not much.

A projectile with a wavy band may not be completely spin stabilized under all conditions.

Worn Out Band

This indicates a band that is smooth with no evidence of a discontinuous wear event (such as stripping).

A projectile with a worn out band may not be completely spin stabilized under all conditions.

Stripped Band

This indicates a band that has no driving edge, but there are rough areas with a fracture appearance where the band land was at one time. The band was engraved and may have worn a little, and then a rifling torque overload caused the band lands to be sheared off. If the amount of shear can be measured, it is recorded.

A projectile with a stripped band may not be completely spin stabilized under all conditions.

Coppering of Boat-tail

The rotating band is melt-lubricated. The liquid metal film does not stay with the projectile completely but is plated out on the gun tube.

If the obturator band integrity is lost in-bore, some of the liquid metal film can be plated out on the projectile boat-tail.

Coppering of the boat-tail indicates loss of obturator band in-bore, which could increase the amount of blow-by.

Blow-by Marks

These features can only be observed on recovered projectiles that have retained their original paint. Blow-by is exhibited by helical burn marks in the paint initiating at the trailing edge of the gun tube land and traveling forward of the rotating band where they dissipate.

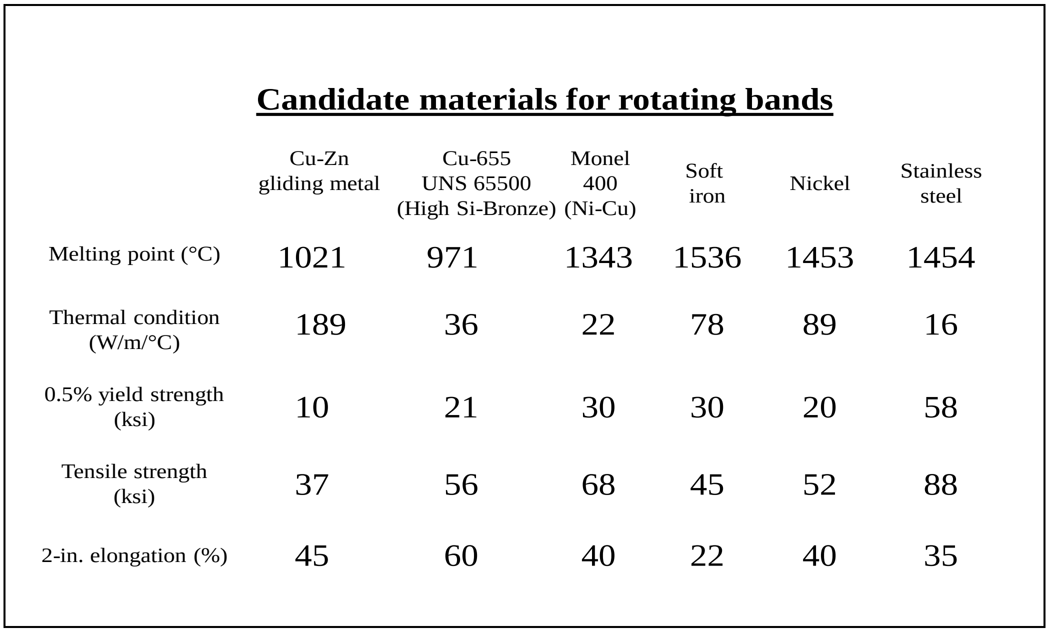
Blow-by increases the amount of thermal loading and wear of the gun tube and may decrease muzzle velocity.

For the above definitions and criterion, it is important to note that projectile rotating bands undergo an extremely fast dynamic event that is influenced by many factors (such as the charge, gun tube plating, projectile properties, rotating band shapes, etc.). These factors, which are a part of the overall gun system, ultimately determine how compatible and effective a given rotating band design can be improved.

ROTATING BAND MATERIAL SELECTION

In order to determine which viable alternate rotating band materials were good candidates in evaluating through testing, an extensive historical search and review of material data properties was conducted by the U.S. Army Research Laboratory (ARL), Aberdeen Proving Ground, MD, ARDEC, and ArrowTech Associates, South Burlington, VT. Desirable material properties were defined and compared to the current 155-mm rotating band material (copper/gliding metal). All aspects of the materials were evaluated including their feasibility in welding, machining, tensile strength properties, melting point characteristics, their availability, and cost. Most importantly, the material properties were reviewed in order to determine their ability to readily form to the contour of the gun tube while maintaining its engraved shape and integrity during launch. Basically, the rotating band material must have sufficient ductility and sufficient tensile (shear) strength in order to engrave and survive 300 in. of tube travel. In the materials, these properties are mutually exclusive, as the higher a material's tensile strength, the less its ductility. Thus, some materials that had no favorable data or any data at all to indicate that it could be used as a rotating band material were eliminated from being a candidate rotating band material. A list of the candidate materials that were selected for further evaluations and how their basic properties compare to the current copper/gliding metal material is shown on table 1.

Table 1
Candidate materials for rotating bands



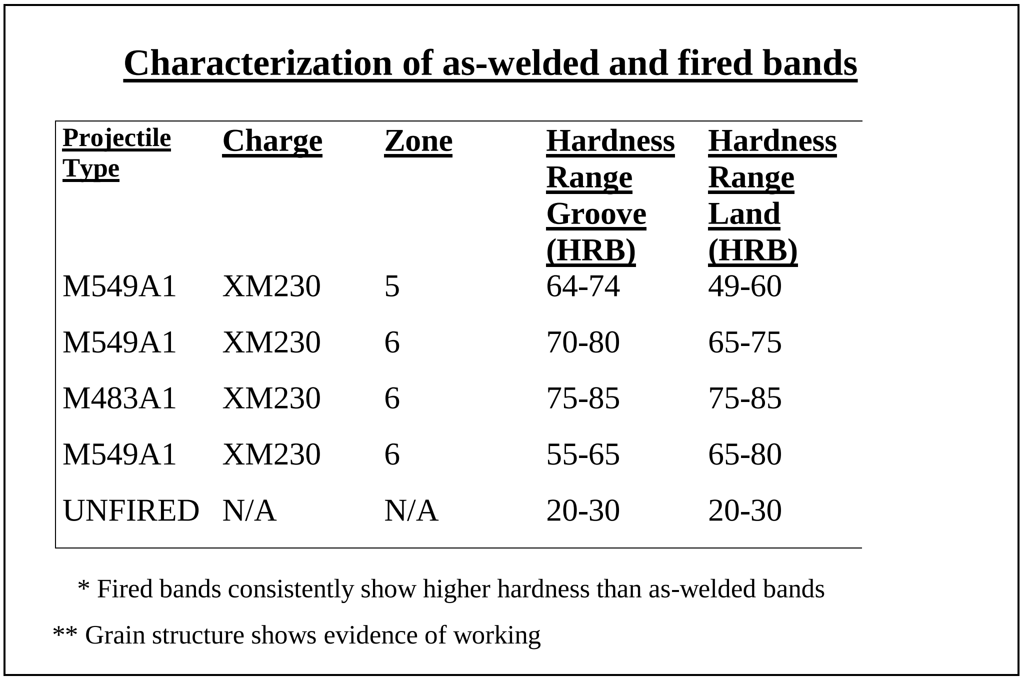
Candidate materials for rotating bands

	Cu-Zn gliding metal	Cu-655 UNS 65500 (High Si-Bronze)	Monel 400 (Ni-Cu)	Soft iron	Nickel	Stainless steel
Melting point (°C)	1021	971	1343	1536	1453	1454
Thermal condition (W/m/°C)	189	36	22	78	89	16
0.5% yield strength (ksi)	10	21	30	30	20	58
Tensile strength (ksi)	37	56	68	45	52	88
2-in. elongation (%)	45	60	40	22	40	35

The five alternate materials that were chosen for further evaluations were silicone-bronze, MONEL®, soft iron, nickel, and stainless steel. Each of these materials had their advantages and disadvantages as a rotating band material either in cost, producibility, availability, or operationability. Silicone-bronze was selected because of the fact that it is a copper alloy with a high tensile strength. An attempt to adopt a higher strength copper alloy as a new rotating band material is prudent because of the fact that most existing rotating bands are copper based. The MONEL® and nickel were selected for their high melting point as well as their high tensile strengths. Soft iron was selected from historical studies of medium caliber systems (20 to 40 mm and 80-mm anti-aircraft gun) and the fact that welded rotating bands in the past were made from ARMCO Inc. iron. Stainless steel was selected because like iron and nickel, it has exceptional wear characteristics, but unlike iron, it does not corrode during long-term storage. Stainless steel is also readily available unlike ARMCO Inc. iron, which is no longer commercially available.

As part of the CPC program, the Materials and Structures Branch at ARDEC had conducted work on characterizing as-welded and fired rotating bands. Previously fired M549A1 and M483A1 projectile rounds were examined and analyzed to determine rotating band changes in hardness and physical condition as compared to as-welded, nonfired rotating bands. This analysis was performed in order to help understand the degree of work hardening and to correlate hardness data to the tensile/shear strengths of the materials. Some of the results of this analysis are shown in table 2.

Table 2
Characterization of as-welded and fired bands



Characterization of as-welded and fired bands

Projectile Type	Charge	Zone	Hardness Range Groove (HRB)	Hardness Range Land (HRB)
M549A1	XM230	5	64-74	49-60
M549A1	XM230	6	70-80	65-75
M483A1	XM230	6	75-85	75-85
M549A1	XM230	6	55-65	65-80
UNFIRED	N/A	N/A	20-30	20-30

* Fired bands consistently show higher hardness than as-welded bands

** Grain structure shows evidence of working

Fired bands consistently showed higher hardness values than as-welded bands. The results indicated that the grain structures of fired bands were changed in such a way that they were work hardened. Upon performing this analysis, the Materials and Structures Branch at ARDEC also conducted over lay welding experiments. These welding experiments were used to establish the welding parameters required of the five selected material candidates for rotating bands. The experiments consisted of welding each of the five candidate materials to AISI 4140 substrates and then analyzing them in terms of “bond” and “damage.” Metallurgical analyses of the as-welded parts were performed in addition to bend tests, which were used to determine the final integrity of the welding process and its capability to withstand a live-gun firing. The resulting developed welding processes were then used to assist the CPC program in the fabrication of ballistic test projectiles (BTP).

MODELING

As a member of the CPC program, ArrowTech Associates was able to generate a rotating band wear program in which the wear function was determined by experimental data. This program, which is part of their Projectile Design and Analysis System software, used an empirically determined wear constant for each band material. This constant, which is an exponent, was determined for iron and copper. Their values are 17 and 16.7, respectively. Because no experimental data had been obtained in the past for nickel and stainless steel, ArrowTech Associates interpolated a wear function by comparing the melt temperatures of iron, stainless steel, and pure copper. Upon determining the constants for stainless steel and nickel, a predicted band wear for the M549A1 projectile fired in a 48 land and groove crusader tube with an 8.927-deg exit angle (20 cal/rev) using a Modular Artillery Charge System zone 6 propelling charge was plotted. The results are shown in figure 3.

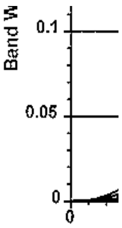


Figure 3
Wear predictions for new rotating band materials

The projected wear plot shown in figure 3 was used as an initial indicator of how well the alternate rotating band materials would perform as the length of the gun tube exceeds 39 calibers. In addition to the ArrowTech wear model, the Structural and Thermomechanical Modeling Department at Sandia National Laboratories (SNLL) in Livermore, CA had conducted a projectile rotating band compatibility study as part of the CPC program. The objective of the SNLL study was to generate a simplified structural, heat transfer, and wear analysis model that could be used to estimate projectile rotating band capabilities for existing and new in-bore loading environments. As a result of the SNLL study, a one-dimensional (1-D) model that estimates temperature distributions and wear in rotating bands taking into account parameters such as axial acceleration-time histories, projectile masses, and rifling twist rates was developed. This model was used to estimate the test results of down selected rotating band designs.

The SNLL 1-D model is written in FORTRAN system and runs on a UNIX® platform. The model incorporates the use of the five candidate rotating band material properties in addition to gilding metal and pure copper. A schematic of the wear mechanism used for the model is shown in figure 4. In figure 4, the basic heat input on the rotating band land is produced by the pressure and velocity of the rotating band as it travels down the gun tube. As the rotating band material heats up between the interface of the rotating band land and the gun tube land, a given percentage of melt will occur. When this melt occurs, the model removes the melt layer and the model is restarted with a new temperature boundary condition. The resulting output represents the remaining rotating band material width (X=L) at the end of gun tube travel.

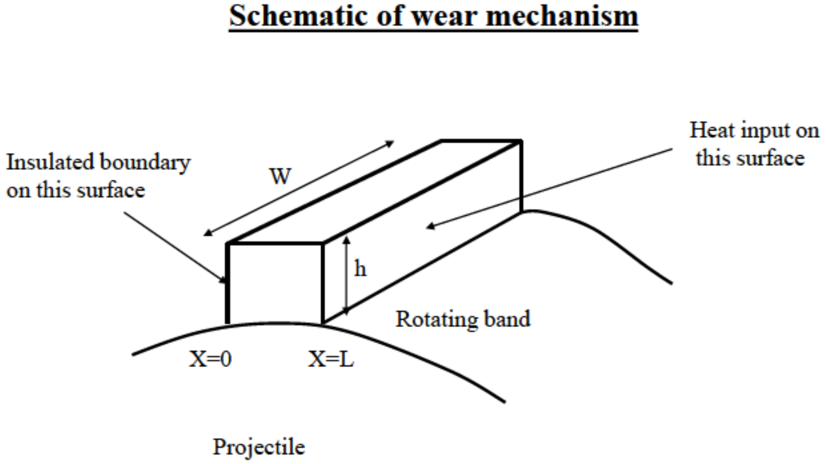


Figure 4
Schematic of wear mechanism for Sandia 1-D model

ROTATING BAND TESTS AND RESULTS

Because of the fact that most fielded projectiles have different rotating band shapes and different mass properties, it would not be fair to test a rotating design with an alternate band material unless the test was conducted with similar configuration rotating bands under similar conditions. In addition, it is not feasible to test a rotating design on a projectile that is already in the field due to the fact that fielded projectiles can no longer be modified to accept a new rotating band anyway. Thus, a new rotating band design could only be incorporated on new projectiles in development. For this reason, the CPC program developed a CPC BTP that was based on a (6.3 design) projectile design for the XM982. The XM982 (6.3 design) was a developmental projectile; it was one of the candidate projectiles that could incorporate a new rotating band design that would satisfy the required extended range capabilities. The CPC BTP was thus designed to have the same interior ballistic characteristics of the XM982 (6.3 design) projectile. The basic design of the CPC BTP is shown in figure 5 with its mass properties as compared to the XM982 (6.3 design) shown in table 3.

Notes:
1. Material: Structural Steel (4340 MIN YIELD=160,000 PSI)
2. Material: Structural Steel (4140 MIN YIELD=120,000)

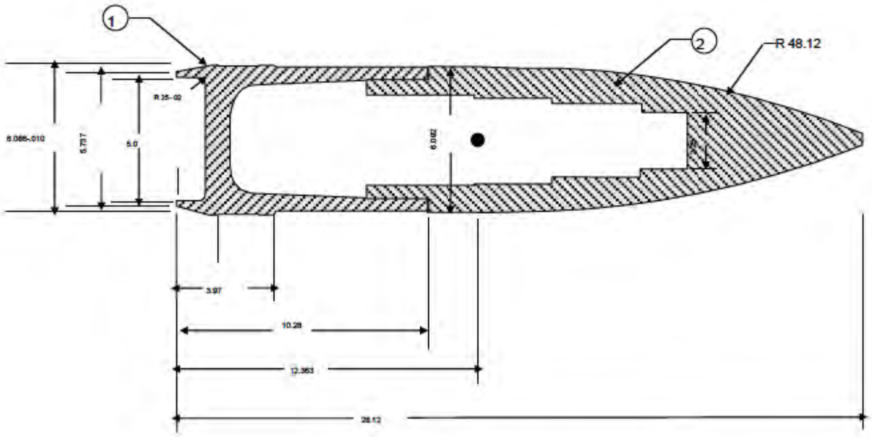


Figure 5
CPC (XM982) BTP

Table 3
Mass properties comparison

• XM982 6.3 DESIGN	• CPC BTP SIMULATOR
– WEIGHT = 106.57 LB	– WEIGHT = 106.4 LB
– C.G. = 12.62" FROM BASE	– C.G = 12.35" FROM BASE
– POLAR = 517.34 LB*SQ.IN	– POLAR = 564.939 LB*SQ.IN
– TRANS = 7480.83 LB*SQ.IN	– TRANS = 5319.63 LB*SQ.IN
– WHEELBASE	– WHEELBASE
• 10.835 IN	• 10.835 IN

The first fabrication of CPC BTPs began in mid-1996. They were rough machined by a contractor, sent back to ARDEC for the welding of rotating bands, and returned to the contractor for final machining, heat treating, and assembling. This procedure allowed the CPC program to dictate what rotating band materials could be tested and gauge how effective the welding parameters used could be applied to future applications. The first lot of projectiles consisted of rotating bands fabricated out of copper, silicon-bronze, soft iron, and nickel. The M864 rotating band shape was used on these projectiles thereby providing a close comparison to the M864 projectile for analyses. Because the CPC BTP was designed to withstand a 60 KPSI base pressure environment, a preliminary stress analysis was performed in order to verify its structural integrity. The output of the stress analysis using ANSYS software is shown in figure 6.

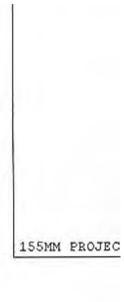


Figure 6
CPC BTP stress analysis

Inputs for the ANSYS stress analysis included band pressures of 40,000 PSI and axial accelerations of 15,000 g’s. These inputs are associated to a base pressure of 60,000 PSI, which is representative of extended range firings.

Upon completion of the first lot of BTPs, ARDEC conducted a structural integrity test to confirm the results of the ANSYS stress analysis. This test also provided some preliminary data on the effectiveness of the candidate rotating band materials. A completed CPC BTP welded with a nickel rotating band material is shown in figure 7.

Figure 7
CPC (XM982) BTP simulator

The structural test was conducted on July 30 and 31 of 1997. The test consisted of 16 rounds fired out of an M199 tube using M203A1 zone 8 propelling charges conditioned hot (+145°F). Eight CPC BTPs were fired. Four of the eight CPC BTPs that were fired had copper rotating bands. The copper rotating bands were used as a direct comparison to the two silicon-bronze and one soft iron and nickel band. The M864 and M483 projectiles were also fired as comparison rounds and warmer rounds. Hadland camera data showed that the projectiles were structurally qualified to survive a pressure of at least 56 KPSI. Upon recovery of the fired rounds, rotating band inspections and measurements were performed. The results of these inspections are shown in table 4.

39 caliber, average pressure= 56,000 psi, average muzzle velocity (MV)=812.6 m/s

Projectile	Rotating Band	RB Left (thousands)	% Worn
BTP	Copper	110	56
BTP	Copper	NA	NA
BTP	SiBr	Disbonded	NA
BTP	Soft Iron	200	20
BTP	Nickel	220	12
M864	Copper	105	58
M864	Copper	90	64
M483	Copper	140	44
M483	Copper	125	50

Note: RB stands for rotating band.

From the test data and the observations made on the recovered hardware, the silicon-bronze rotating bands did not survive the gun firing. This confirmed some of the earlier metallurgical bend tests that the Materials and Structures Branch at ARDEC had conducted during preliminary welding experiments. Although the earlier welding experiments indicated that the silicone-bronze may not be well bonded to the projectile, it was speculated that its bond had just enough strength to survive the firing. Thus, silicon-bronze was not totally eliminated from the candidate rotating band materials list early on so that its bond and welding parameters could be evaluated via a live-firing. The results of the firing also indicated that the CPC BTPs with the copper rotating bands were comparable to the M864 projectiles. Thus, as a measure of performance, the standard copper band of the M864 projectile is used for future analyses.

Based on the ARDEC structural test results, a firing at Yuma Proving Ground (YPG), Yuma, AZ was conducted in order to evaluate the rotating band materials in a 58 caliber gun. This firing was completed in November of 1997. It consisted of using an XM282, 58 caliber, high contractile chrome cannon with a 1,700-in.^{3} chamber. The tube rifling twist was 1 in 22.5, and the propelling charge used was an XM230 zone 6 conditioned at ambient temperatures. Along with three M864 projectiles used as comparison rounds, a total of 14 CPC BTPs were fired. The 14 CPC BTPs consisted of rotating bands manufactured out of copper, silicon-bronze, soft iron, nickel, MONEL®, and stainless steel. All of the test projectiles were fitted with standard M864 obturators. The results of this test are summarized in table 5 and photographs of some of the recovered hardware are shown in figures 8 and 9.

Table 5
Yuma rotating band test results

58 caliber, average pressure= 41,700 psi, average MV=874.6 m/s

Projectile	No. fired	Rotating band	Rotating band left (thousands)	% worn
BTP	1	Copper	Sawtooth	NA
BTP	2	Silicone Bronze	Disbonded	NA
M864	3	Copper	107	57.2
BTP	2	Monel	190	24
BTP	3	Nickel	204	18.4
BTP	3	Iron	217	13.2
BTP	3	Stainless Steel	215	14

Figure 8
Recovered M864 and BTP projectiles

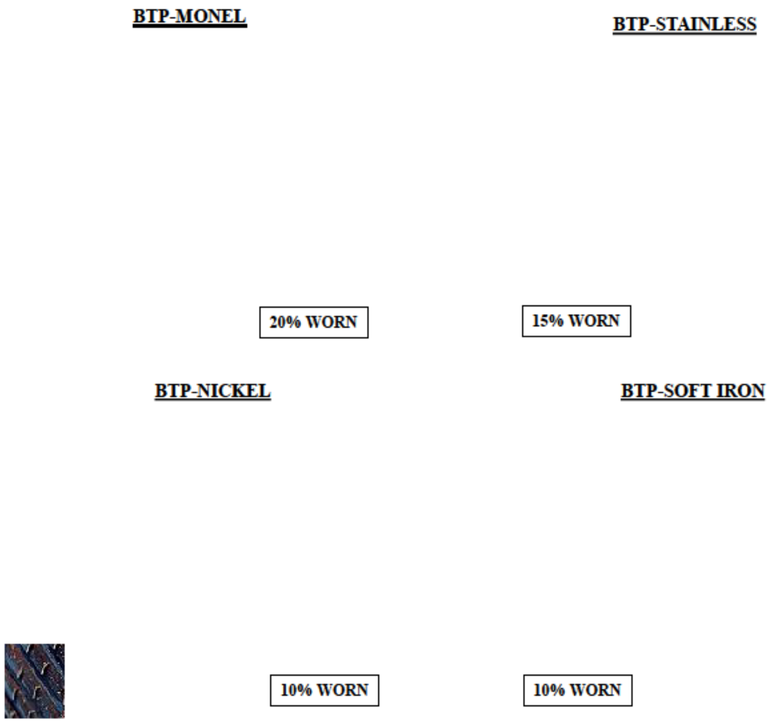


Figure 9
Recovered BTP projectiles

Due to the fact that this gun employs a 1,700-in.^{3} chamber, the pressures obtained were only in the neighborhood of 42 KPSI, which resulted in a muzzle velocity of around 875 m/s. Typically, the CPC program was looking to conduct a test at higher velocities somewhere in the neighborhood of 950 m/s. It was determined that this could be accomplished only by adding additional propellant to the standard XM230 zone 6 charge or by using a super propelling charge such as an XM224 charge. It was decided that the XM224 charge could be used on a follow-on test. This follow-on test was conducted in August of 1998. From the results of this first YPG test, it was noted that again the silicon-bronze rotating band had disbonded. The nickel, iron, and stainless steel rotating bands performed well indicating that they were approximately 80 to 95% better than the copper rotating bands tested. The MONEL® rotating band material was approximately 73% better than the copper rotating bands tested.

Because of the encouraging results obtained from this first YPG test, a low-zone sticker test was conducted at ARDEC using the same test projectile configurations and materials. This test was conducted in June of 1998 and its objective was to determine how the candidate rotating band materials would perform under low-zone conditions as designed using the current M864 projectile rotating band configuration. The low-zone sticker test consisted of firing 18 rounds that included rotating bands with one silicon-bronze, one soft iron, one stainless steel, two nickels, and several PXR6325 projectiles with various newly designed obturators. The obturator work associated with the CPC program is discussed in latter sections of this report. The test was conducted using M4A2 zone 3 propelling charges conditioned at -40°F and a first quarter 39 caliber gun tube. The results of the test are shown in figure 10. It was noted that one of the nickel bands stuck in the tube after the stainless steel band had gotten stuck. It was also noted that the projectile with the stainless steel band moved approximately 1.25 in. before it got stuck indicating that the stainless steel rotating band, in this case, was marginally acceptable. After further review and analysis, it was concluded that the nickel rotating band would be marginally acceptable at low zones and that the stainless steel rotating band would definitely not be acceptable for most low-zone applications.

39 caliber, average pressure= 6,700 psi, average MV=271 m/s

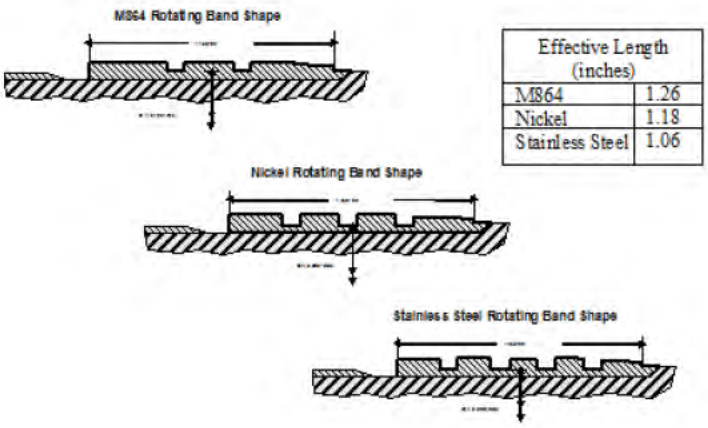
Firing order
3-M483
SiBr
Soft iron
Nickel
MONEL®
Stainless steel
PXR6325-LNP
M864
3-PXR6325
Nickel
PXR6325
3-PXR6325-UK MOD

STICKERS

- **All obturators discarded.**
- **Must redesign rotating band profile for nickel and stainless steel, if low-zone application is required as is.**

Figure 10
ARDEC low-zone test results

Upon further analysis of the data and the utilization of the SNLL 1-D rotating band model, it was concluded that the causes of the low-zone sticker problems associated with the nickel and stainless steel materials could be eliminated by a redesigned nickel and stainless steel rotating band configuration. The redesigned nickel and stainless steel rotating band configurations are shown in figure 11. These redesigns were developed to only affect the shear stress and strain relationship of the rotating band material against the gun tube rifling during the engraving process thereby eliminating their potential to cause a projectile to get stuck in the gun tube. The redesign was also developed to have a minimal effect to the high-zone application.



Effective Length (inches)	
M864	1.26
Nickel	1.18
Stainless Steel	1.06

Figure 11
Rotating band redesign

The redesigned nickel and stainless steel rotating band configurations were fabricated on the final lot of CPC BTPs and further tested at YPG and ARDEC to validate the Sandia and ARDEC analyses.

Figure 12 shows the redesigned nickel and stainless steel rotating bands machined on the CPC BTPs. The major noticeable configuration differences between the nickel rotating band and the stainless steel rotating band is the additional cannelure (or groove) machined on the stainless steel band. The nickel rotating band is incorporated with three cannelures while the stainless steel rotating band is incorporated with four. The additional cannelures were also increased in depth as compared to the standard M864 rotating band. This depth increase of the cannelures with the reduction of the rotating band's effective length were essentially the main elements of the redesign that were necessary in relieving the high shear forces required to engrave the nickel and stainless steel rotating bands subjected to most low-zone applications. It was determined that the new design
subjected to h strengths
and the natur avel down
the gun tube.

Nickel rotating band

Stainless steel rotating band

Figure 12
Redesigned band configurations

Based on the results of the first YPG test and the two ARDEC test firings, the CPC program down selected from the five candidate materials to the new nickel and stainless steel rotating band designs. The down selection was based on many factors, which included all aspects of the materials in terms of performance, logistics, fabrication, availability, and cost. The CPC program then conducted a follow-on high-zone test at YPG during August of 1998 using the redesigned nickel and stainless steel rotating band designs. Again, this test used the XM282 58 caliber Serial Number (SN): XP2 Cannon with a 1 in 22.5 rifling twist and a 1700 cu in chamber. In order to obtain the higher pressures and velocities desired by the CPC program objectives, special charges known as XM224 propelling charges (conditioned at ambient temperature) were used for this test. These charges consisted of two components (a forward charge and a base charge) that together produce a chamber pressure of approximately 54,000 PSI with a muzzle velocity of about 984 m/s for an M864 projectile fired out of the XM282 58 caliber cannon. The average velocity of 970 m/s and an average pressure of 54,000 PSI was obtained for most of the rounds conducted on this test. The XM282 58 caliber cannon and the XM224 propelling charge is shown in figure 13.

1700 cu in chamber,
1 in 22.5 twist
propelling charge
XM224

Figure 13
XM282, 58 caliber SN:XP2

Thirteen CPC BTPs (seven nickel rotating bands and six stainless steel rotating bands) were fired along with three M864 rounds. Because of the fact that analytical analyses and test data had indicated that the new redesigned nickel and stainless steel rotating bands would perform similarly to previously tested high-zone firings, the 13 CPC BTPs were also fitted with new obturators. These obturators were designed for an M549A1 projectile and they incorporated the use of a polyphthalamide material called AMODEL. The AMODEL material had previously been tested as part of an ongoing obturator development effort. A specific design was developed for these test projectiles in order to supplement the performance of the rotating band design as well as to gather additional obturator test data for future obturator developmental efforts.

All of the test rounds fired on this test were recovered and inspected within a week. The recovered hardware was inspected by ARDEC and ARL members of the CPC program, and it was noted that the test results were extremely favorable in terms of rotating band wear. The results as determined by the amount of band worn was similar to the November 1997 test. The amount of rotating band wear for each of the materials (nickel and stainless steel) was noted to be consistent or stable from round to round. The copper rotating bands on the M864 rounds were noted to be over 66% worn and inconsistent from round to round as compared to the consistent 22% worn nickel rotating bands and the 28% worn stainless steel rotating bands. The results of this test are shown in table 6 and photographs of some of the recovered hardware are shown in figures 14 and 15.

Tube XM282 SN XP@, WTV-F31665, 58 caliber; 1 22.5 Twist; HC chrome bore

TRN	PROJECTILE	WEIGHT	RB TYPE	OBTURATOR	RB WEAR	MUZZLE VELOCITY	PRESSURES
120	M107						
121	M864	100.1	Standard	Standard	0.167	983.5	53100
122	BTP-Ni	106	Nickel	Amodel	0.207	961.45	54300
123	BTP-Ni	106	Nickel	Amodel	0.209	969.25	55200
124	BTP-Ni	106	Nickel	Amodel	0.206	959.8	52500
125	BTP-Ni	106.1	Nickel	Amodel	0.206	964.15	52400
126	BTP-Ni	106.3	Nickel	Amodel	0.206	968.45	55000
127	BTP-Ni	105.8	Nickel	Amodel	0.205	963.1	52500
128	BTP-Ni	106.1	Nickel	Amodel	0.208	964.15	52700
129	M864	100.2	Standard	Standard	0.085	977.6	50200
130	BTP-SS	105.8	Stainless Steel	Amodel	0.195	964.25	52600
131	BTP-SS	105.8	Stainless Steel	Amodel	0.195	966.05	53200
132	BTP-SS	105.8	Stainless Steel	Amodel	0.195	965.6	54800
133	BTP-SS	106	Stainless Steel	Amodel	0.195	970.4	55000
134	BTP-SS	105.9	Stainless Steel	Amodel	0.195	969.95	54500
135	BTP-SS	105.5	Stainless Steel	Amodel	0.197	966.7	53000
136	M864	100.2	Standard	Standard	Body Engraved	979.1	50600
			Nickel	Amodel	0.206714286		
			Stainless Steel	Amodel	0.195333333		

M864

Copper

Nickel

Stainless steel

Figure 14
Recovered hardware - part 1

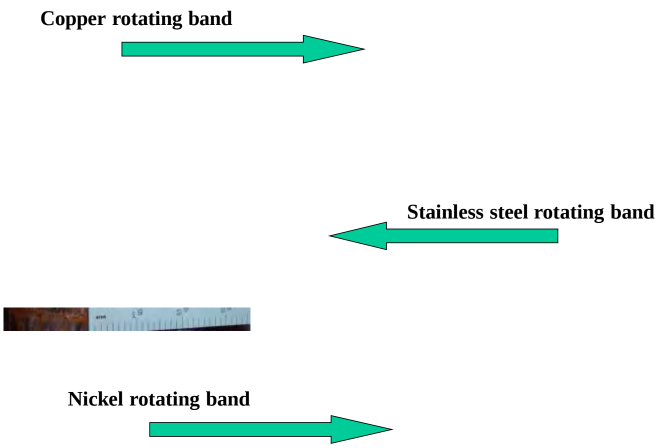


Figure15
Recovered hardware - part 2

It is interesting to note that the nickel band slightly outperformed the stainless steel. This is apparent by examining the tabulated average wear measurements shown in table 7. As the data is compared to the predicted Sandia 1-D wear model, it is noted that the stainless steel should have performed similarly to nickel. Reasons for the differences may be due to the changes in the stainless steel material properties from welding and fabrication in addition to the limitations of the 1-D wear mode

Y

58 caliber, Average pressure= 54,000 psi, average MV=967.2 m/s

Projectile	No. fired	Rotating band	Rotating band left (thousands)	% worn	
BTP	7	Nickel	206	18	24 △
BTP	6	Stainless Steel	195	22	23 △
M864	3	Copper	87	65	40 △

△ Predicted wear based on SNLL 1-D model.

The predicted wear measurements shown in table 7 were generated based on pressure profiles not used in the actual gun firing. Due to this difference in pressure profiles, the correlation of predicted versus actual rotating band wear could be slightly skewed. Additional factors affecting the percentage differences in the predicted data versus the actual data are due to the fact that wear is three-dimensional and contingent upon surface conditions of the gun tube. Nevertheless, the generated data can still be somewhat correlated to expected wear values, and the Sandia 1-D wear model has been and is currently used as a very useful design tool.

Other observations noted upon examination of the recovered hardware from this test include the fact that the AMODEL obturator did successfully supplement the performance of the rotating band and projectile. This is apparent by noting that the blue paint at the location of the obturator on the projectile was still intact. All Star Gauge reports on the XM282 58 caliber gun tube generated prior to and after testing were analyzed to indicate that the rotating bands tested did not significantly generate any excessive or abnormal wear on the gun tube. The test results also showed that the reduced effective length of the rotating bands using nickel and stainless steel did not affect the performance of the projectile at high-zone firings.

After the YPG test, the CPC program continued to evaluate the two down selected nickel and stainless steel rotating bands in another low-zone sticker test. This low-zone sticker test was conducted on October 21, 1998 at ARDEC. The test objective was to verify that the new design would be adequate in satisfying the low-zone application. The low-zone sticker test again used a 1st quarter M199 gun tube. A total of nine rounds were fired, which included two CPC BTPs with nickel
rotati sed
M864 ors. The
PXR6 s again
the M .

CPC BTP with nickel and stainless steel rotating bands

Figure 16
ARDEC low-zone sticker test

The average pressures obtained for the CPC BTPs with the nickel and stainless steel rotating bands were about 10,000 PSI and 11,750 PSI, respectively. The average velocities were in the neighborhood of 282 to 285.9 m/s. The M864 projectile rounds and PXR6325 projectile rounds obtained lower pressures and velocities due to the fact that they are 7 to 10 lb lighter than the CPC BTPs. All projectiles were successfully fired and no sticker problems were encountered. After a review of all the test results and firing data along with recovered projectile analyses, the CPC program members down selected to a candidate nickel rotating band design and an AMODEL obturator as the most viable solution for new ERO. Stainless steel was a good candidate material also; however, its exceptionally high tensile and yield strength and very high melting point require it to be further evaluated through more advanced design configurations.

CONCLUSIONS

In the Cannon Projectile Compatibility (CPC) program, alternate rotating band materials were demonstrated to be superior to copper alloy bands for high velocity applications. The higher melt temperature and tensile strength properties of nickel and stainless steel are capable of outstanding performance in extended range weapon systems. The test results validated the design objectives established for the CPC program. Models developed under this program will be useful tools for evaluating new band materials and cannon parameters and their effect on band wear. The combination of a projectile rotating band with an alternate band material and an improved obturator will meet the requirements of the next generation artillery systems.

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