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WEAR OF PROJECTILE ROTATING BANDS

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
LARGE CALIBER WEAPON SYSTEMS LABORATORY
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Rotating or driving bands are bands of relatively soft materials surrounding a projectile. They have a number of functions the chief of which is probably that they produce stabilizing rotating of the projectile when they are "engraved" or keyed into the rifling. These bands are used on spin-stabilized projectiles as small as 20 mm caliber, but this discussion concerns especially the larger cannon, i.e., in excess of 105 mm. Excess wear of projectile

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20. ABSTRACT (CONT'D)

rotating bands has a number of important negative consequences including inaccuracy and "short rounds". There are two distinctly different mechanisms of wear. At low speeds near the beginning of motion, wear is by adhesion, abrasion, and even under some conditions, scuffing. After a few centimeters of sliding, a thin surface film of molten band material is formed and the remainder of the sliding is melt-lubricated. While metal-on-metal sliding is limited to the first few centimeters, it is very important and can result in serious wear problems down bore. The exact wear of rotating bands depends on the motion of the projectile in the bore of the cannon. Therefore, this motion can be inferred from the wear.

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INTRODUCTION

Rotating bands are bands of relatively soft materials surrounding a projectile toward its rear which "when engraved" or keyed into the rifling produces the stabilizing rotation. Modern U.S. artillery is in excess of 105 mm caliber although the older cannon of 75 and 90 mm operated in exactly the same way. Figure 1 is a diagram of a typical artillery projectile illustrating the appearance and location of the rotating band. Cannon projectiles use a band as opposed to small arms in which most of the bullet is engraved. Almost all rotating bands are made of copper or gilding metal (an alloy of 10 percent zinc and 90 percent copper). Excessive wear of the band can result in unsatisfactory functioning of the projectile and even in damage to the cannon.

A projectile begins sliding from rest and rapidly gains speed. The initial sliding is unlubricated dry sliding. However, within a few centimeters a thin lubricating film of molten metal is produced on the surface of the band. Almost the entire travel of the projectile down the bore is lubricated sliding and the band wear mechanism is melting of the surface (refs 1-3). Therefore, the wear of rotating bands for almost all the sliding is controlled by the melting point of the band material and its heat conductivity (ref 4). However, in spite of the fact that almost all the sliding is melt-

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[1]R. S. Montgomery, "Surface Melting of Rotating Bands," Wear, Vol. 38, 1976, p. 235.
[2]R. S. Montgomery, "Projectile Lubrication by Melting Rotating Bands," Wear, Vol. 39, 1976, p. 181.
[3]R. S. Montgomery, "Evidence for the Melt-Lubrication of Projectile Bands," Trans. A.S.L.E., 1983 (in press).
[4]R. S. Montgomery, "Friction and Wear at High Sliding Speeds," Wear, Vol. 36, 1976, p. 275.

lubricated, the initial unlubricated sliding is very important and generally wear problems can be traced to this very short period of dry sliding.

MECHANISMS OF WEAR

Because of the two distinct mechanisms of wear, there are two distinct kinds of wear of projectile rotating bands. The first occurs near the origin-of-rifling. There can be abrasive wear, adhesive wear, and even scuffing of the band material in this location. The other kind of wear is that which occurs throughout the rest of the tube.

INITIAL WEAR OF ROTATING BANDS

The wear of the rotating bands cannot be separated from damage to the bore of the cannon. This is especially true for the first kind of wear, that near the origin of rifling. Cannon bores are ordinarily of gun steel which is a modified AISI 4340, but in a few cases the gun steel is plated with chromium. The cannon bore erodes quite differently near the origin-of-rifling depending on whether it is steel or chromium-plated steel. While the bores are originally well-machined, they do not remain in this condition long in use. Figure 2 shows a used steel tube at the origin-of-rifling. There is considerable steel removed by the firing. The raised lands are even eroded away entirely right at the origin-of-rifling. The remaining steel is heavily heat-checked, but there are no sharp cracks or edges. Chromium-plated steel, on the other hand, does not erode significantly much beyond the origin-of-rifling. Figure 3 shows a used chromium-plated tube. The origin of rifling is severely worn and there are sharp edges exposed where the plating has been removed. There is sometimes as much as one-third more wear on the bands of projectiles that were fired in chromium-plated tubes (ref 5). This increased wear cannot be attributed to the chemical nature of the surfaces before melt-lubrication has been established. In laboratory pin-on-disk studies with a bearing pressure of from 55,000 kN/m^2 (8,000 psi) to 83,000 kN/m^2 (12,000 psi) a gilding metal pin wore at a rate of essentially zero at a velocity of 1.70 m/s and only 0.02 mm/m at a velocity of 3.05 m/s sliding on chromium plate. Sliding on gun steel under these conditions gave wear rates of 0.07 mm/m and 0.06 mm/m, respectively. In addition, there is no reason to expect any difference at all in the melting wear in the faster sliding melt-lubricated regime. There is no wear data in this regime, but there is friction data and the coefficients are identical (ref 6). It seems reasonable to attribute the increased wear with chromium-plated tubes to much greater abrasive wear near the origin of rifling. Rather large amounts of band material could well be torn off by the sharp edges produced when the plating is removed in this region. In the case of the steel tubes, there are no sharp edges and so little or no abrasive wear.

WEAR RESULTS

Evidence which corroborated the abrasive wear at the origin of rifling of chromium-plated gun tubes was found in the case of an eight-inch cannon. With this cannon, there was occasionally difficulty encountered in chambering a

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[5] J. A. Lannon and A. C. Vallado, "Effect of Chrome Plating on the Wear Characteristic and Ballistic Performance in the 155 mm M198 Artillery System," U.S. ARRADCOM Technical Report No. ARLCD-TR-60018, Large Caliber Weapon Systems Laboratory, Dover, NJ, 1981.

[6] R. S. Montgomery, "Friction of Gilding Metal Sliding of Chromium-Plated Steel," Wear, Vol. 50, 1978, p. 387.

particular model of projectile which was somewhat longer than usual. This was attributed to fragments of rotating bands which had been removed from previous projectiles by irregularities in the bore topography coupled with the fact that chromium-plated bores do not wear much beyond the origin of rifling, so consequently, clearances here are closer. Even a rather small deposit can cause difficulty in chambering the next projectile in the case of a chromium-plated cannon tube. Figure 4 is a section through a particle found in a particularly severe irregularity. This particle is an agglomerate of unmelted individual particles bound together by a "mastic" of band material which had been molten.

Another example of initial wear in the region of the origin-of-rifling where there is metal-on-metal unlubricated sliding, was the case where iron rotating bands were used in cannons with steel bores. Apparently, the soft iron bands scuffed and the iron adhered strongly to the steel bore. Actually rough deposits near the origin of rifling from whatever cause are not as much of a problem as might be expected. After the projectile moves past, the deposit is subjected to intense heat from the propellant gases which tends to smooth it out.

EFFECTS OF EXCESSIVE WEAR OF BANDS

Excessive wear of rotating bands might at first seem unimportant. After all, rotating bands have no purpose at all after the projectile has left the muzzle. While this is true, it is vitally important that too much wear does not occur in the travel of the projectile from rest to the muzzle. If too much wear occurs on the bands radially to the center line of the projectile, the body will contact the bore near the muzzle. While the steel of the body will form a molten surface film just as was produced on the rotating bands, for a short time there will be unlubricated sliding which will result in muzzle wear at this location and serious damage to the bore and decreased accuracy. This is illustrated by comparing the erosion of a steel bore of a developmental 155 mm cannon with the erosion of an identical chromium-plated bore (see Figure 5). There was more serious muzzle wear found with the chromium plate (ref 7).

Another problem is caused by excessive wear on the driving surfaces of the rotating band. In this case the excessive wear results in reduction of the shear area so that the raised portion of the engraved bands shears before the projectile reaches the muzzle. If this happens, the projectile never reaches stabilizing rotation and falls short of its intended range. It is probable that all cases of rotating band failure can be attributed to excessive wear in the initial portion of the projectile's travel even where the failure doesn't occur until well down the tube.

MELT-LUBRICATED WEAR

Wear in the second regime, that is, where the bands are melt lubricated, is completely controlled by the melting point of the band material and its thermal conductivity (ref 4). In general, wear here is not a problem. With the low-melting plastic band materials, wear is many times that of metal.

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[4] R. S. Montgomery, "Friction and Wear at High Sliding Speeds," Wear, Vol. 36, 1976, p. 275.
[7] R. S. Montgomery, "Muzzle Wear of Cannon," Wear, Vol. 33, 1975, p. 359.

However, a problem may not be encountered if the bands can be made wide enough so that there will be more material available to be worn away and the bearing pressure will be less. It is also possible that the band material has a melting point high enough so that it doesn't melt. In this case the retarding force owing to friction would be so high that projectile travel in the bore would stop before the projectile exits the tube except at very high propellant pressures. However, this is unlikely to be a problem since such a high-melting material would probably be too hard to engrave properly and material even as high melting as iron melts at the sliding interface (ref 3).

A problem associated with melt lubrication is encountered in this region. Any liquid lubricated slider travels on a film which moves at an average velocity of half that of the slider. From this it is apparent that there will be considerable lubricant left behind. In the case of a melt-lubricated slider, such as a projectile sliding on a film of molten band material, the material left behind will be a film of band material (generally copper or a copper alloy). This is the phenomenon of "coppering" of a gun tube. After many successive films have been laid down on the bore, the clearance between the projectile and the bore can be eliminated entirely. This problem is obviated by incorporating metallic lead into the more powerful propellant charges. The lead removes the deposited copper through a mechanism which is not well-known.

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[3] R. S. Montgomery, "Evidence for the Melt-Lubrication of Projectile Bands," Trans. A.S.L.E., 1983 (in press).

RELATION OF BAND WEAR TO PROJECTILE MOTION

The specific band wear on recovered projectiles is indicative of the motion of the projectile in the cannon bore. Calculations of the yaw or "cocking" of a balanced projectile as it travels down the bore have shown that if it begins on the center line it moves rapidly to one wall or the other where it continues to the muzzle. That is, it rapidly attains the maximum degree of "cocking". This is, of course, because there is little restoring force when the projectile moves from the center line of the bore for some reason. The small restoring force resulting from the rebounding of the projectile after it strikes the wall depends on the elasticity of the projectile, the cannon bore, and the energy of the impact (ref 8) but could only delay the attainment of a fully "cocked" attitude. This motion is called "balloting" and it was thought to be more important. There are two things wrong with the above analysis (I do not mean to imply that the analysts are not aware of this). First, no U.S. projectile is balanced in production because of cost. Projectiles are designed so that if they are manufactured correctly the balance will be acceptable. Therefore, a few projectiles are perfectly balanced, but there will also be a few with extreme imbalance. Second, large U.S. cannon use caseless ammunition where there is nothing to support the projectile when it has been rammed. These projectiles have considerable weight so they lie on the bottom of the bore at rest and start their movement from there. These two facts mean that the actual projectile

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[8] R. D. Kirkendall, "The Yawing Motion of Projectiles in the Bore," Ballistics Research Laboratory Report No. BRL-TN-1739, Aberdeen, MD, 1970.

has a different motion in the bore than does a perfectly balanced projectile starting on the center line.

Large cannon projectiles start from rest with their bourrelets in contact with and supported by the bottom of the bore. If they are balanced or if an off-center center-of-gravity is toward the bottom, they will not move from contact with the bore. (Of course, contact with the bore will follow the twist of the rifling.) If the bearing pressure is sufficient, the bourrelet will engrave as illustrated in Figure 6. There will also be a single engraving of the rotating bands. On the other hand, if the projectile is sufficiently imbalanced and the center-of-gravity is toward the top, it will move to a fully "cocked" attitude with the bourrelet contact on the bore on the side of the projectile toward the off-center center-of-gravity. An asymmetrically eroded origin-of-rifling as usually occurs with a chromium-plated bore, might also result in a fully "cocked" attitude of the projectile. In this case, there is seldom enough bearing pressure sufficiently long to cause body engraving on the bourrelet of the projectile. However, there is sometimes body engraving produced to the rear of the rotating band. In this case, there is also "double" engraving observed on one side of the band. (This would be the side of the projectile originally in the 6 o'clock position.) This is where the band is worn significantly deeper near the driving edge and there is a definite "shelf" in the grooves of the band worn by the lands of the rifling. This is illustrated in Figure 7 which shows a portion of the band from a recovered eight-inch projectile. This "shelf" is produced when the projectile assumes the "cocked" attitude and the bearing pressure becomes significantly greater on the band on the side opposite the bourrelet contact.

The ogive on the projectile tends to center it in the bore of the cannon and although the bourrelet remains in contact with the bore wall, it does reduce the bearing pressure on the wall. Frequently, a flat ended "slug" is used in the early stages of the development of a new cannon because these slugs are considerably less expensive than actual projectiles and actual projectiles may not be available at this time. A flat-ended slug does not have the centering of an ogive and so band wear, body engraving, and muzzle wear on the gun tube are sometimes severe. This is illustrated in Figure 8. This extreme wear then disappears when actual projectiles begin to be used.

SUMMARY

Excessive wear on projectile rotating bands in a radial direction will result in wear of the bore of the cannon near the muzzle leading to inaccuracy. However, if there is excessive wear on the driving edges of the band, the shear area can be reduced enough so that there will be band shearing and the projectile never reaches stabilizing rotation and so falls much shorter than expected.

There are two distinct wear mechanisms and so there are two distinct kinds of wear. At the beginning of motion near the origin-of-rifling there is metal-on-metal sliding and wear is by adhesion, abrasion, and even scuffing in certain cases as when soft iron rotating bands are used in cannon with steel bores. After a few centimeters of sliding, a thin surface film of molten band material is formed and the remainder of the sliding is melt-lubricated. In this second wear regime there is normally no wear problem except that which can be attributed to excessive wea· before melt-lubrication near the origin-of-rifling. For example, there is sometimes excessive wear on the bore near the muzzle with chromium plated tubes probably owing to abrasion on the rougher origin-of-rifling. In this case also, there may be as much as one-third more wear on the bands than was experienced with a steel tube.

The exact wear of rotating bands depends on the motion of the projectile in the bore of the cannon. If the projectile began its motion on the center-line of the bore, it would rapidly go to one wall or the other and continue in a fully "cocked" attitude until it exits from the muzzle. However, the ammunition of large cannon is caseless, and so there is nothing to support the projectile and it begins motion from a position on the bottom of the bore. In this case, if the projectile is perfectly balanced or if the center-of-gravity is on the side toward the bottom wall, the projectile will continue sliding on this wall (following the rotation of the rifling of course) until it exits from the muzzle. If, on the other hand, the center-of-gravity is originally in an upward direction, the projectile will yaw or "cock" and then it will travel down the bore with this attitude. The wear on the rotating bands is different for the different motions of the projectile in the bore.

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1. R. S. Montgomery, "Surface Melting of Rotating Bands," Wear, Vol. 38, 1976, p. 235.

2. R. S. Montgomery, "Projectile Lubrication by Melting Rotating Bands," Wear, Vol. 39, 1976, p. 181.

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6. R. S. Montgomery, "Friction of Gilding Metal Sliding of Chromium-Plated Steel," Wear, Vol. 50, 1978, p. 387.

7. R. S. Montgomery, "Muzzle Wear of Cannon," Wear, Vol. 33, 1975, p. 359.

8. R. D. Kirkendall, "The Yawing Motion of Projectiles in the Bore," Ballistics Research Laboratory Report No. BRL-TN-1739, Aberdeen, MD, 1970.

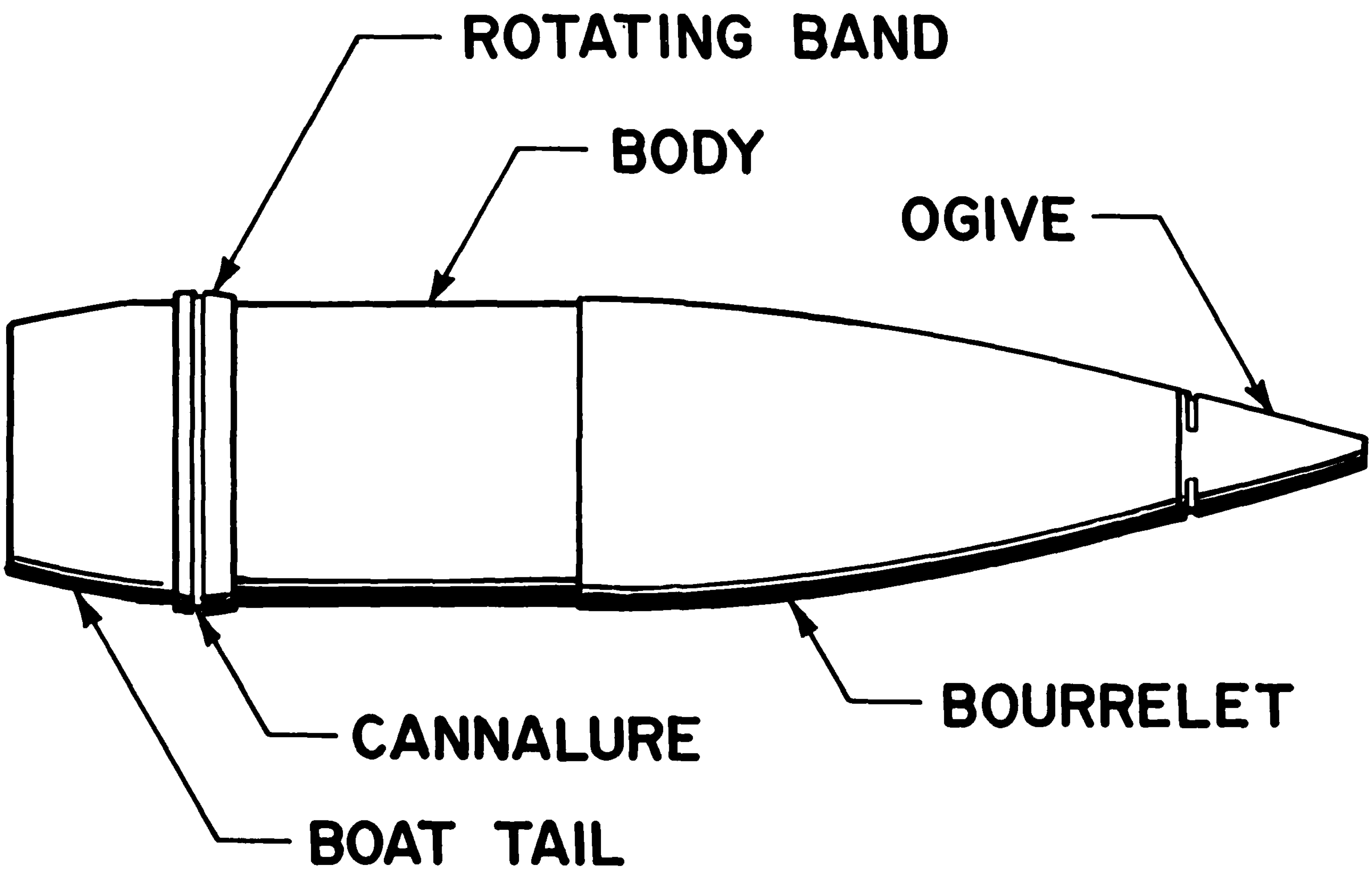

Figure 1. Diagram of typical artillery projectile.

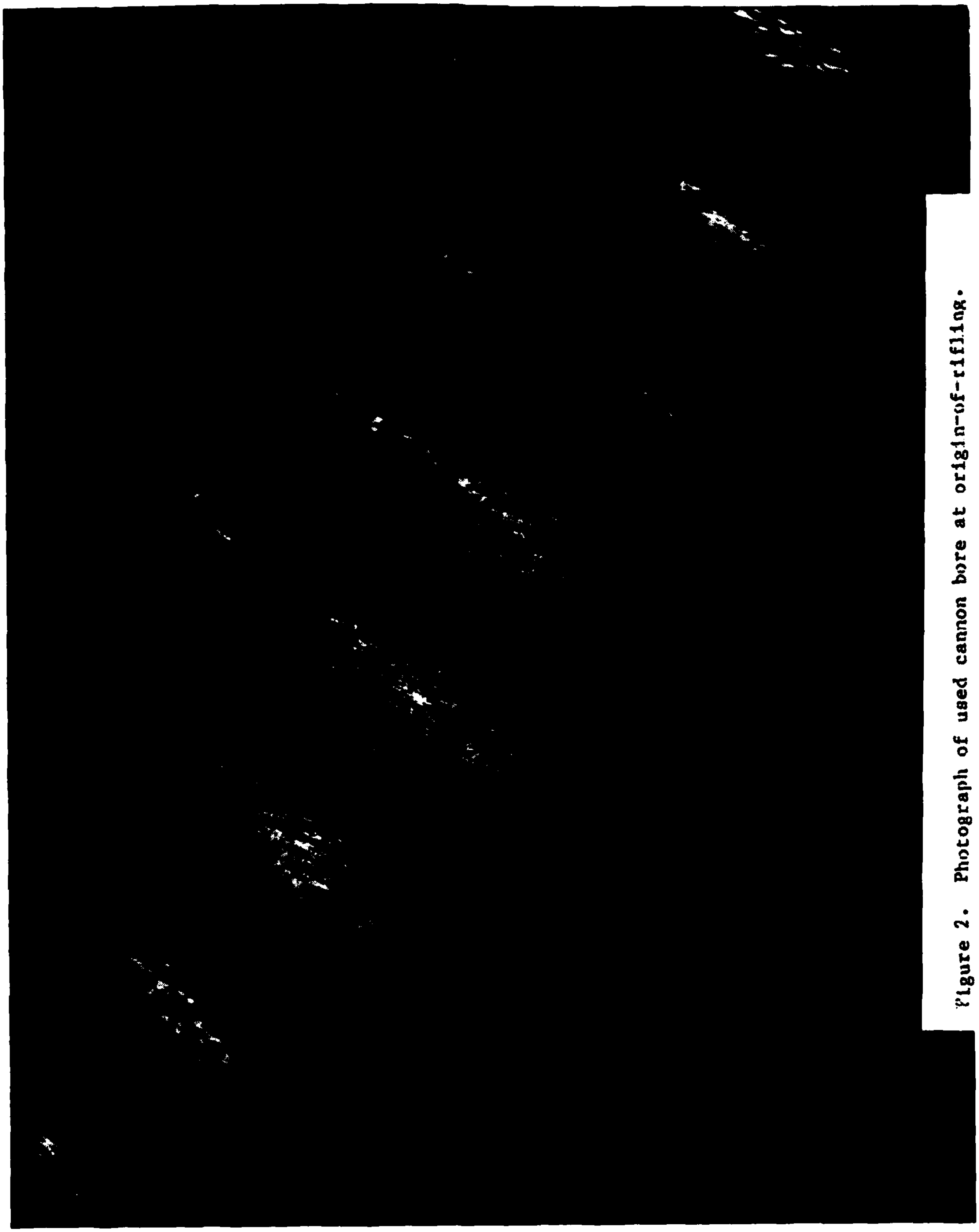

Figure 2. Photograph of used cannon bore at origin-of-rifling.

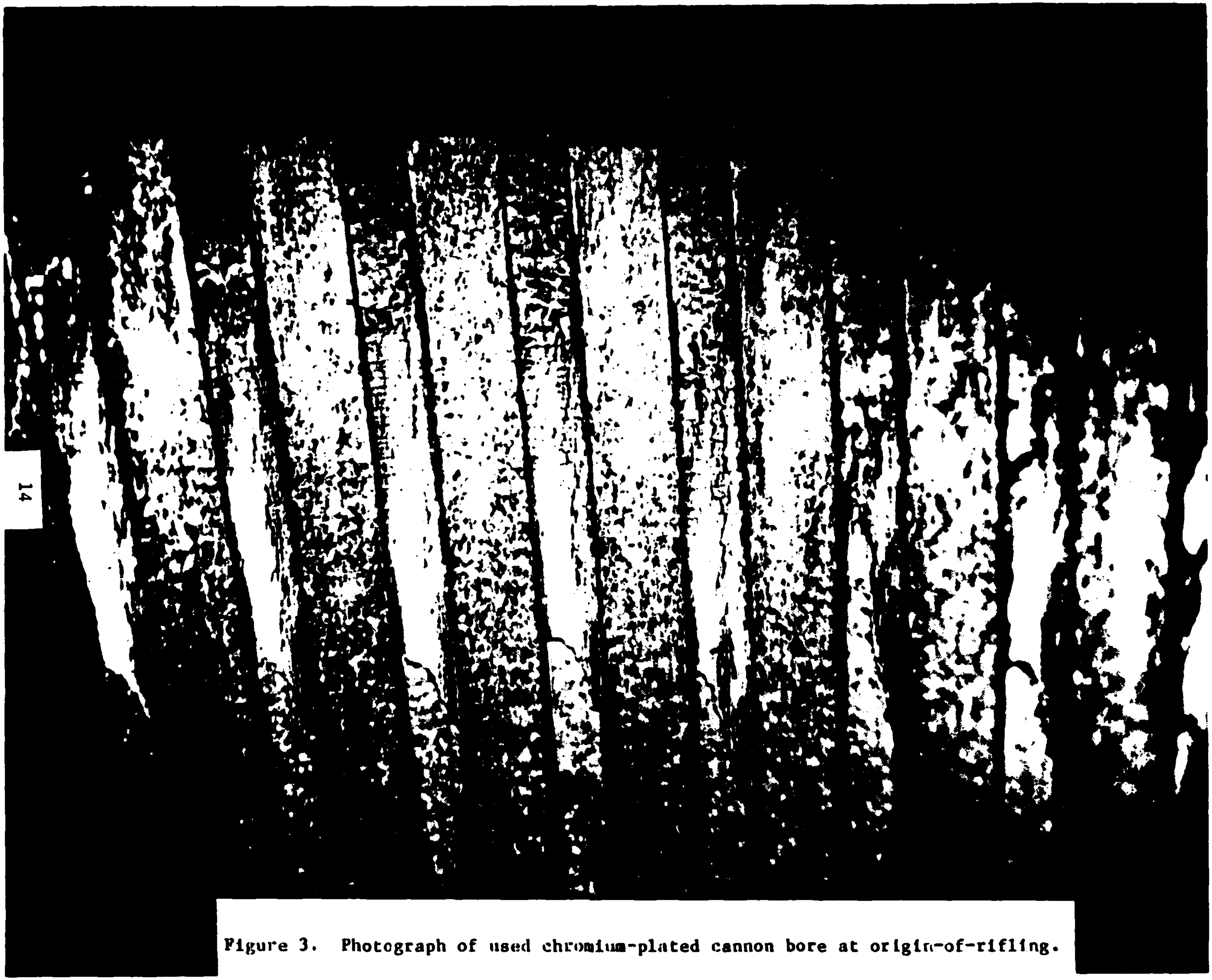

Figure 3. Photograph of used chromium-plated cannon bore at origin-of-rifling.

Figure 4. Photograph of section through particle found in a particularly severe irregularity near the origin-of-rifling of a chromium-plated cannon bore. Hardnesses: gilding metal - 320 KHN; copper - 360 KHN; matrix - 250 KHN.

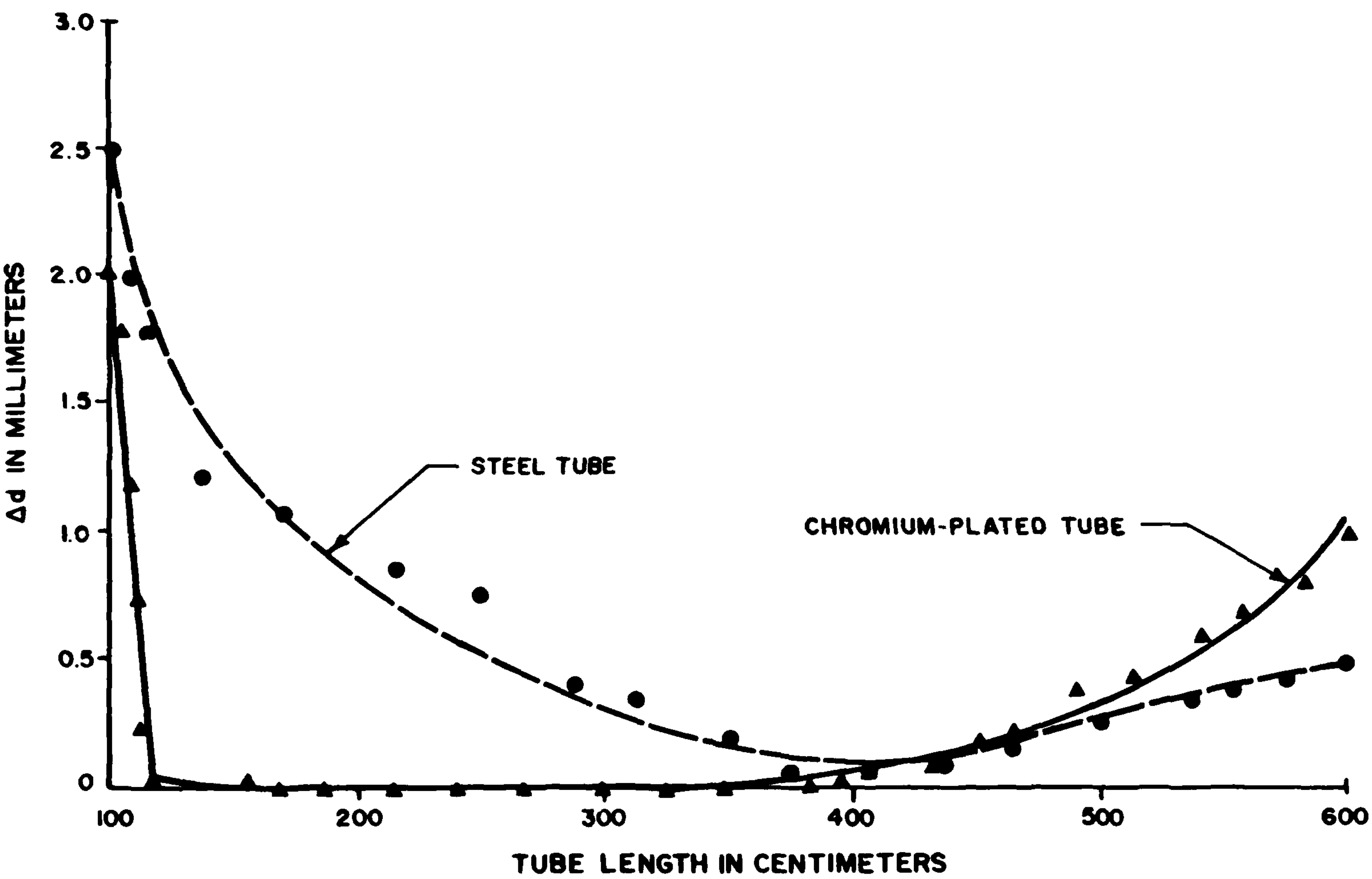

Figure 5. Comparison of erosion of steel bore with chromium-plated bore after about 1800 rounds for a developmental 155 mm cannon.

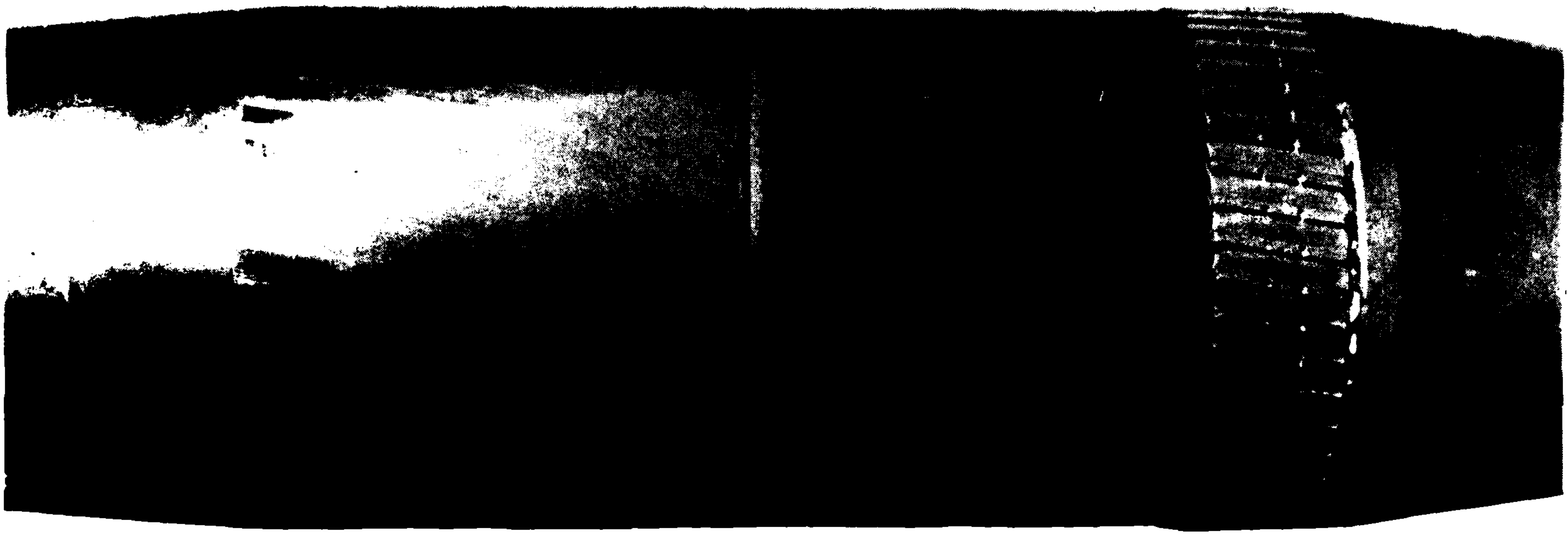

Figure 6. Recovered 155 mm projectile showing bourrelet engraving.

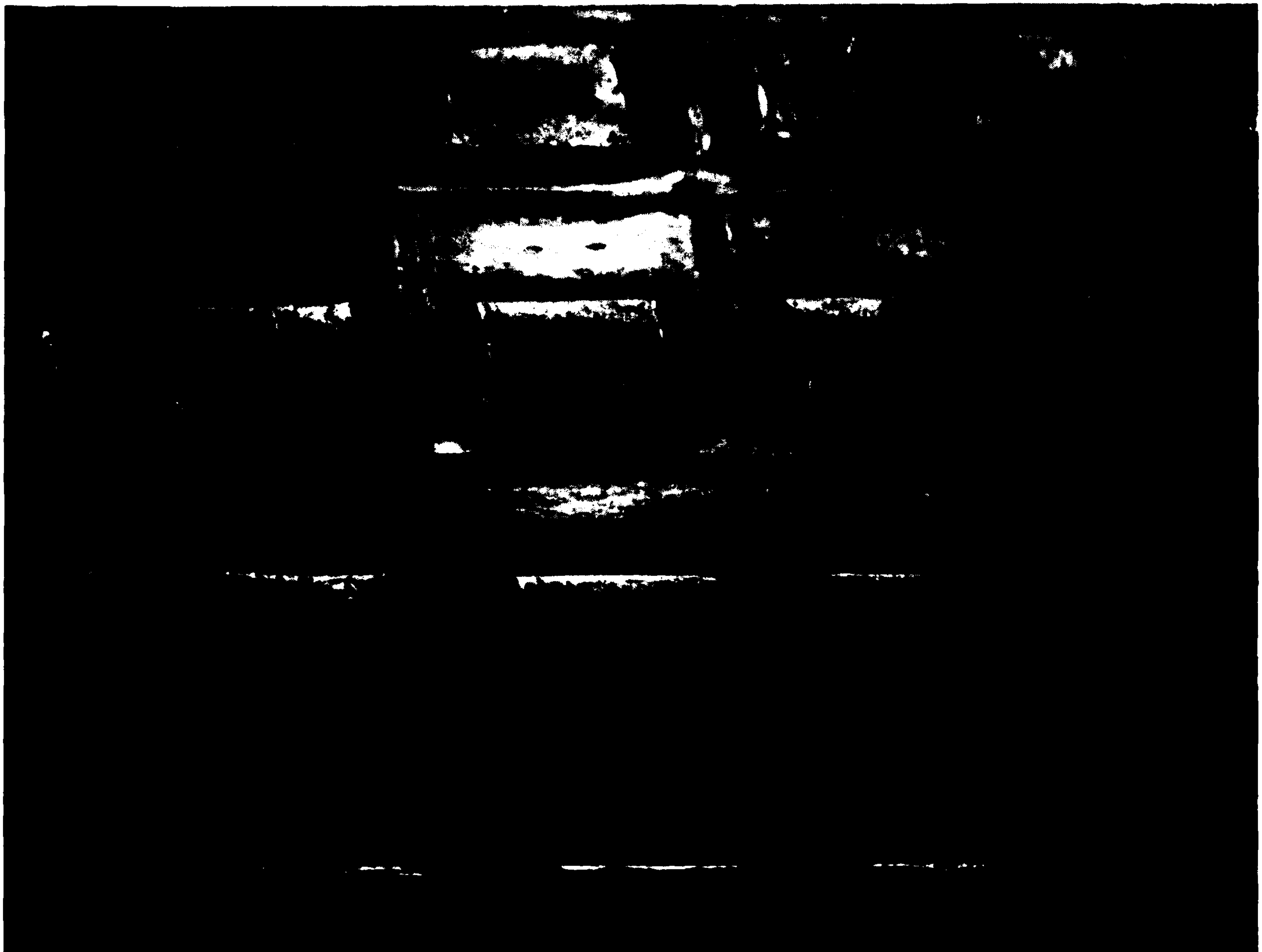

Figure 7. Engraved rotating band from recovered eight-inch projectile showing "double" engraving.

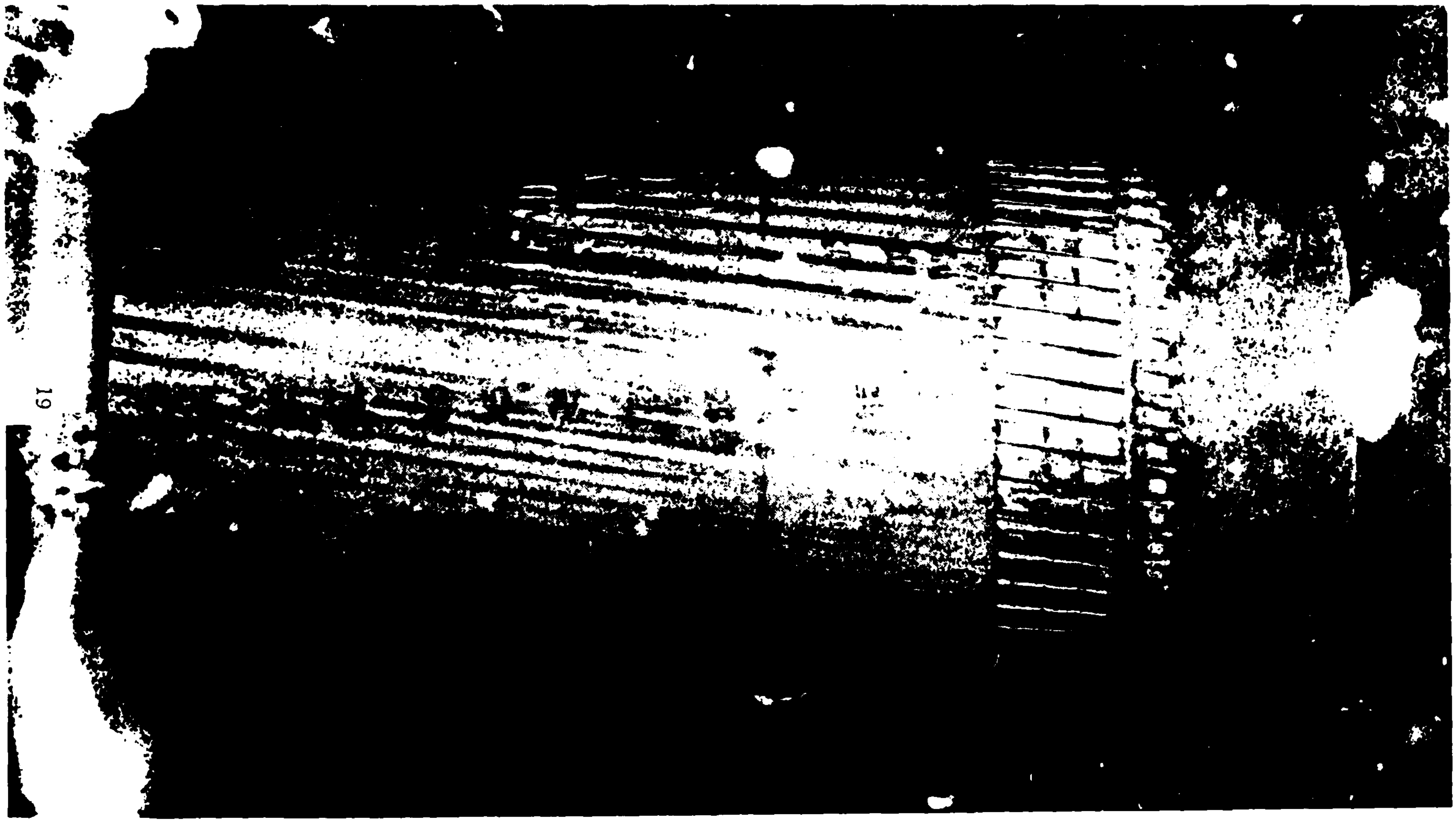

Figure 8. Photograph of 155 mm slug in flight during development of new 155 mm cannon.

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