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BALLISTIC PROPERTIES OF BARIUM TITANATE ARMY AIRCRAFT STRUCTURES

By

Arthur J. Gustafson, Jr.

May 1972

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

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Ballistic tests were conducted to determine the ballistic resistance of a barium titanate piezoelectric material with and without a polarizing voltage. It was hypothesized that the polarizing voltage increases ballistic resistance. The tests were designed to use thicknesses insufficient to stop a round but sufficient to determine effectiveness of polarization. Based on limited tests, the barium titanate with a polarizing voltage was 31 percent and 45 percent more resistant to penetration by .30-caliber ball and armor-piercing projectiles, respectively, at impact velocities of 2000 fps than the barium titanate without a polarizing voltage. At a lower velocity of 1500 fps, the polarizing voltage had no effect.

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SUMMARY

Ballistic tests were conducted to determine the ballistic resistance of a barium titanate piezoelectric material with and without a polarizing voltage. It was hypothesized that the polarizing voltage increases ballistic resistance. The tests were designed to use thicknesses insufficient to stop a round but sufficient to determine effectiveness of polarization. Based on limited tests, the barium titanate with a polarizing voltage was 31 percent and 45 percent more resistant to penetration by .30-caliber ball and armor-piercing projectiles, respectively, at impact velocities of 2000 fps than the barium titanate without a polarizing voltage. At a lower velocity of 1500 fps, the polarizing voltage had no effect.

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TEST OBJECTIVE

The objective of this study was to test for improved ballistic resistance of a piezoelectric material upon application of a polarizing voltage to this material. This improvement was expected to result from slight changes at the molecular level produced by the polarizing voltage. These changes include a deepening of the potential function* and increased separation of the material's molecules along the polarizing axis.

*Described in THEORETICAL STRENGTH OF MATERIALS, The Materials Advisory Board, MAB-221-M, National Academy of Sciences, National Research Council, Washington, D. C., August 1966, AD 636917.

TEST MATERIAL

Barium titanate is a ferroelectric material that has good mechanical properties. Because of the piezoelectric effect, the barium titanate expands on one axis when subjected to an electric field. For the test material, the direction of expansion and the polarization axis were normal to the disc.

The test pieces were 0.125-inch-thick, 4-inch-diameter barium titanate discs bonded to 0.125-inch-thick aluminum plate with a conductive cement. Areal density of this combination was 5.45 pounds per square foot. Areal density of the barium titanate alone was 3.67 pounds per square foot. Figure 1 is a sketch of the test article.

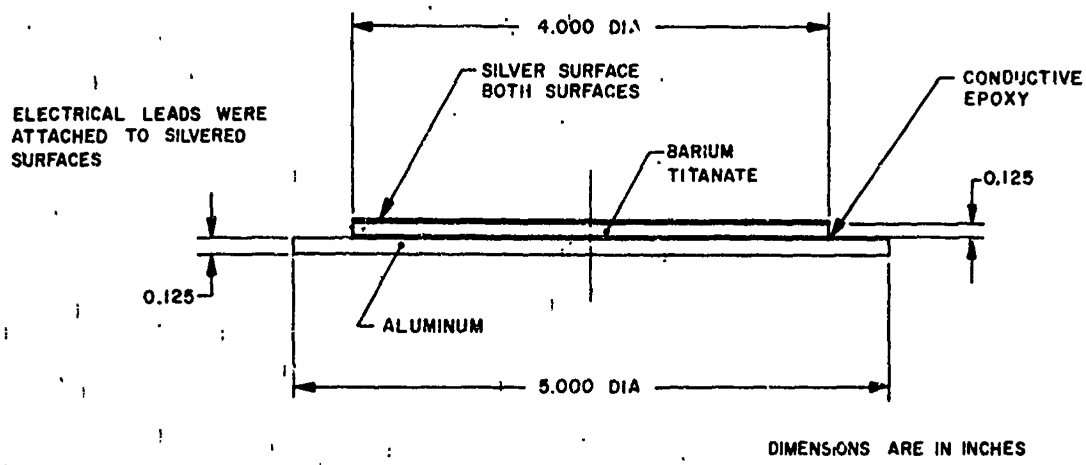

Figure 1. Barium Titanate Tile.

TEST METHOD

Ballistic tests were conducted with and without a 450-volt DC polarizing voltage impressed across the barium titanate. Projectiles used were .30-caliber ball and armor piercing, both at 2000-foot-per-second and 1500-foot-per-second nominal velocity, untumbled, at 0-degree obliquity. A new disc was used for each test condition, since the discs were destroyed by each shot.

Entry and exit velocities were measured as a means of detecting changes in ballistic resistance due to the polarizing voltage. Entry velocities were measured photographically and with an electronic timer. Exit velocities were measured photographically only. Use of the electronic timer for measuring exit velocity was impractical because spall tended to trigger the start/stop switches prior to the impact of the projectile. Figure 2 shows a typical film record.

On the last ten tests, the entry velocity was measured only with an electronic timer. This change in instrumentation improved the extent of the photographic coverage on the exit side and facilitated data reduction. Figure 3 shows a typical film record obtained with this setup. The electronic counter results for entry velocities were found to be reliable and did not require the photographic backup.

The range setup for the tests is shown in Figure 4, and the test article mounted in the holding fixture is shown in Figure 5.

Sample sizes for each of the four test conditions were equal; however, some tests were invalid due to instrumentation failure. No data were developed on those tests.

Figure 2. Armor-Piercing Projectile on Exit Side of Barium Titanate Test Specimen (Initial Camera Position).

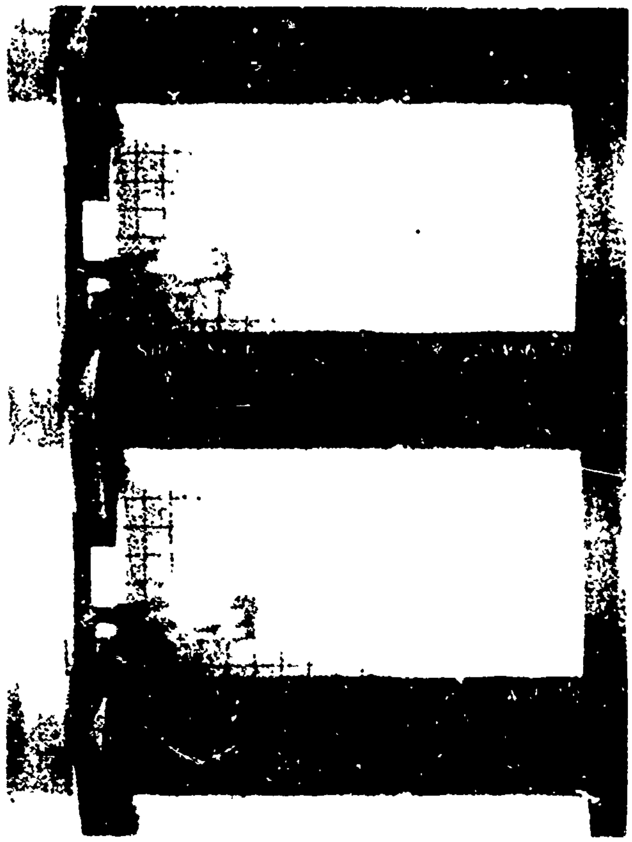

Figure 3. Armor-Piercing Projectile on Exit Side of Barium Titanate Test Specimen (New Camera Position).

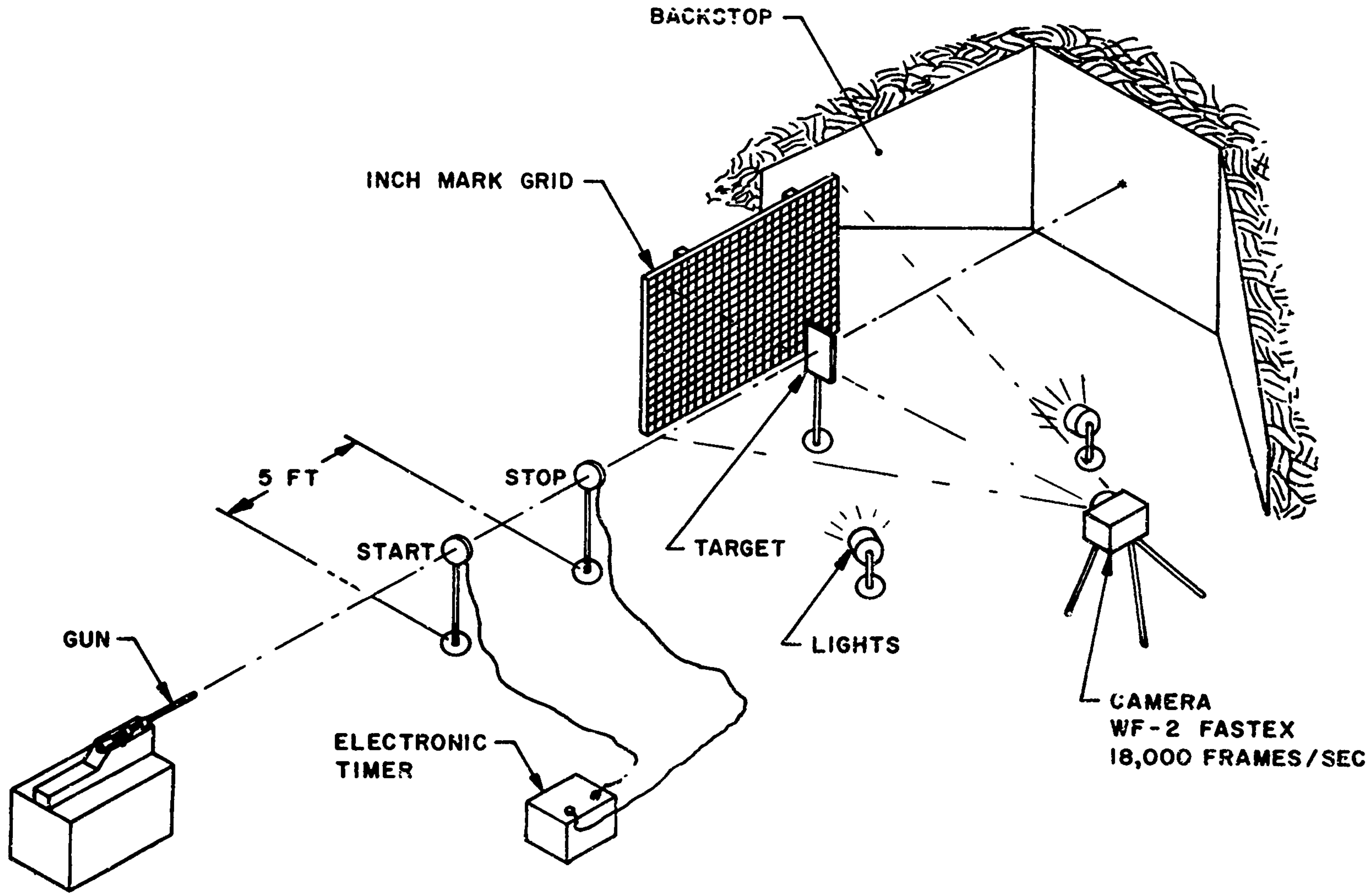

Figure 4. Range Layout.

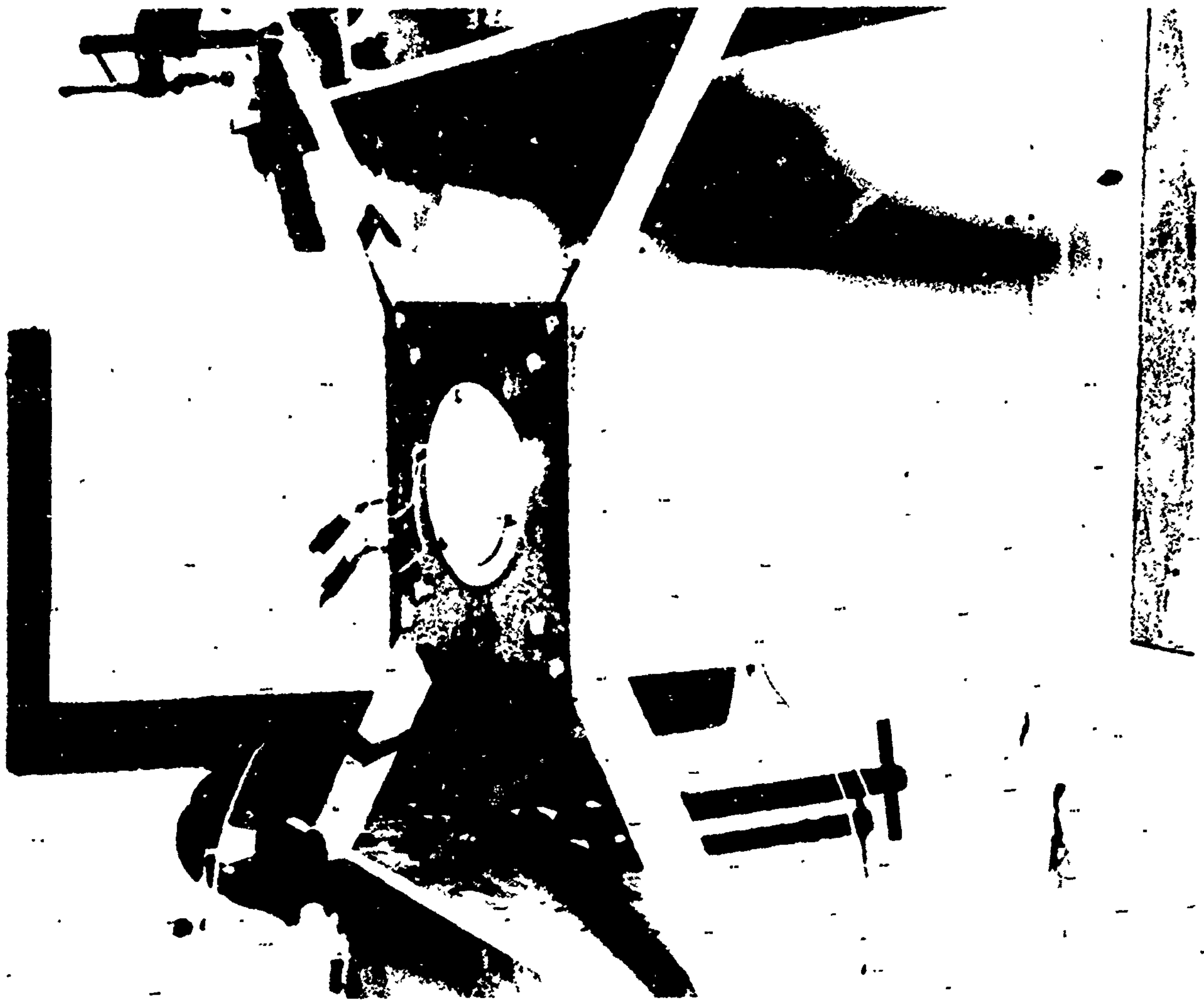

Figure 5. Barium Titanate Tile Mounted in Ballistic Test Fixture.

TEST RESULTS

FOUR BASIC TEST CONDITIONS

Ball, .30 Caliber, 1500-FPS Muzzle Velocity

Ten tests were conducted: five with a polarizing voltage and five without this voltage. The average change in velocity of the projectile with polarizing voltage was 332.2 fps; the average change without polarizing voltage was 335.8 fps. The change in velocity of the projectile with voltage was approximately equal to the change in velocity without voltage.

Ball, .30 Caliber, 2000-FPS Muzzle Velocity

Seven tests were conducted: three with a polarizing voltage and four without this voltage. The average change in velocity of the projectile with polarizing voltage was 366.3 fps; the average change without polarizing voltage was 276.8 fps. The change in velocity of the projectile with voltage was 31 percent greater than the change in velocity without voltage.

Armor Piercing, .30 Caliber, 1500-FPS Muzzle Velocity

Ten tests were conducted: five with a polarizing voltage and five without this voltage. The average change in velocity of the projectile with polarizing voltage was 206.8 fps; the average change without polarizing voltage was 214.0 fps. The change in velocity of the projectile with voltage was 3.5 percent less than the change in velocity without voltage.

Armor Piercing, .30 Caliber, 2000-FPS Muzzle Velocity

Nine tests were conducted: five with a polarizing voltage and four without this voltage. The average change in velocity of the projectile with polarizing voltage was 259.0 fps; the average change without polarizing voltage was 178.3 fps. The change in velocity of the projectile with voltage was 45 percent greater than the change in velocity without voltage.

GENERAL

Table I summarizes the results of tests. The complete set of data is given in Table II.

The test results show that a polarizing voltage across the barium titanate greatly affects the ballistic resistance of these tiles for projectile velocities of 2000 fps. At the lower velocity of 1500 fps, there was no effect. Armor-piercing projectiles, although greater in mass, experienced slightly more resistance than did ball projectiles.

The large variation within each test group and the small sample size prevent meaningful statistical treatment of the results. However, these results may be qualitatively explained by comparing the function of the barium titanate to the hard facing of dual hardness steel (DHS) armor. The hard facing on DHS fragments the projectile, and the tough backing stops the fragments. The barium titanate maintains this function only for a short period of time because of depolarization caused by impact of the projectile. Thus, high-velocity, hard-core projectiles are expected to be most affected by polarization of the barium titanate. The slower velocity projectiles "see" a hard facing for a smaller percentage of their impact time than do the higher velocity projectiles. The hard-core projectiles experience higher internal loads than the soft-core projectiles for equal deformation, and they are therefore more affected by the hard facing material.

TABLE I. SUMMARY OF TEST RESULTS

Type of Round	Nominal Muzzle Velocity (fps)	Average Change in Velocity (fps)	
		With Polarization	Without Polarization
.30 cal	1500	332.2	335.8
ball	2000	366.3	276.8
.30 cal	1500	206.8	214.0
armor piercing	2000	259.0	178.3

TABLE II. TEST DATA				
	Entry Velocity (fps)	Exit Velocity (fps)	ΔV (fps)	Serial No.
Ball, Muzzle Velocity 1500 fps, Polarizing Voltage On				
	1570.000000	1286.000000	284.000000	2
	1584.000000	1234.000000	350.000000	13
	1515.000000	1080.000000	435.000000	24
	1619.000000	1340.000000	279.000000	31
	1512.000000	1199.000000	313.000000	40
Mean	1560.000000	1227.799805	332.199951	
Std Dev	46.059738	98.347321	64.044479	
Coef of Var	0.029525	0.080100	0.192789	
Ball, Muzzle Velocity 1500 fps, Polarizing Voltage Off				
	1561.000000	1236.000000	325.000000	6
	1575.000000	1174.000000	401.000000	21
	1497.000000	1115.000000	382.000000	45
	1492.000000	1192.000000	300.000000	27
	1462.000000	1191.000000	271.000000	16
Mean	1517.399902	1181.599854	335.799805	
Std Dev	48.345596	43.729828	54.732956	
Coef of Var	0.031861	0.037009	0.162993	
Armor Piercing, Muzzle Velocity 1500 fps, Polarizing Voltage On				
	1646.000000	1426.000000	220.000000	1
	1849.000000	1631.000000	218.000000	23
	1709.000000	1520.000000	289.000000	17
	1518.000000	1380.000000	138.000000	30
	1525.000000	1356.000000	169.000000	42
Mean	1649.399902	1462.599854	206.799988	
Std Dev	137.972076	113.114075	57.486496	
Coef of Var	0.083650	0.077338	0.277981	

Table II. Continued				
	Entry Velocity (fps)	Exit Velocity (fps)	ΔV (fps)	Serial No.
Armor Piercing, Muzzle Velocity 1500 fps, Polarizing Voltage Off				
	1682.000000	1427.000000	255.000000	7
	1771.000000	1552.000000	219.000000	18
	1538.000000	1291.000000	247.000000	22
	1450.000000	1276.000000	174.000000	36
	1544.000000	1369.000000	175.000000	38
Mean	1597.000000	1383.000000	214.000000	
Std Dev	127.867111	112.478882	38.457764	
Coef of Var	0.080067	0.081330	0.179709	
Ball, Muzzle Velocity 2000 fps, Polarizing Voltage On				
	2067.000000	1592.000000	475.000000	9
	2026.000000	1696.000000	330.000000	10
	2138.000000	1844.000000	294.000000	33
Mean	2077.000000	1710.666504	366.333252	
Std Dev	56.665680	126.638580	95.814026	
Coef of Var	0.027282	0.074029	0.261549	
Ball, Muzzle Velocity 2000 fps, Polarizing Voltage Off				
	2049.000000	1857.000000	192.000000	28
	2045.000000	1690.000000	355.000000	8
	2004.000000	1770.000000	234.000000	14
	2189.000000	1863.000000	326.000000	34
Mean	2071.750000	1795.000000	276.750000	
Std Dev	80.768692	81.890167	76.504333	
Coef of Var	0.038986	0.045621	0.276438	

Table II. Concluded				
	Entry Velocity (fps)	Exit Velocity (fps)	ΔV (fps)	Serial No.
Armor Piercing, Muzzle Velocity 2000 fps, Polarizing Voltage On				
	2093.000000	1767.000000	326.000000	43
	2046.000000	1926.000000	120.000000	35
	2143.000000	1748.000000	395.000000	11
	2185.000000	1940.000000	245.000000	15
	2119.000000	1910.000000	209.000000	19
Mean	2117.199951	1858.199951	259.000000	
Std Dev	52.251282	92.780350	106.068375	
Coef of Var	0.024679	0.049930	0.409530	
Armor Piercing, Muzzle Velocity 2000 fps, Polarizing Voltage Off				
	2039.000000	1882.000000	157.000000	26
	2133.000000	2056.000000	77.000000	32
	2189.000000	1961.000000	228.000000	39
	2140.000000	1889.000000	251.000000	3
Mean	2125.250000	1947.000000	178.250000	
Std Dev	62.665100	80.964996	78.466003	
Coef of Var	0.029486	0.041584	0.440202	

EVALUATION OF RESULTS

The effectiveness of polarized piezoelectric material as a component of an armor system cannot be assessed from the tests reported herein. Further research is required to establish the effectiveness of barium titanate, or some other ferroelectric ceramic, for this purpose. The effects of thickness, backup material, and strength of polarization would have to be examined to minimize areal density prior to establishing ballistic effectiveness.

This work should emphasize a reduction in the thickness of the barium titanate, the establishment of a value of polarization for optimum ballistic resistance, and the determination of an optimum mix of hard ferroelectric ceramic and energy-absorbent laminae backup material. It is anticipated that the DC power supply for polarization will weigh very little because the electric current requirement is small.