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ULTRASONIC INSPECTION OF BRAZED AND WELDED OVERLAY ROTATING BAND ATTACHMENT ON ARTILLERY SHELLS

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ABSTRACT

This report describes an effort to generate the correlation data necessary to establish ultrasonic standards and specifications for the inspection of brazed and weld overlay joints of artillery shell rotating bands. Ultrasonic pulse-echo C-scan tests were made of the brazed and weld overlay areas of projectile motor bodies. Mechanical test plugs were machined from selected areas of these bands. The shear bond strengths of the plugs were measured and correlated with C-scan results. Artificial and actual unbond areas of bond joints were destructively examined and correlated with C-scans.

CONTENTS

INTRODUCTION

The application of improved techniques for attaching artillery shell rotating bands over the conventional mechanically hot-swaged method has been the subject of considerable attention since it was recognized that their use could result in significant savings in cost and critical materials. Two completely distinct banding techniques, the weld overlay and foil interlayer braze, have been demonstrated to possess the above advantages and they are applicable to both conventional and nuclear shell. Further exploitation and application of these methods is contingent upon implementation of industrial testing techniques that assure the maintenance of required mechanical properties. In the case of the weld overlay banding technique, problems exist in inspecting not only for bond defects between the rotating band and projectile body, but also for discontinuities (cracks and craters) in the steel under the rotating band. Inspection of brazed joints is concerned only with the detection of unbonds because the process has no adverse effects on the steel body.

Ultrasonic C-scan techniques were initially employed during the developmental stages of braze banding in order to provide a fast, reliable means of bond evaluation. Ultrasonic testing was found to be more sensitive to changes in the condition of the brazed joint than radiography. Although conventional black and white or go-no-go ultrasonic C-scan techniques have been successfully applied to detect unbonds at the braze interface surface, very little correlation data are available for establishing complete nondestructive testing (NDT) standards and specifications for production inspection of these components. This Materials Testing Technology Program study was undertaken to perform a destructive analysis and to correlate the physical condition and mechanical properties of silver and nickel brazed joints and weld overlay joints with ultrasonic test results. This report addresses the problem of unbonded detection. A preliminary study involving the inspection of weld overlay motor bodies for cracks and craters was the subject of a previous report.[1] A more comprehensive crack investigation study is currently being conducted at AMMRC.

TEST PREPARATION AND PROCEDURE

Brazed Motor Bodies

Eight forged motor bodies for the XM650 RAP (rocket-assisted projectile) were available for brazing. For purposes of this report the motor bodies were arbitrarily identified as forged bodies 1 through 8. Forged body 4 was found to be defective prior to brazing and removed from the test sampling. The brazing materials employed were Palcusil and Cusil, silver base alloys, and Nicrobraz 10, a nickel base alloy, all of which have been successfully used in previous applications. All brazing was done in an inert atmosphere except for forged body 5, which was brazed in air. Forged body 1 was used as the C-scan standard.

1. BROCKELMAN, R. H., MULDOON, R. A., and RODERICK, D. *Preliminary Development of Ultrasonic C-Scan Test Methods and Standards to Determine Projectile-Rotating Band Integrity.* Army Materials and Mechanics Research Center, AMMRC TR 76-1, January 1976.

Forged bodies 1, 2, and 3 were brazed with Palcusil 15 foil. To produce unbonds of known dimensions, six 0.005-inch-thick Grafoil disks, two each of 1/16-, 1/8-, and 1/4-inch diameter, were positioned at the interface of bodies 1 and 2. (These disks prevent wetting of the mating surfaces during the brazing cycle; if bonding takes place adjacent to the disks, unbonds of known dimensions will be produced.) Forged bodies 5 and 8 were brazed with Nicrobraz 10 paste, body 6 with electroless nickel, and body 7 with Cusil foil. Prior to brazing forged body 6, both the forging and rotating band were plated with 2 to 5 mils nickel. On forged body 8, too much pressure at temperature was applied and the rotating band was deformed. Figure 1 shows a typical brazing operation.

Six of the brazed motor bodies were heat treated to obtain the property requirements for a 4340 steel, i.e., austenitized for 1 hour at 1500 F in a vacuum, oil quenched, then tempered for 1 hour at 800 F and air cooled to room temperature. The bodies were processed in two lots - 2, 6, and 8, and 3, 5, and 7 - due to furnace size limitations.

Weld Overlay Bodies

Two finish machined XM650 plasma-arc weld overlay RAP motor bodies were made available by Picatinny Arsenal for correlation of ultrasonic and destructive test results.

Ultrasonic C-Scan Tests

The seven brazed motor bodies and two weld overlay bodies were C-scanned in accordance with the test procedure for unbonds.[1] A pulse-echo immersion

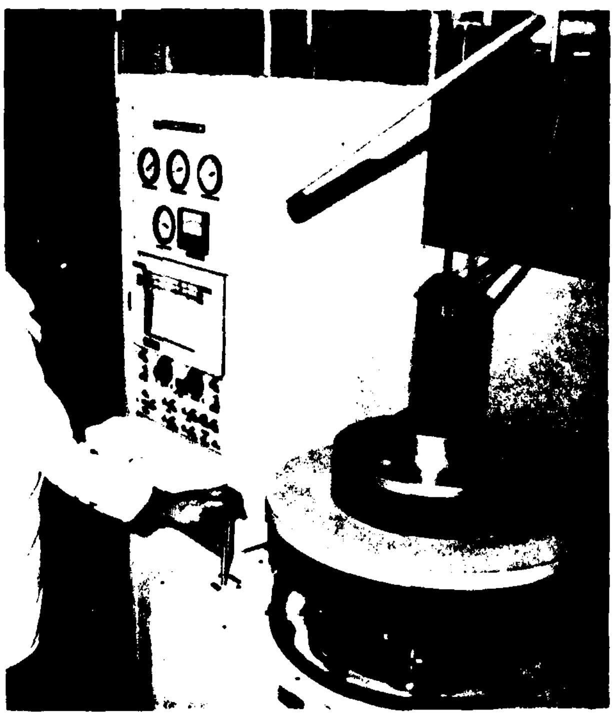

Figure 1. Typical brazing operation

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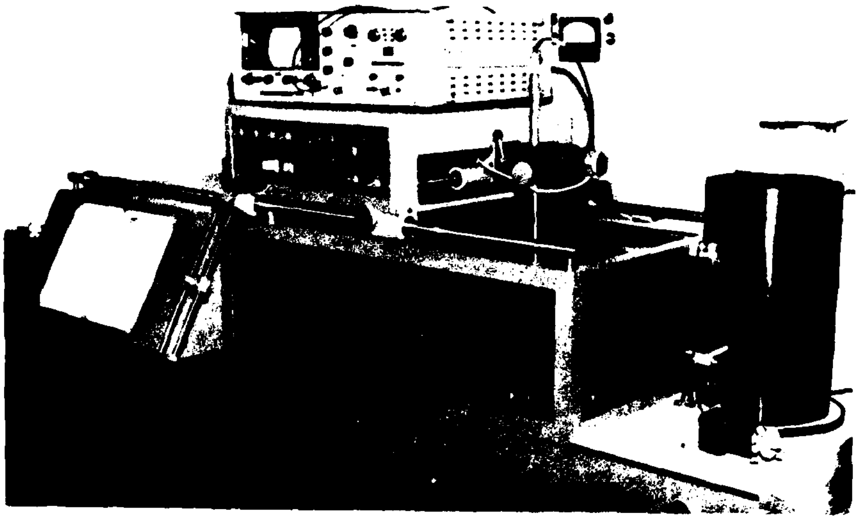

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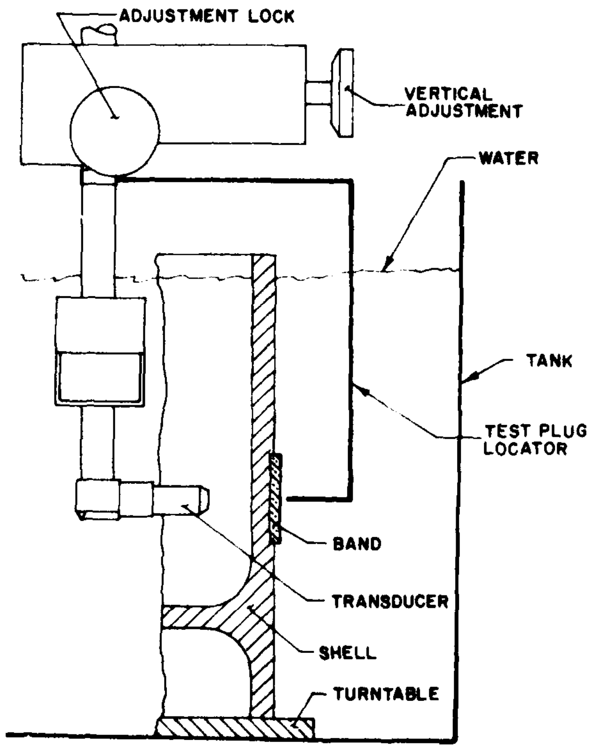

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19-066-25/AMC-74 Figure 2. Ultrasonic C-scan test equipment (a) and schematic of test setup (b)

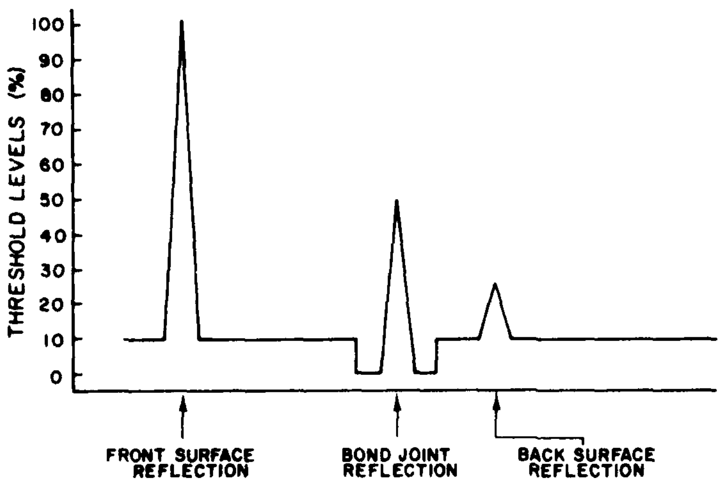


Figure 3. Screen picture of ultrasonic pulse echo signals

system using the longitudinal wave technique was employed. Figure 2 shows the inspection equipment and a schematic of the test setup. Figure 3 is a typical A-scan presentation.

The acoustic energy generated by the transducer is reflected sequentially at the inside diameter of the steel shell (front surface reflection), the interface between the outside diameter of the steel shell and the inside diameter of the copper rotating band (bond joint reflection), and the outside diameter of the copper rotating band (back surface reflection). The reflected signal from the interface of the steel shell and copper rotating band is separated for C-scan recording purposes by means of a time gate. Negative black and white C-scan recordings were made of the test motor bodies. With this method of recording, the reflected signal has to exceed a preset threshold level to interrupt marking of the recording paper. Each body was scanned at three arbitrary threshold levels (30%, 50%, and 70% of full-scale screen height) to provide the range of amplitude data necessary for subsequent correlation with destructive testing. After alignment, the sensitivity of the test is set by moving the transducer above the rotating band and then adjusting the reflection from the outside steel body diameter and water interface to 100% screen height. Fine adjustment of the sensitivity is then made to duplicate a standard scan of a motor body containing both artificial and actual unbonded areas.

C-scan recordings of the test motor bodies are shown in Figures 4a through g. The figures do not present the entire C-scans but only the sections that are of interest to this program.

Test Plug Specimens

Mechanical test plugs (Figure 5) were machined from selected areas in the rotating bands of seven of the test motor bodies to fit a destructive shear test fixture. The locations selected are noted as circles in Figure 4. Only two test plugs were taken from weld overlay motor body 110. Each brazed plug was marked for complete identification, e.g., 2-7. The first number represents the forged body and the second number locates the test plug on the C-scan.

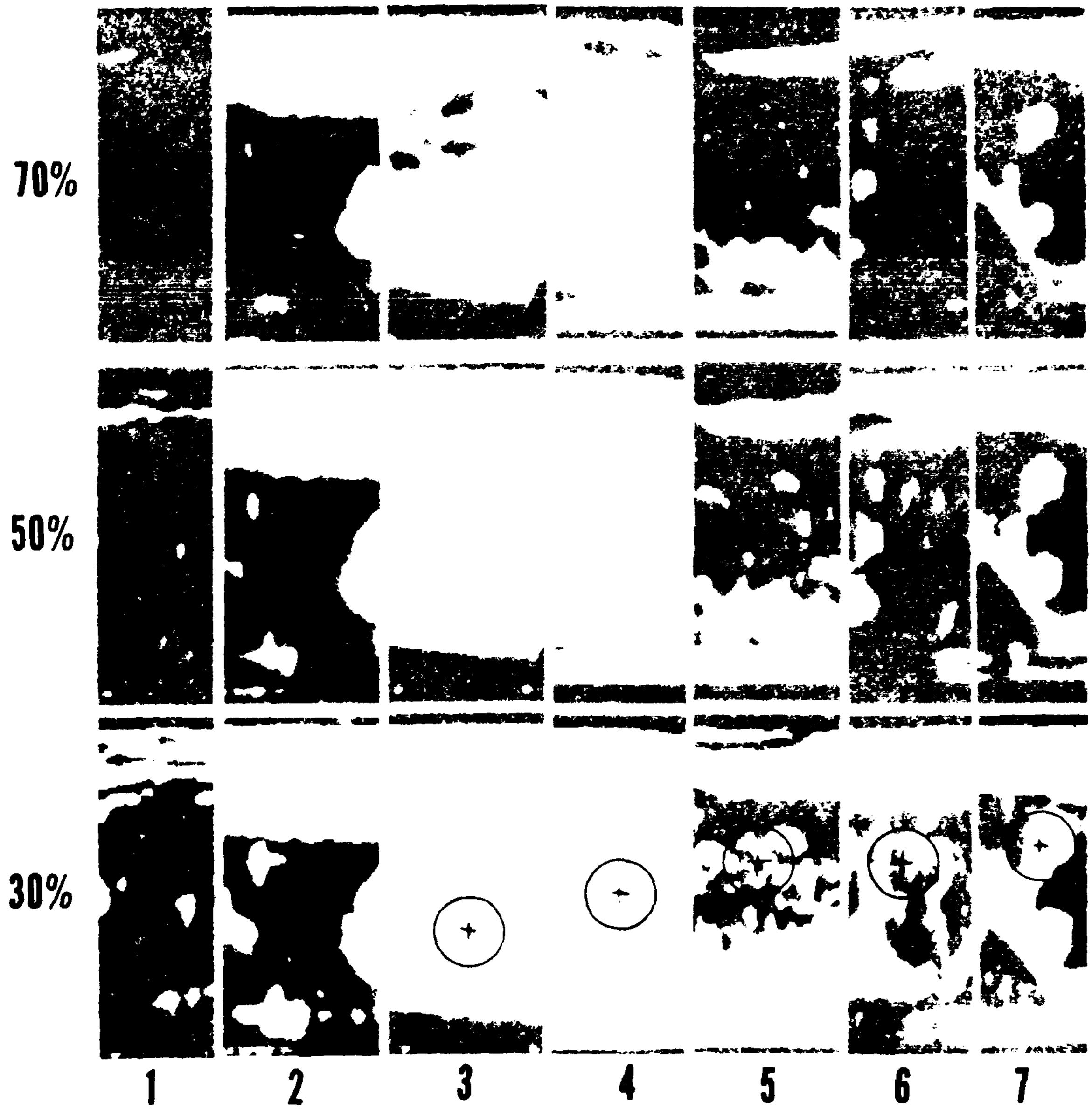


Figure 4a. C-scan recording of forged body 2

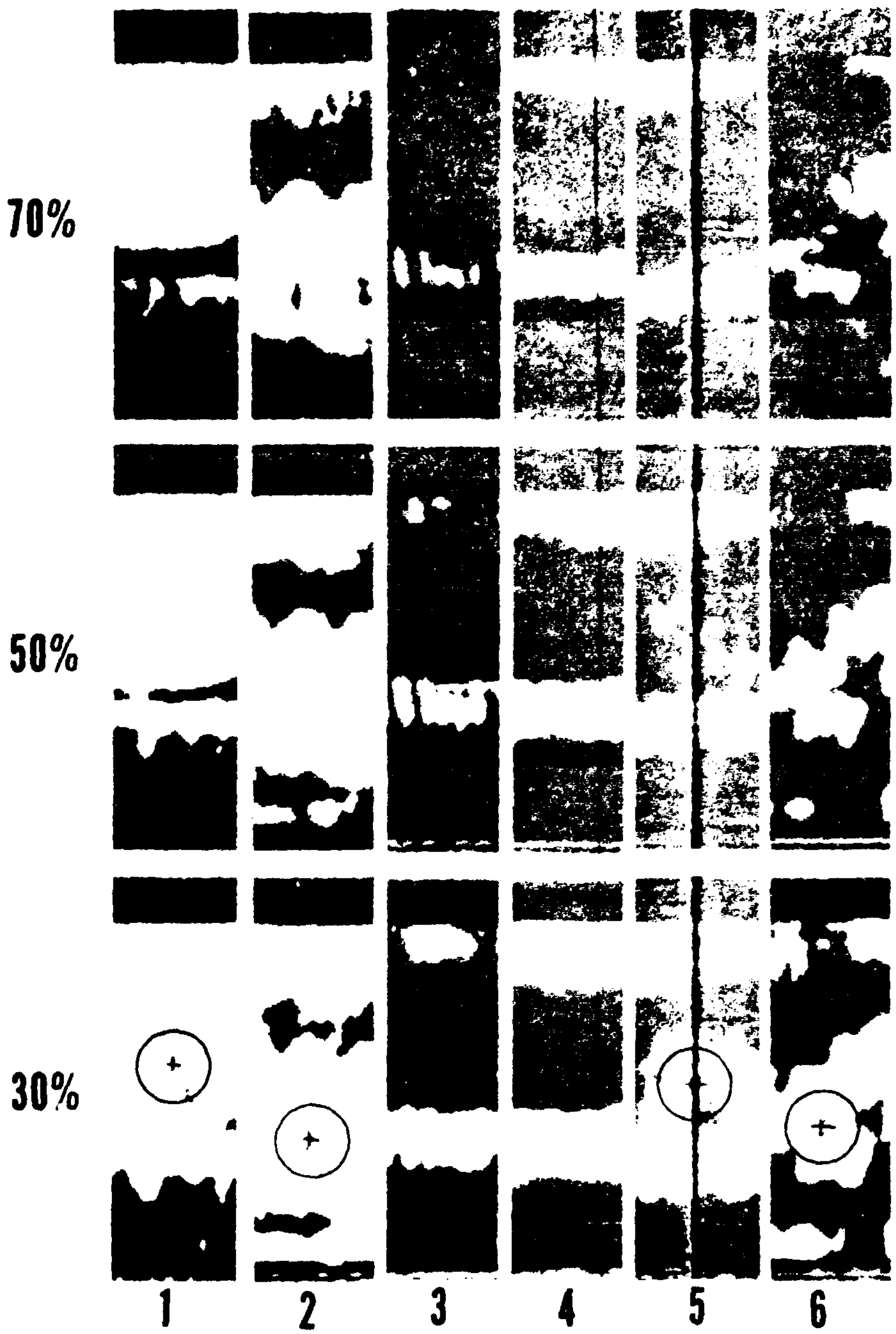


Figure 4b. C-scan recording of forged body 3

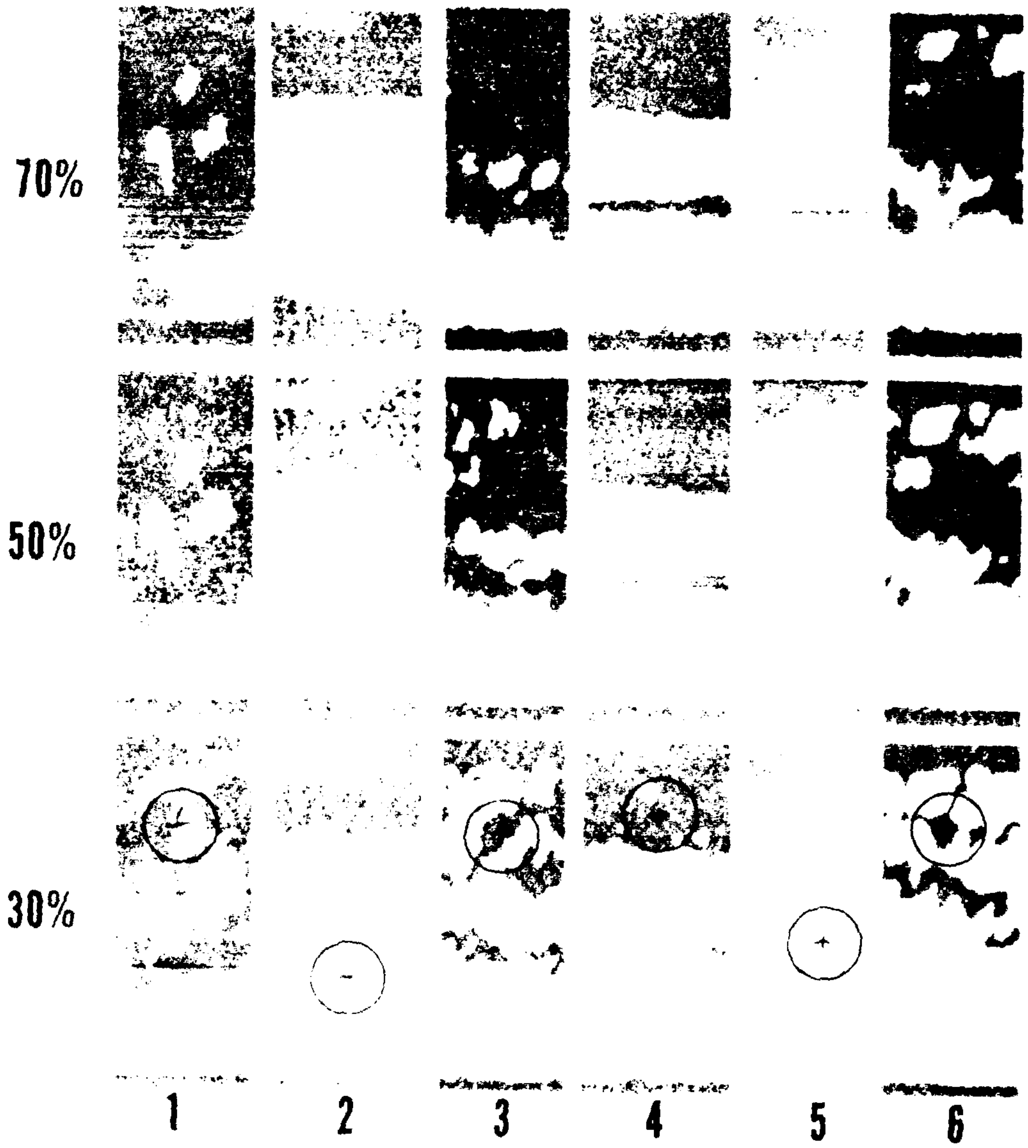


Figure 4c. C-scan recording of forged body 5

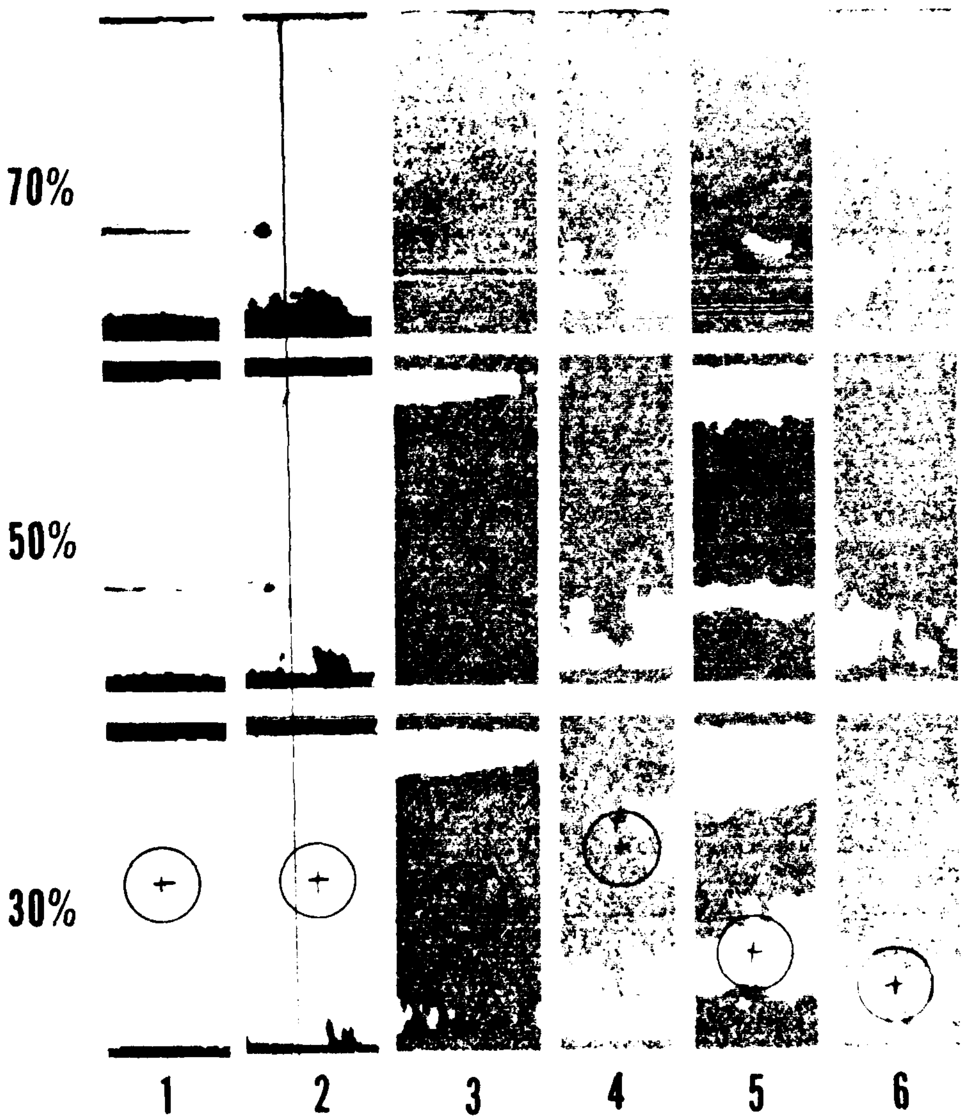


Figure 4d. C-scan recording of forged body 6

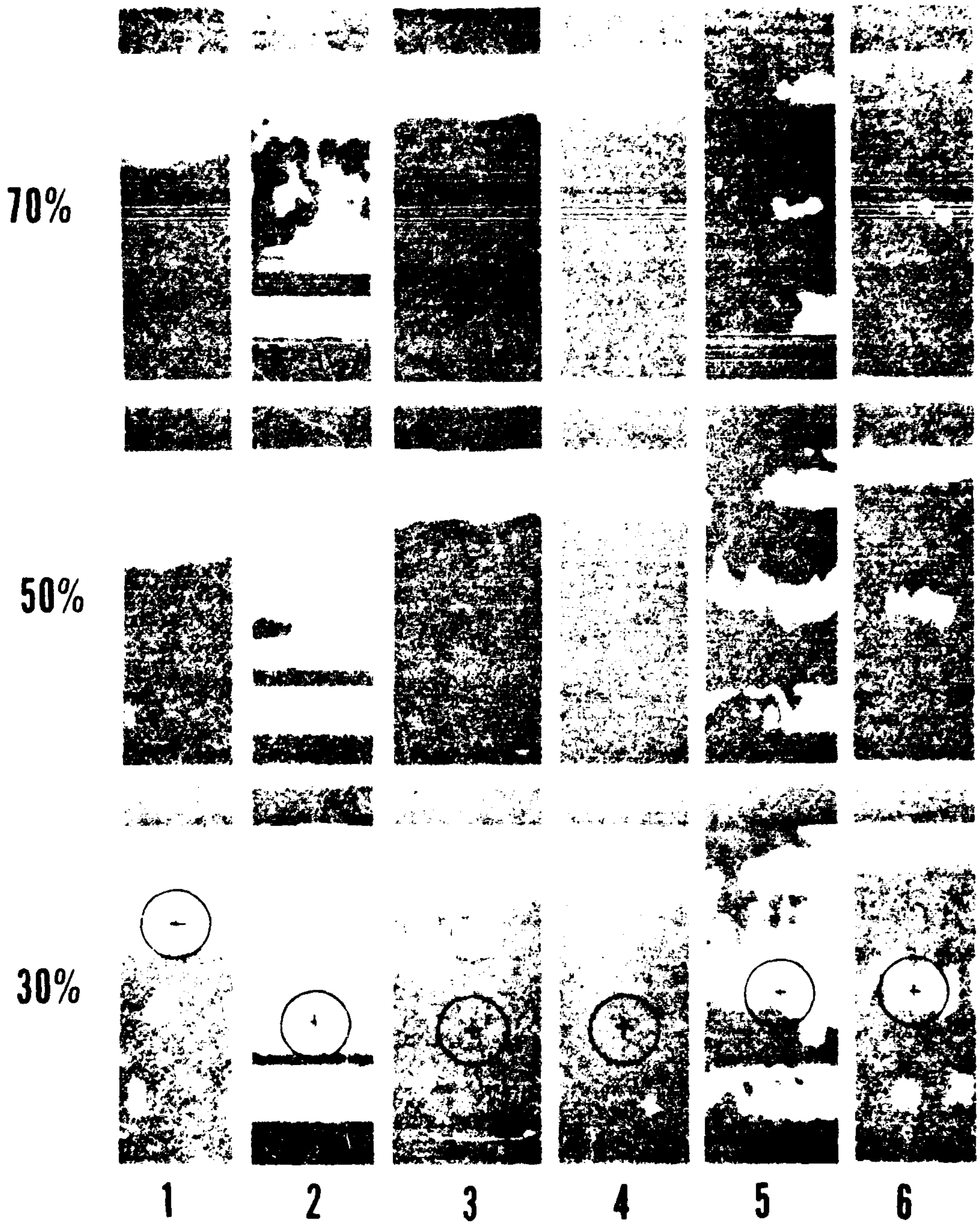


Figure 4e. C scan recording of forged body 7

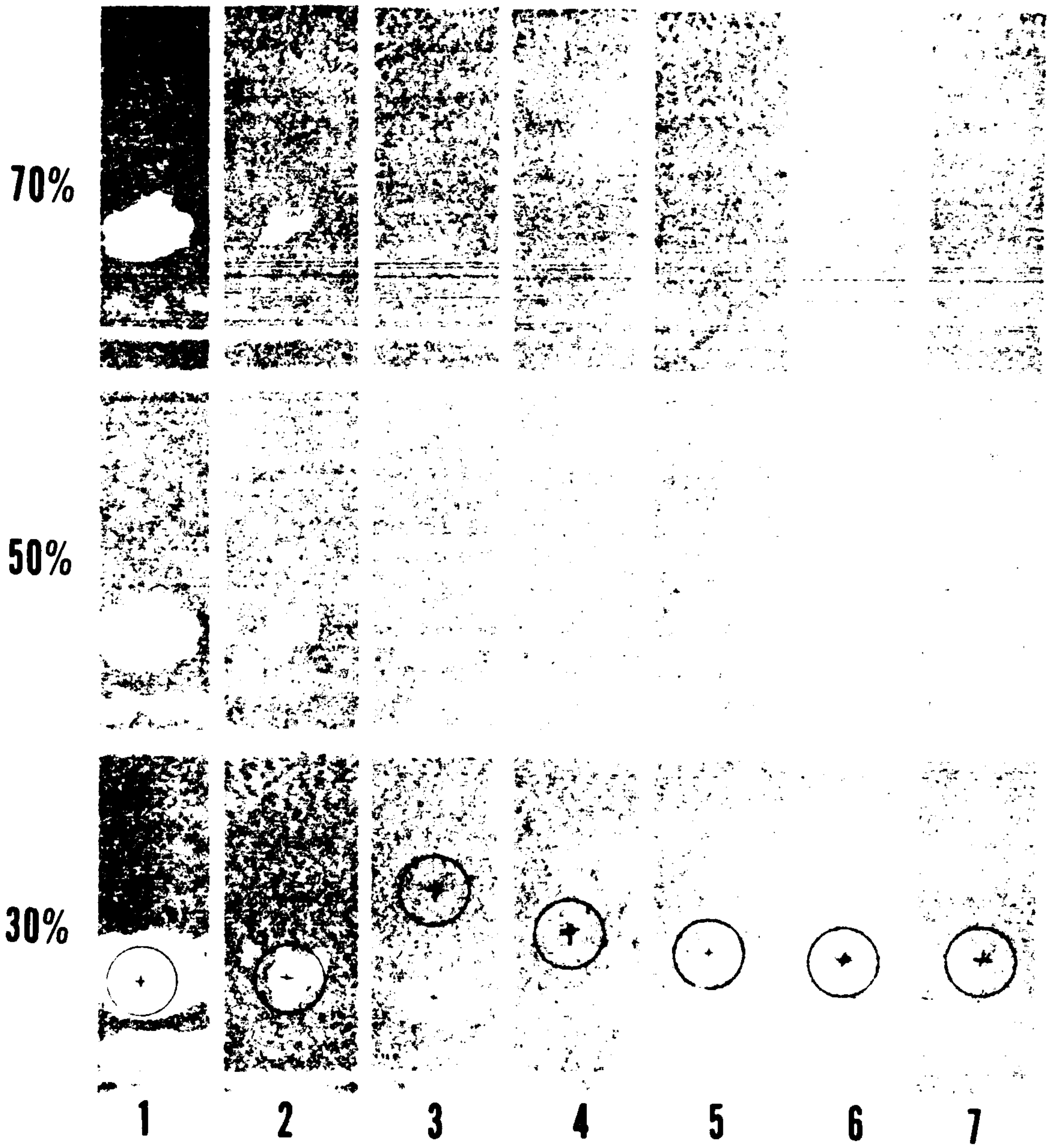


Figure 4f. C-scan recording of forged body 8

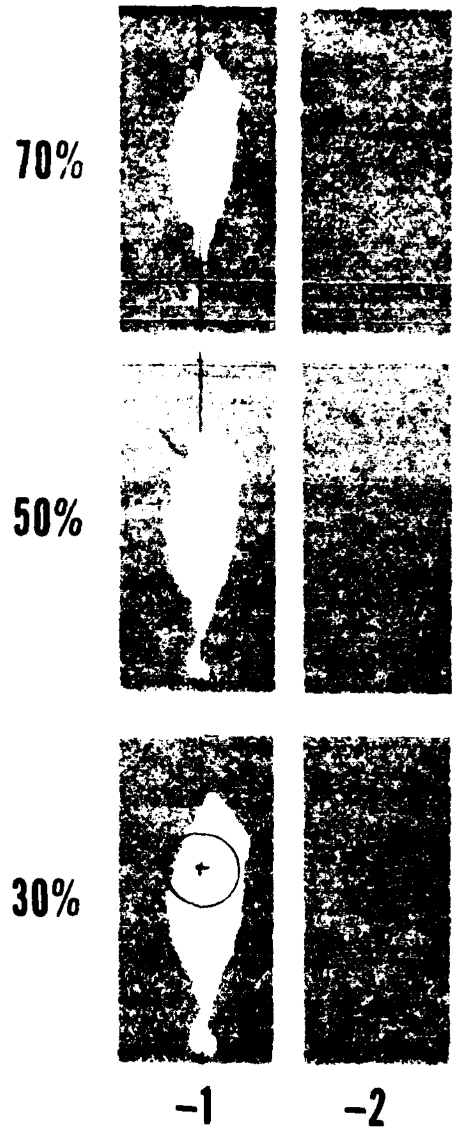
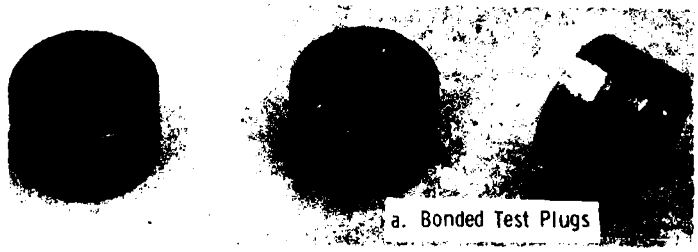


Figure 4g. C-scan recording of weld overlay motor body 110



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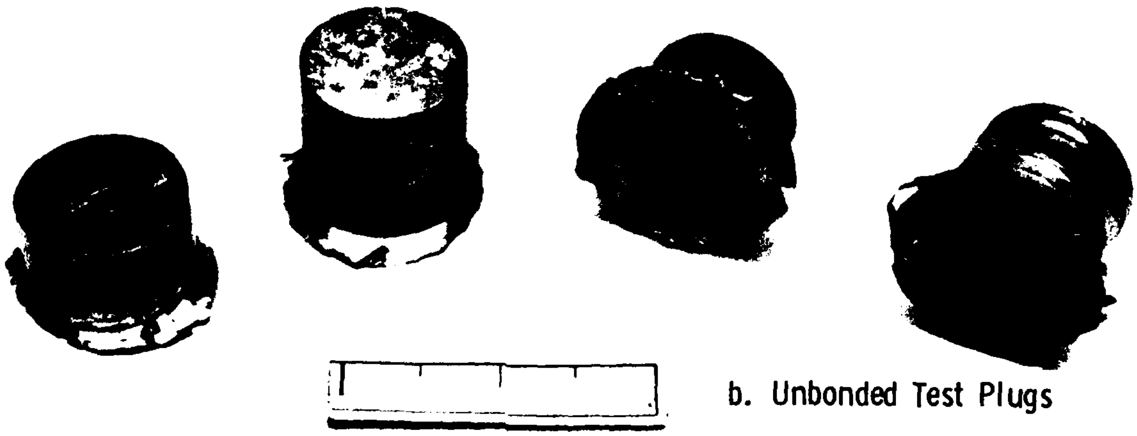

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Figure 5. Mechanical test plugs

The actual test plugs are 0.500 $^{+.000}_{-.005}$ inch in diameter by 0.30 ±0.01 inch thick, with the interface at mid-thickness. A minimum of six test plugs were taken from six of the brazed motor bodies. Two were taken from an area that remained predominantly dark throughout the three threshold levels, signifying good bonding; two were taken from an area that remained predominantly light, signifying poor bonding; and two were taken from an area that contained both light and dark patches throughout the three levels

A number of test plugs did not have sufficient bond strength to withstand the machining operations (Figure 5b). Those which had sufficient bond strength were X-ray tested at one time and dye-penetrant inspected for open porosity at the interface.

Destructive Tests

The shear test fixture (Figure 6) is comprised of five basic components: a movable center slide, two stationary guide blocks, a tapered wedge, and a retaining box. The test plug is inserted into the appropriate diameter hole of the moveable slide (Figure 7). The test plug braze or weld overlay interface is positioned at the shear surface by an adjusting screw. The second guide block is positioned to accept the other half of the test plug and pin aligned with the first guide block. These three components are placed into the retaining box along with the tapered wedge. The actual test setup utilizes a compression machine which records the load in pounds (Figure 8).

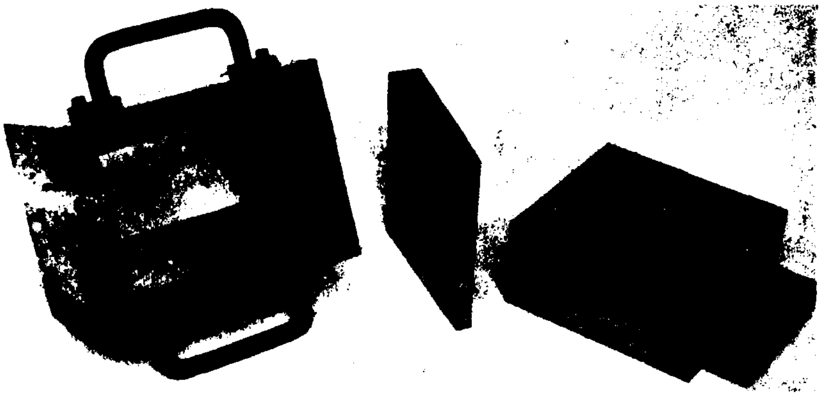

Figure 6. Complete shear test fixture, disassembled

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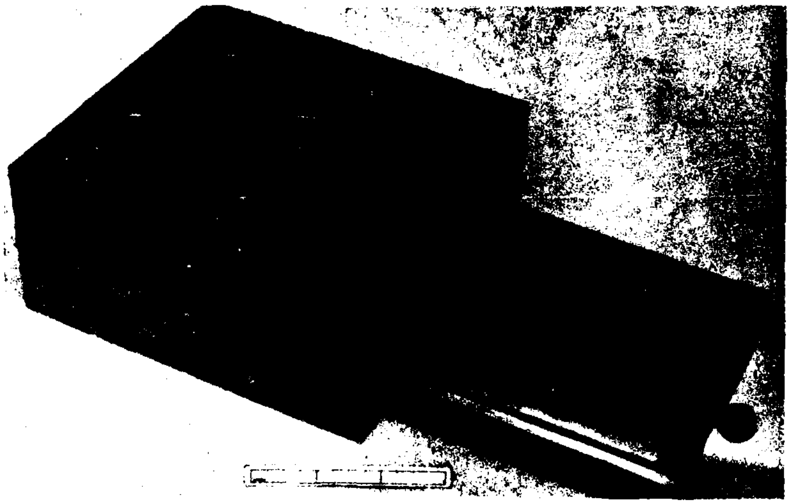

Figure 7. Movable slide with test plug

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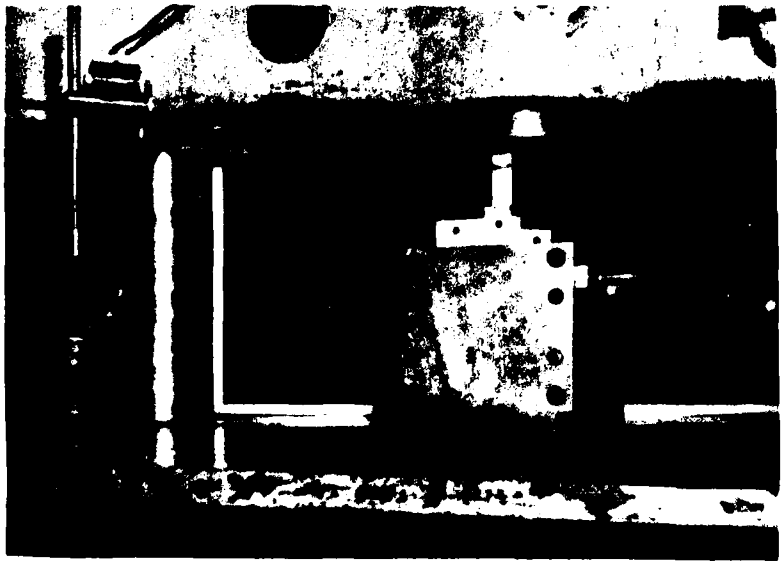

Figure 8. Shear test setup in compression machine

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RESULTS AND DISCUSSION

Visual Correlation of C-Scans with Unbonds

A C-scan section of the standard, brazed motor body 1 with its six foil disks, is shown in Figure 9. The unbonded areas produced by these disks are readily detected by C-scanning, and by adjustment of transducer size and water path, a one-to-one correspondence between artificial unbond size and C-scan presentation was attainable.

While inspecting other weld overlay bodies for Picatinny Arsenal (PA), a significant unbond area was observed on body 41105. Accordingly, permission was obtained from PA to remove the weld overlay material and correlate the C-scan findings with the unbond area. The bulk of the copper rotating band was quickly removed in a lathe to just shy of the interface. The remaining copper material was removed in 0.001-inch increments until the unbond areas were visible. The thin copper layer over the unbond was easily peeled off. Figure 10 illustrates the success with which the C-scan technique details actual unbonded areas.

X-Ray and Dye Penetrant Examination of Mechanical Test Plugs

X-radiographic inspection of the mechanical test plugs did not reveal any of the unbonds but did disclose gross copper voids in brazed test plugs 8-2 and 8-5 and in weld overlay test plug 110-1 (Figure 11). The void in test plug 8-5

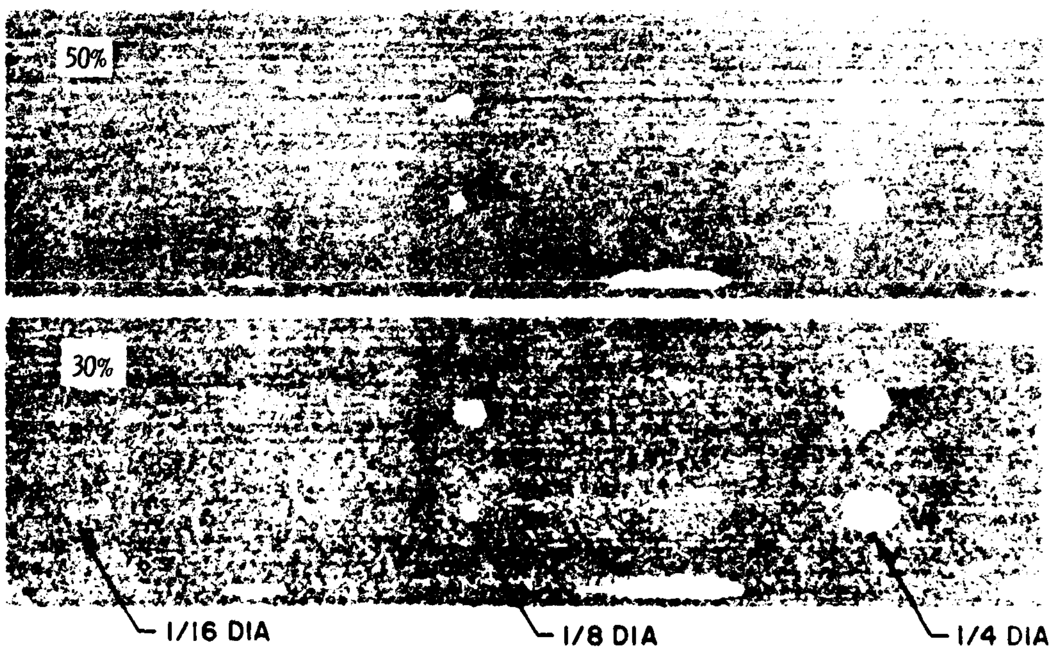

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Figure 9. C-scans of motor body standard

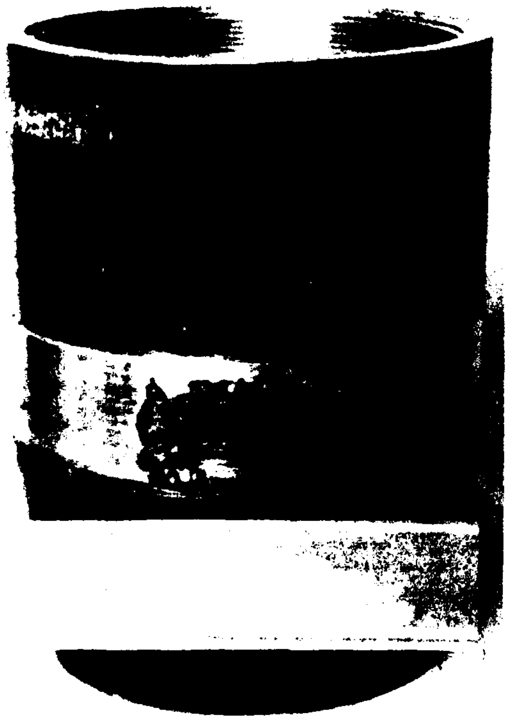

Figure 10. Ultrasonic C-scan and corresponding unbonded area of copper weld overlay rotating band

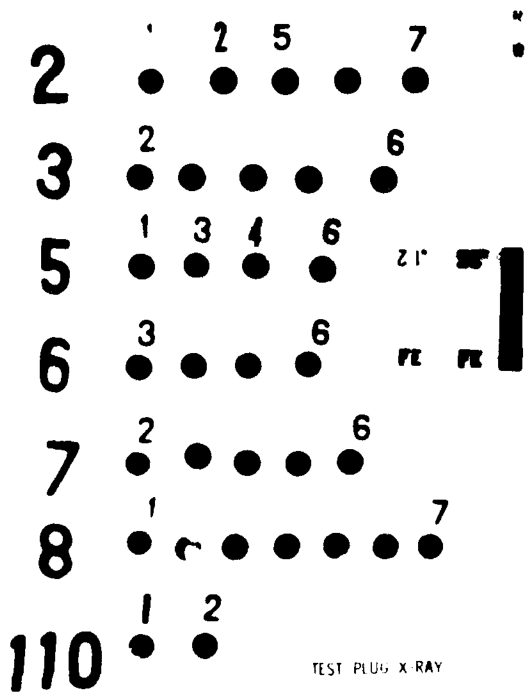

Figure 11. Test plug X-ray

was so far removed from the shear area that it had no effect on the shear load (see Table 1). While not discernible in the figure the actual X-ray negative does show the presence of the 1/8-inch-diameter Grafoil disk in test plug 2-7.

In general there was fairly good agreement between the extent of dye penetration and the C-scans (see Table 2 and Figure 4 for actual comparison). Test plugs 2-6, 3-5, and 6-6 were exceptions in that the C-scans indicated a greater dye penetration than was actually observed. Visual examination of the sheared test plugs generally showed that even when the dye did penetrate it did not penetrate deeply, indicating that the unbonds were not gross. Correspondingly, visual examination of the test plugs that came apart during machining indicated a complete unbond.

Correlation of Mechanical Shear Strength and C-Scan Results

The C-scan predictions of Table 3 are based on a visual examination of the C-scans of Figure 4, i,e., an area that remains completely white throughout the three threshold levels is assumed to be unbonded; an area that remains completely dark throughout the three levels is assumed to be bonded; and an area that is partially white and which contracts over the three levels is assumed to be partially bonded. The latter case is a prime area of interest for it represents the

Table 1. MAXIMUM SHEAR LOAD ON TEST PLUGS*

Test Plug	Load (lb)	Test Plug	Load (lb)
2-1	8400	6-3	7300
2-2	8750	6-4	7450
2-5	8050	6-5	7000
2-6	3900	6-6	4300
2-7	5800	7-2	3350
3-2	1350	7-3	6850
3-3	6900	7-4	3520
3-4	6525	7-5	6850
3-5	5800	7-6	6200
3-6	6700	8-1	7100
5-1	4600	8-2	2500
5-3	7850	8-3	7450
5-4	6700	8-4	6800
5-6	7600	8-5	7225
110-1	3150	8-6	6700
110-2	6900	8-7	7100

*Unreported plugs parted at the interface during machining.

Table 2. FRACTION OF OPEN POROSITY AT THE INTERFACE CIRCUMFERENCE AS DETERMINED BY DYE PENETRANT INSPECTION

(Fraction Percent)							
7/8	3/4	5/8	1/2	3/8	1/4	1/8	0
#3-2	#3-6	#5-1	#5-6	#5-3	#2-5	#2-7	Remainder
7-2	6-5		110-1	5-4	7-5		
8-1	8-2				7-6		

Table 3. C-SCAN PREDICTION VERSUS PERCENT RATING

Completely Unbonded Test Plugs	Rating (%)	Completely Bonded Test Plugs	Rating (%)	Partially Bonded Test Plugs	Rating (%)
2-3	0	2-1	96	2-5	92
2-4	0	2-2	100	2-6	45
				2-7	66
3-1	0	3-3	100	3-5	84
3-2	20	3-4	95	3-6	97
5-2	0	-	-	5-1	59
5-3	0	-	-	5-3	100
				5-4	85
				5-6	97
6-1	0	6-3	98	6-5	94
6-2	0	6-4	100	6-6	58
7-1	0	7-3	100	7-5	100
7-2	49	7-4	51	7-6	91
8-1	95	8-3	100	8-2	34
		8-4	91	8-5	97
		8-6	90		
		8-7	95		

transition from bonded to unbonded. The percent rating is an arbitrary number arrived at by taking the shear load for each test plug and dividing it by the highest shear load developed within each forged body category (see Table 1 for shear loads). From Table 3 it is readily observable that of the eleven test plugs categorized as completely unbonded, eight failed during the machining operation, two had significantly lower percent ratings, and only 1 had a high percent rating. Of the eleven predictions for unbonds, ten proved to be accurate. It is equally as observable that of the twelve test plugs categorized as completely bonded, eleven had percent rating over 90 and only one was low. The partial bonds are not so easily described nor interpreted. Attempts to correlate the C-scans made at the three threshold levels with a visual examination of the sheared surfaces were impossible as the unbonds were indistinguishable, although gross copper voids and the Grafoil disk are clearly visible (see Figure 12). Comparisons made on the ratio of dark areas throughout the three threshold levels to shear load were inconclusive in determining which more accurately predicts bond strength (although the test plug C-scans at the 70% level appeared more accurate than those at 30% and 50%).

While examination of a specific level C-scan was useful in predicting the relative bond strengths, the best approach was to examine the three C-scan levels together (see Figure 4). Starting with the 30% C-scan, note the white areas (indicating unbonds) and observe how the white areas contract as a function of increased threshold level. The quicker and more extensive the contraction (white area), the greater the relative bond strength. While admittedly the sample population is small it may be observed from Table 3 that the average percent rating for the partially bonded test plugs was about 80. Considering that the completely bonded test plug categories averaged about 93% and the unbonded about 15%, it would appear that partially bonded areas cannot automatically be relegated to the rejection box.

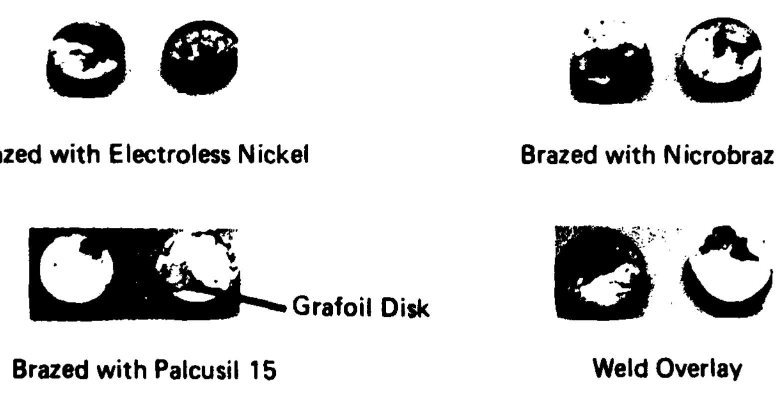

Figure 12. Typical trepanned test specimens after shear testing

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CONCLUSIONS

1. The size and shape of unbond areas can be accurately depicted by nondestructive ultrasonic C-scan tests.

2. The dark areas on a C-scan taken at the 30% threshold level are representative of the bonded areas of the shell and will be characterized by fully bonded strength levels.

3. The white areas on a C-scan taken at the 70% threshold level are representative of the unbonded areas of the shell and will be characterized by low strength levels.

4. White areas on a C-scan that contract (or dark areas that expand) as the threshold level decreases from 30% to 70% are partially bonded and their bond strength is directly related to how fast and to what extent this contraction (or expansion) occurs.

5. Gray scale ultrasonic C-scan recordings should be applied for testing brazed rotating band joints to eliminate the necessity of generating more than one C-scan per component and the uncertainty involved in interpretation of black and white ultrasonic C-scans.

6. Strength requirements of rotating bands are needed before NDT specifications can be formalized.

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Frederick S. Hannon, Robert H. Brockelman, James M. Quigley, and Daniel J. Roderick

Technical Report AMMRC TR 76 20, July 1976, 21 pp - illus-tables, D/A Project A1-5-R0020-01-AW-AW, AMCMS Code 685801.49.11100

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Key Words

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Projectiles

This report describes an effort to generate the correlation data necessary to establish ultrasonic standards and specifications for the inspection of brazed and weld overlay joints of artillery shell rotating bands. Ultrasonic pulse-echo C-scan tests were made of the brazed and weld overlay areas of projectile motor bodies. Mechanical test plugs were machined from selected areas of these bands. The shear bond strengths of the plugs were measured and correlated with C-scan results. Artificial and actual unbond areas of bond joints were destructively examined and correlated with C-scans.

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