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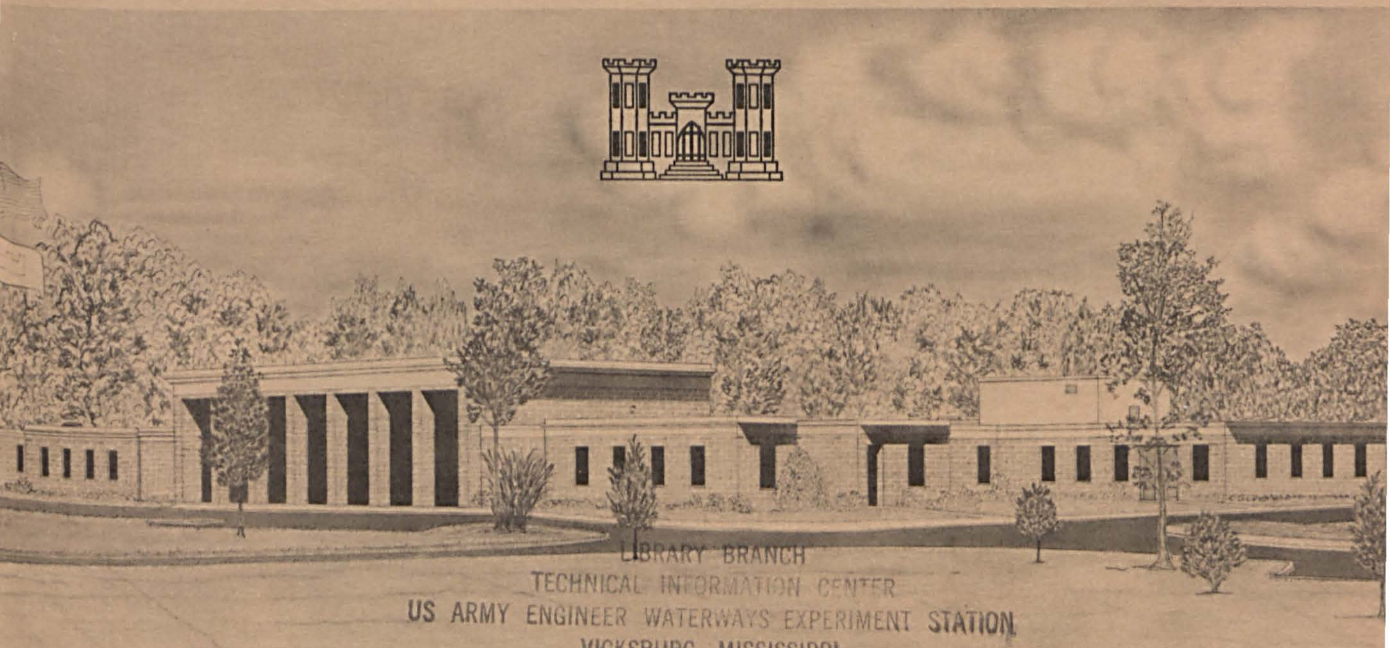
BRONZE-BRAZED JOINTS FOR SEALING REBAR PENETRATIONS OF ELECTROMAGNETIC PULSE SHIELDS

by

J. R. Hossley



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June 1972

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Conducted by **U. S. Army Engineer Waterways Experiment Station**
Weapons Effects Laboratory
Vicksburg, Mississippi

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ABSTRACT

The objective of this study was to determine whether bronze brazing could be used to seal steel reinforcing bar penetrations through the electromagnetic pulse (EMP) shields of Perimeter Acquisition Radar Buildings (PARB) when such seal joints are required to withstand design loads without degradation of the EMP shielding properties or of the mechanical properties of the reinforcing bars. Initially, five tests were performed on three concrete-encased bars that represented full-scale penetrations of reinforcing bars (No. 11, Grade 75) through 1/4-inch-thick steel plates that represented the EMP shield. After completion of each test, the concrete was removed from the brazed joint, and dye penetrant was used to examine the joint for cracking.

During this initial series of five tests, it became evident that a significant degradation in bar ductility had occurred as a result of the brazing process. Consequently, 26 tension tests were performed on No. 11 bars with a 1/4-inch-thick steel plate attached by four different methods, i.e. bronze braze, preheated bronze braze, alloy braze, and Cadweld splice, to determine a brazing technique that did not degrade bar ductility. All samples were tested at static or dynamic (intermediate) loading rates. The time to yield at the intermediate loading rate was about 0.10 second (approximately 0.08 in/in/sec). Transient load and strain measurements were recorded during the tests.

The results of the full-scale penetration tests indicated that it is possible for a brazed penetration of the type tested to withstand shear and tensile loads of a magnitude expected in a PARB. The test results, however, indicated that the brazing process caused a significant reduction in the ductility of the reinforcing bar.

All tension-tested samples exceeded the American Society for Testing and Material's minimum requirements for tensile and yield strength; however, the test results indicated that brazing of the Grade 75 reinforcing bars can result in a considerable loss of ductility (elongation at rupture being less than 1 percent) if during brazing the temperature is excessive. If the brazing procedure outlined in Appendix A is used

by an experienced and certified welder, bar elongations greater than 5 percent can be obtained. The Cadweld-spliced samples produced the greatest final elongation (8.5 percent).

Test results showed that the brazed joint between the bar and plate leaked dye penetrant at approximately 2.5 percent bar elongation. Thus, it is possible that the EMP shielding properties will be significantly degraded at bar elongations above 2.5 percent.

PREFACE

This study was conducted at the U. S. Army Engineer Waterways Experiment Station (WES) and sponsored by the U. S. Army Engineer Division, Huntsville (HND). The work was accomplished during the period August to December 1971 under the general supervision of Mr. G. L. Arbuthnot, Jr., Chief of the Weapons Effects Laboratory, WES. Mr. W. J. Flathau, Chief of the Protective Structures Branch (PSB), and Mr. T. E. Kennedy of PSB coordinated the testing program. Mr. F. P. Hanes of the Design and Development Branch, Instrumentation Services Division, provided technical advice and guidance. This report was prepared by Mr. J. R. Hossley of the Operations Group, PSB.

COL Ernest D. Peixotto, CE, was Director of WES during the conduct of this study and the preparation of this report. Mr. F. R. Brown was Technical Director.

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TABLES

FIGURES

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
square inches	6.4516	square centimeters
pounds (force)	4.448222	newtons
kips (force)	4.448222	kilonewtons
pounds per square inch	6.894757	newtons per square centimeter
kips per square inch	6.894757	kilonewtons per square centimeter
Fahrenheit degrees	5/9	Celsius or Kelvin degrees[a]

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[a] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

In the design and construction of shear wall structures to resist the effects of nuclear weapons, it is frequently necessary to shield internal equipment from electromagnetic pulse (EMP) radiation. This is usually accomplished by using a continuous shield made of a heavy-gage steel on either the interior or the exterior surfaces of the structure. In some SAFEGUARD structures, this shield is on the interior surfaces. This means that the shield must cross each junction of a floor and wall in a continuous manner. A technique was developed to accomplish this by using a mechanical shear key system. Current practice calls for the use of Cadweld sleeves welded to the shield and to each reinforcing bar that penetrates the shield to insure the existence of a continuous EMP shield.

Because of the expense and on-site complications involved in using Cadweld sleeves for sealing and because a Cadweld sleeve cannot be placed in locations with limited space, alternate techniques for sealing reinforcing bar penetrations through the EMP shield are being investigated. Initially, direct welding and brazing appeared to be potential expedient methods for forming seals. However, tests of welded and steel-brazed reinforcing bars (Reference 1) have indicated that an unacceptable degradation of ductility occurs due to the high temperatures required for joining the bars to the steel plate (EMP shield) using these techniques.

This degradation did not seem to occur in steel reinforcing bars that were bronze-brazed to a steel plate. Hence, it appears that the use of bronze brazing may satisfy the requirement for constructing a continuous shield without using Cadweld sleeves and without causing an unacceptable loss of ductility.

1.2 OBJECTIVE

The objective of this study was to determine whether bronze-brazed reinforcing bar penetration seal joints of a type that can be used in a

Perimeter Acquisition Radar Building (PARB) have sufficient mechanical strength to withstand the design loads for the PARB without degradation either of the EMP shield or of the mechanical properties of the steel reinforcing bars.

1.3 SCOPE

A total of 31 tests were conducted at intermediate (dynamic) and static strain rates on samples of No. 11 reinforcing bars (Grade 75 billet steel, A615). Six different types of samples were prepared: (1) concrete-encased bars, (2) bronze-brazed bars, (3) extensively preheated bronze-brazed bars, (4) alloy-brazed bars, (5) Cadweld-spliced bars, and (6) as-rolled bars. Dynamic loads were applied using the U. S. Army Engineer Waterways Experiment Station (WES) 200-kip-capacity[1] loader, and all static tests were conducted using a 400,000-pound-capacity universal testing machine.

Three concrete-encased bar samples were constructed to represent full-scale penetrations of reinforcing bars through 1/4-inch-thick steel plates utilizing a bronze-brazed seal joint. The steel bars used in these tests were manufactured by Laclede Steel Company and had a barrel-rib-type deformation pattern. These rebars were taken from the same lot of steel that was used in tests described in Reference 2. During testing, the time to yield in all cases was about 0.10 second. Shear and tensile (pull) loads were applied to the three samples. After completion of these tests, the concrete was removed from around each brazed joint, and a dye penetrant was used to examine the joint for cracking. Two control samples were constructed by brazing a 1/4-inch-thick steel plate to a length of rebar. One of these bars was pulled to rupture; the other was hardness-tested in the vicinity of the braze joint.

Twenty-five tests were performed on steel bars manufactured by North Star Steel Company for use at a PARB site. This steel was furnished by the U. S. Army Engineer Division, Huntsville (HND), from a North Dakota

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[1] A table of factors for converting British units of measurement to metric units is presented on page 9.

construction site. The deformations on this steel were the "X" type. A schedule of tests for the various types of samples is shown in Table 1.1. A 1/4-inch-thick, 18-inch-square steel plate was brazed onto all the samples except the as-rolled bars.

TABLE 1.1 TEST SCHEDULE

Type Sample	Test No.	Steel Manufacturer[a]	Type Test
Static Tests:			
Bronze-brazed bars	1	NS	Tension
	2	NS	Tension
	3	NS	Tension
Preheated bronze-brazed bars	4	NS	Tension
	5	NS	Tension
	6	NS	Tension
As-rolled bars	7	NS	Tension
	8	NS	Tension
	9	NS	Tension
Alloy-brazed bars	10	NS	Tension
	11	NS	Tension
	12	NS	Tension
Cadweld-spliced bars	13	NS	Tension
	14	NS	Tension
	15	NS	Tension
Dynamic Tests:			
Concrete-encased bars	209	L	Shear
	210	L	Shear
	211	L	Pull
	212	L	Pull
	213	L	Pull
Bronze-brazed bars	214	L	Tension
As-rolled bars	215	NS	Tension
Bronze-brazed bars	216	NS	Tension
	217	NS	Tension
	218	NS	Tension
Alloy-brazed bars	219	NS	Tension
	220	NS	Tension
	221	NS	Tension
Cadweld-spliced bars	222	NS	Tension
	223	NS	Tension
	224	NS	Tension

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[a] NS - North Star Steel Company; L - Laclede Steel Company.

CHAPTER 2

TEST EQUIPMENT AND PROCEDURES

2.1 TESTING DEVICE

All dynamic tests were performed in the WES 200-kip-capacity dynamic loader. Theory and operation of the machine are described in Reference 2. In all tests, the machine was programmed for a loading rate that would produce a time to yield load of about 0.10 second. A special pour-type gripping system designed at WES was used to fit the No. 11 rebars with grips at each end for attachment to the loader ram.

2.2 SAMPLE PREPARATION

The No. 11 steel reinforcing bars were cut to obtain rebar samples. The samples were threaded on one end for a 1-3/8-inch No. 12 nut.

A 1/4-inch-thick steel (ASTM-A-36, Reference 3) plate was brazed to each bar, as shown in Figure 2.1. The braze joint was approximately 3/8 inch thick (from plate to end of braze) and extended 1/2 inch out on the plate all around the rebar to insure that the 1-5/8-inch-diameter hole drilled in the steel plate would be plugged.

2.2.1 Concrete-Encased Bars. Rebar stirrups (Figure 2.2) were placed on each side of the bronze-brazed plate in order to reinforce the sample during the shear test. A wood form was placed around the assembly and 5,000-psi, high-early-strength concrete was placed to complete the samples. The average compressive strengths of the concrete on the samples at 7- and 21-day ages were 3,990 and 5,250 psi, respectively. A completed sample before testing is shown in Figure 2.3. The shear and pull tests were performed approximately 21 days after the concrete was placed. A bond break was purposely made in Sample 1 between the rebar and the concrete on the brazed side of the plate only.

2.2.2 Bronze-Brazed Bars. The bars were brazed using 1/8-inch-diameter flux-coated National Cylinder Gas (NCG) rediffluxed, 35, high-strength bronze rods. This rod will meet AWS-ASTM Specifications R-CuZn-C, or QQ-R-5712, Type 1, Class FS-R CuZn-2 (Reference 4). The rod has a 60,000-psi tensile strength and melts at 1,620 F. The surfaces to be brazed must be free of foreign matter and scale to obtain a good bond.

The bars with the barrel-type deformation pattern were satisfactorily cleaned with a small file and emory cloth. The bars with the X deformation pattern were more difficult to clean. Wire brushing did not remove the mill scale from the bars. Consequently, sandblasting was used. The bars were brazed at room temperature in a vertical position. Before brazing, the bars and plates were preheated to a temperature of approximately 400 F. The preheated zone extended approximately 2 inches in all directions from the area to be brazed. During the brazing operation, particular care was taken to prevent an excessive weld temperature. In all cases, the weld temperature was determined by visual observation of the color of the heated rebar and with temperature-indicating (melting-type) crayons. The temperature-color relation was as follows: (1) first indication of dark red, 1,150 F; (2) medium red, 1,200 F; and (3) bright red, 1,300 F.

Generally, the color of the bar at the point above the welding fillet was bright red, indicating a temperature of approximately 1,300 F. The crayons indicated that hot spots under the molten material may have reached a higher temperature. To prevent contamination of the welds, the crayons were not used until the welds had been completed. Temperature measurements using thermocouples were made during brazing at two locations (1/4 inch and 2 inches below the plate) on only the bars having X deformation patterns. The gage located 1/4 inch below the plate cooled faster than the gage 2 inches below the plate, indicating that the plate acted as a heat sink.

2.2.3 Extensively Preheated Bronze-Brazed Bars. These samples were prepared in a manner similar to that used to prepare the bronze-brazed bars except that preheating was more extensive. Prior to brazing, the steel bars were heated to 450 F for a distance of 12 inches on each side of the joint. The bars were then heated to dark red at the joint and brazed. Temperature measurements were made with two thermocouple gages located 1/4 inch and 2 inches below the plate. The average peak brazing temperature at both gage locations was greatest when this type of preheat was applied. Temperature measurements made with the melting crayons indicated that a temperature between 1,500 and 1,600 F was reached during brazing.

2.2.4 Alloy-Brazed Bars. The plates were brazed using a 3/16-inch, flux-coated, eutectic 16 FC rod. The brazing rod is a copper based, zinc-nickel-silver alloy with a melting temperature of 1,400 F and a tensile strength of 80,000 psi and is manufactured by the Eutectic Welding Alloy Corporation, New York, New York. This rod was used because it is a high-strength rod that requires a lower heat input than a bronze rod. During brazing, temperature measurements were made on the bar 1/4 inch and 2 inches below the plate. The peak temperature reached at both measuring locations was less than that measured when brazing with the bronze rod. Temperature measurements made with the melting crayons on the bar immediately above the fillet joint indicated a maximum of 1,500 F. This temperature was approximately the same as that recorded for the bronze-brazed bars. After the bronze joint was completed and was allowed to begin cooling, separation (cracking) between the braze and the plate occurred. This cracking occurred for approximately 50 percent of the bars prepared, and was repaired by additional brazing. The alloy brazing rod costs approximately four times as much as the brazing rod discussed in Section 2.2.2.

2.2.5 Cadweld-Spliced Bars. The plates were bronze-brazed to each Cadweld-spliced sleeve before the sleeve was connected to a continuous steel rebar. To allow clearance for positioning the splicing equipment on the sleeve, an offset-type pouring basin (Figure 2.4) was used. The Cadweld sleeve used in this type connection was a No. R.B.T.-11101 (Reference 5). Since venting holes are not available on this type sleeve, a twisted tie wire must be inserted on each end between the sleeve and rebar. This venting arrangement is typical of the type used at the North Dakota construction site. A detailed step-by-step procedure for positioning, charging, and firing the Cadweld splice is presented in Reference 2, and a pretest view of a completed Cadweld-spliced sample is shown in Figure 2.5.

2.3 DESCRIPTIONS OF TESTS

2.3.1 Tests on Concrete-Encased Samples. Five tests (Tests 209 through 213) were performed on the three concrete-encased samples (Table 1.1). Tests 209 and 210 were shear tests. In order to perform the shear tests, a 10-inch box beam was welded to an existing tension frame. The shear sample was then attached to the bottom side of the box beam with four long studs (Figure 2.6a). The studs were attached to two 6- by 3-inch rectangular beams on the lower side of the sample. The support and crossbeams were braced and supported to carry the loads developed during the shear tests.

A yoke was constructed to fit around the shear sample to allow attachment to the loader ram and the lower side, as shown in Figure 2.6b. The yoke was constructed from a 12- by 6-inch rectangular beam placed on the top and bottom of the sample and tied together with a 1/2-inch-thick steel plate. The bottom beam was constructed with a hollow sleeve in the steel beam to allow attachment to the loader ram, through use of a threaded rod and the threaded load cell. The top beam was fitted to a 6-inch-diameter, half-round loading head. In order to distribute the load evenly to the top of the concrete sample, a 1-inch-thick steel plate was placed under the loading head. With this test arrangement, the center of the load was applied 3 inches from the EMP shield plate and exerted an eccentric load on the sample during the test.

Tests 211 through 213 (Table 1.1) were pull tests on the concrete-encased samples. A pedestal was constructed to support the sample over the top of the loader, as shown in Figure 2.7. The pedestal was constructed of 3/4-inch-thick steel plates (top and bottom) connected by eight vertical 1/2-inch-thick plates. The vertical plates were equally spaced and welded to the top and bottom plates. To insure good support of the sample, a 1-1/2-inch-thick steel plate was placed between the pedestal and the sample. After a pour-type gripper had been installed on the exposed rebar, the sample was threaded onto the load cell.

2.3.2 Tension Tests. Tension tests were performed on all types of samples but the concrete-encased samples. A total of 26 tension tests were performed (see Table 1.1). Rebar tests at the dynamic load rate were performed in the WES 200-kip-capacity loader, as shown in Figure 2.8. All but one of the tension tests were performed on the North Star steel. The dynamically tested samples were fitted with grippers and pulled in tension in a manner similar to that described in Reference 2. The brazed joints and Cadweld splices were coated with a dye penetrant before and after the tension tests. After brazing, the steel plates that were to be tested dynamically were machined to 4 inches in diameter to simplify handling.

2.4 INSTRUMENTATION

During the dynamic tests, load was measured by a load cell that was an integral part of the connections on the lower side of each test sample. The load cell (dynamometer) had a maximum capacity greater than 200 kips and was carefully machined from 4130 steel. Four 120-ohm strain gages were mounted on the surface at the midheight of the cell. Two of the gages (mounted 180 degrees apart) were mounted to measure circumferential strain. The gage pairs were connected electrically to form two active arms of a wheatstone bridge, with two additional strain gages as opposite arms of the bridge, i.e. a four-arm bridge circuit.

All dynamically tested samples were instrumented with strain gages in order to determine the state of strain at various locations on the test bars. Strain levels up to and greater than yield strain were measured using 0.25-inch metal-foil gages.

Four separate longitudinal strain measurements were made with gages located approximately 4 inches below the bottom of the concrete-encased samples and diametrically opposite one another. Two separate longitudinal strain measurements were made on the tension samples with gages located 3 inches below the plate and opposite each other. Measurements of dynamic load and strain were recorded simultaneously on magnetic-tape machines having a frequency response of 20,000 Hz. Static load measurements were taken directly from the load-indicating dial on the universal testing machine. Strain measurements were made on the statically tested samples with a mechanical extensometer that measured strains over an

8-inch gage length. In the case of the Cadweld-spliced bars, two extensometer measurements were made: (1) across the splice (8-inch gage length), and (2) across a section of the bar above the splice (Tests 1, 2, 3, 13, 14, and 15 with an 8-inch gage length, and Tests 222, 223, and 224 with a 4-inch gage length). The indicating dial on the extensometer was readable to 0.0001 inch. However, some slight slippage at the attachment points may have occurred while the extensometer was being used.

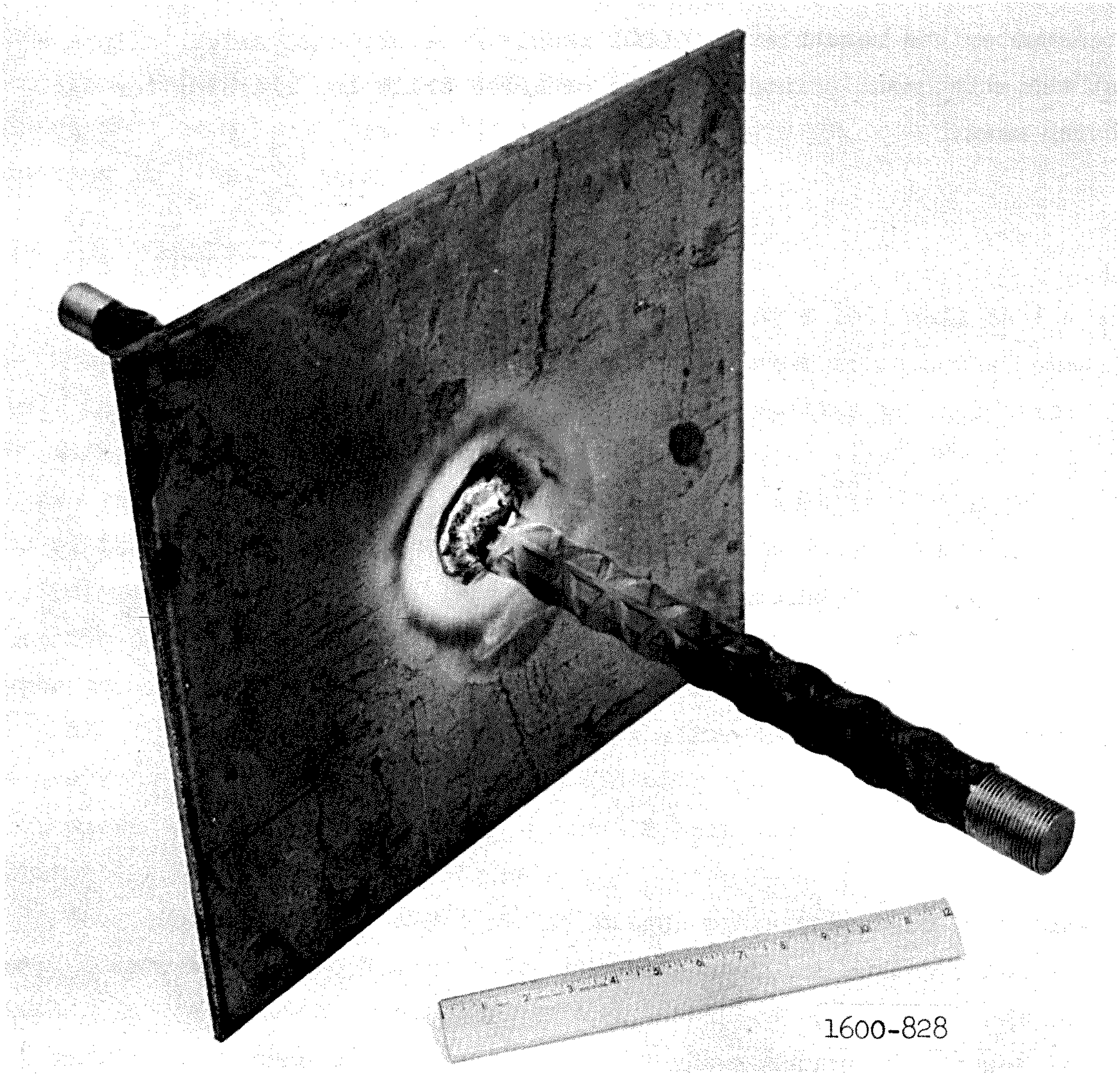


Figure 2.1 Pretest view of 1/4-inch-thick steel plate brazed to No. 11 rebar.

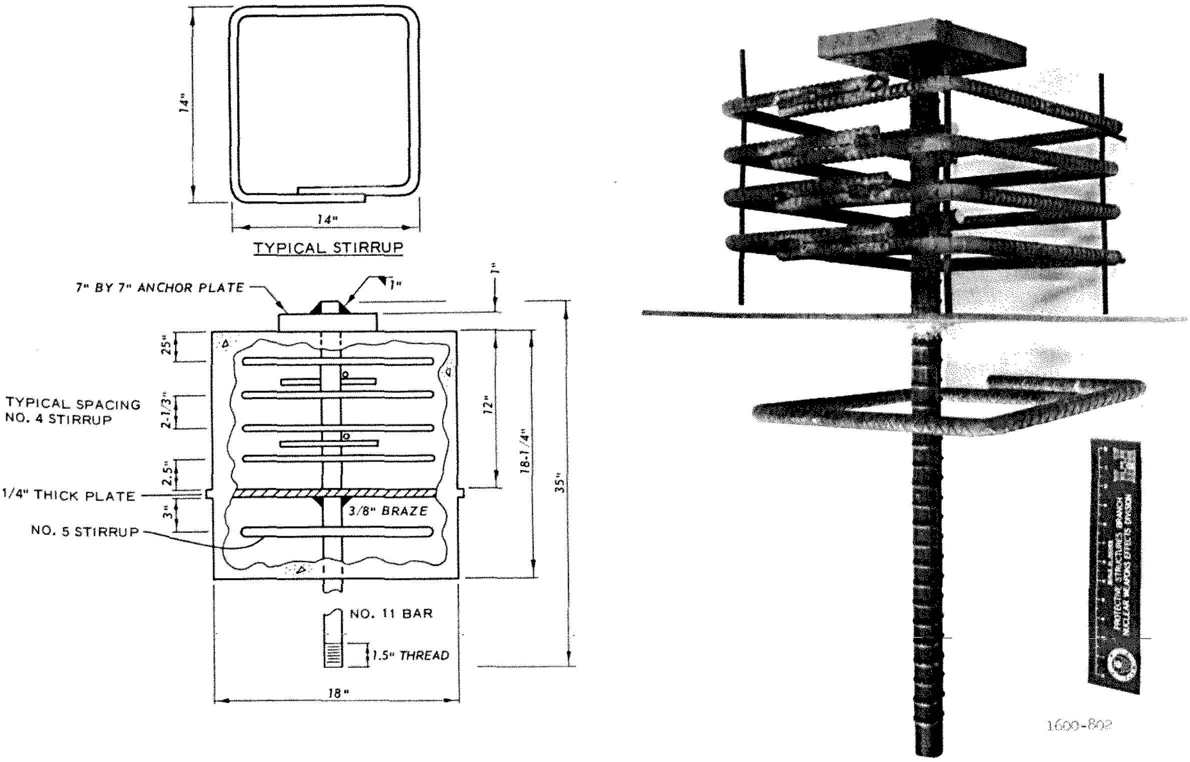


Figure 2.2 Schematic diagram and photograph of test bar with plate and rebar stirrups prior to placement of concrete.

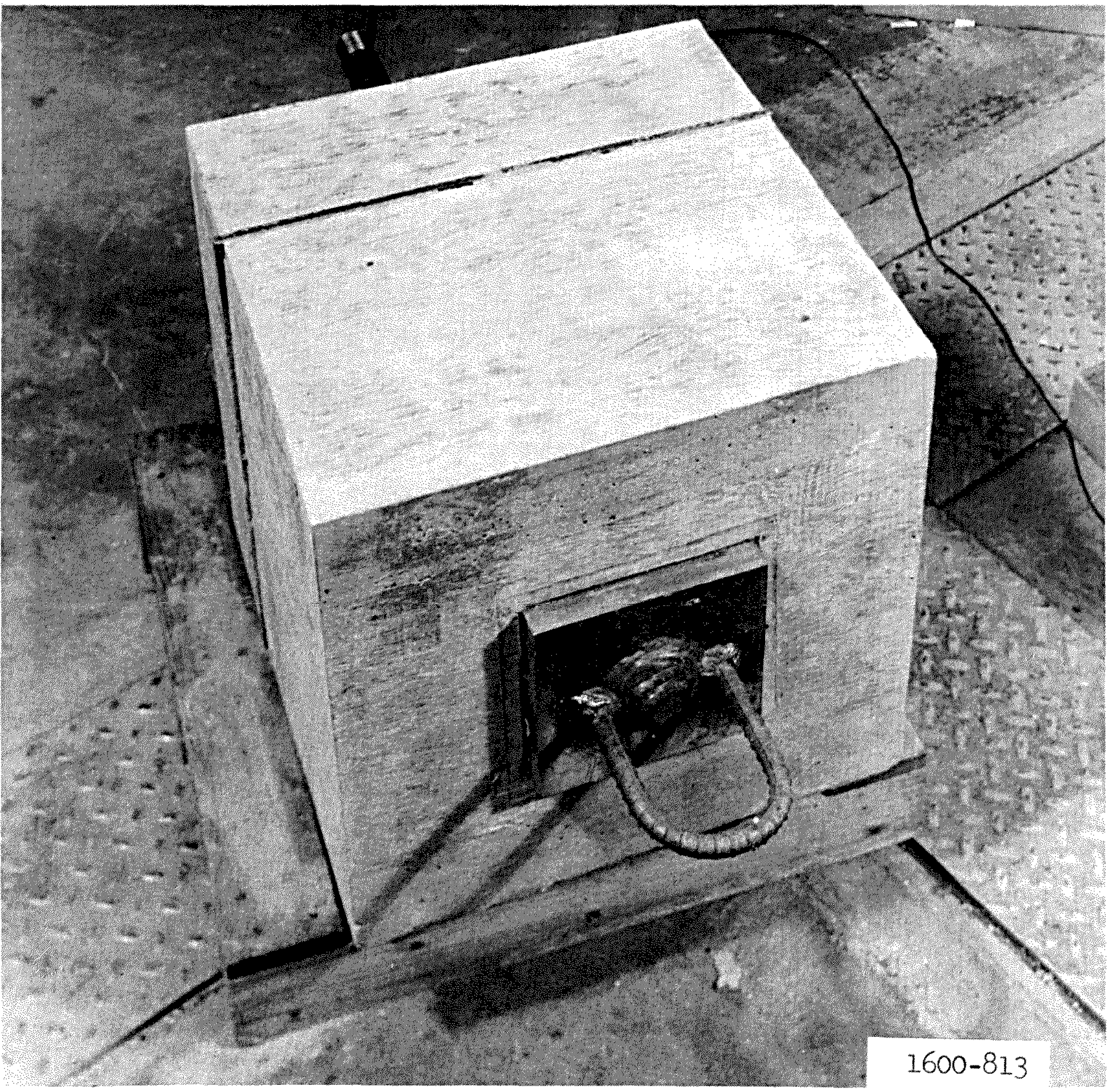


Figure 2.3 Pretest view of concrete-encased test sample.

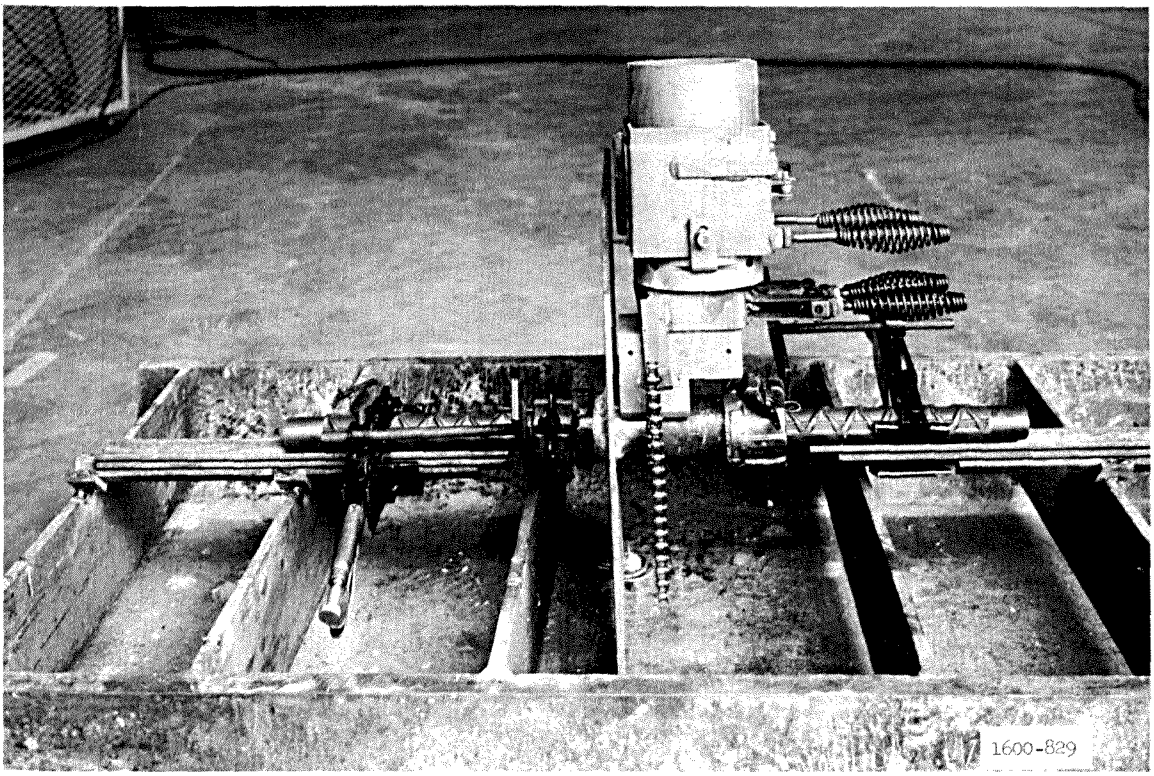


Figure 2.4 Pouring basin, crucible, and fitting for Cadweld-splice process.

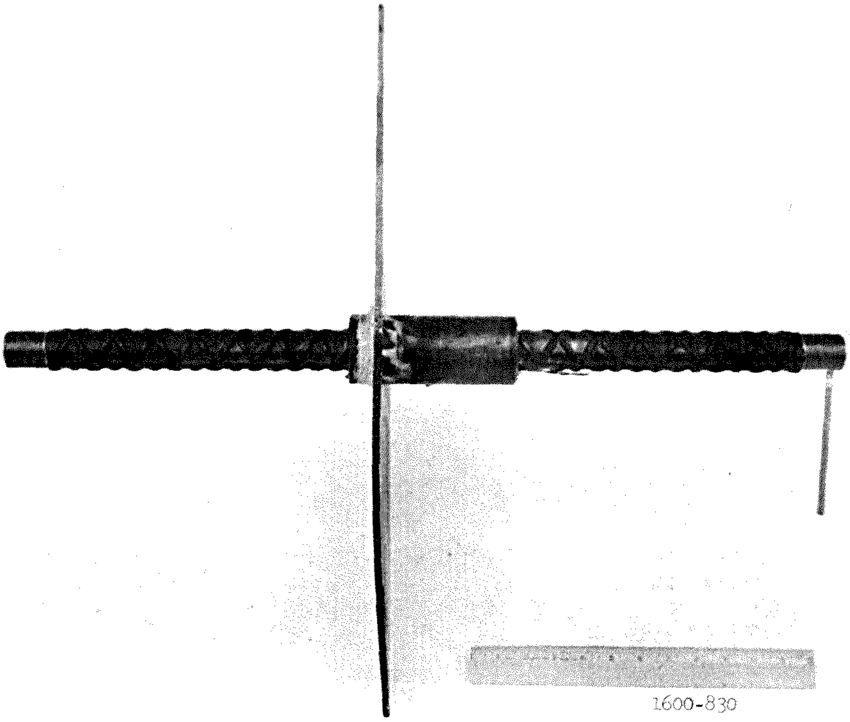
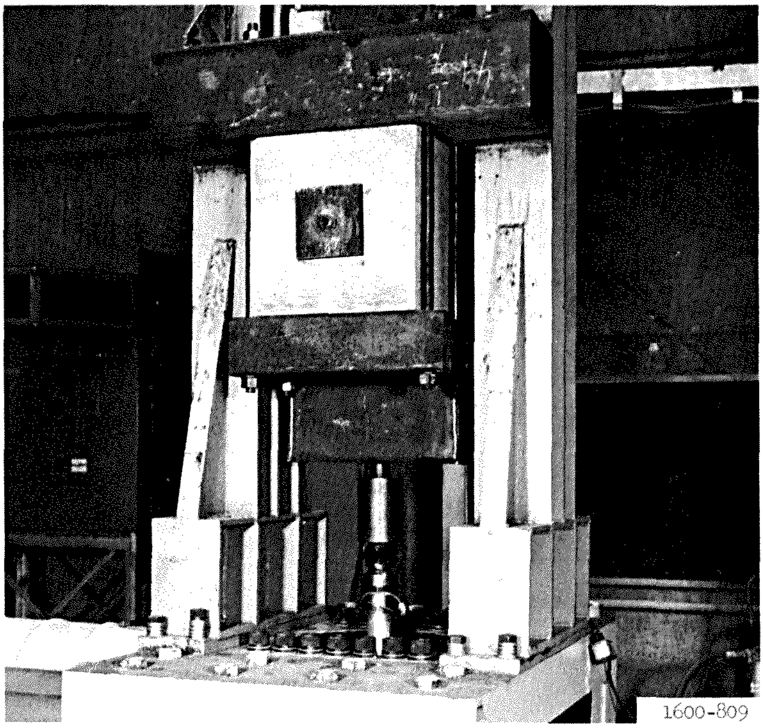


Figure 2.5 Pretest view of completed Cadweld-spliced sample.



a. Rear view.

b. Front view.

Figure 2.6 Sample in place in shear test assembly.

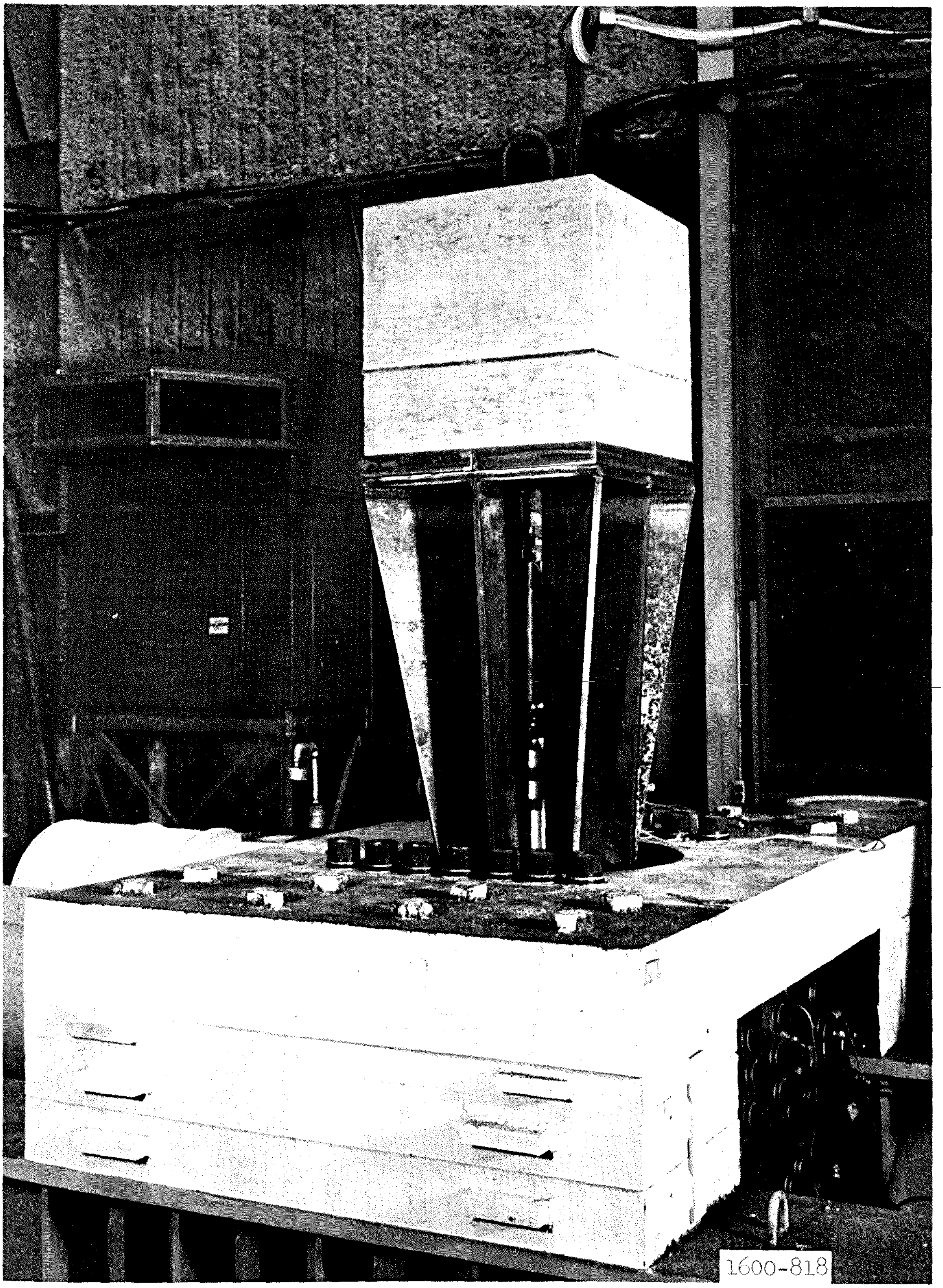


Figure 2.7 Concrete-encased sample in place on pedestal ready for pull test.

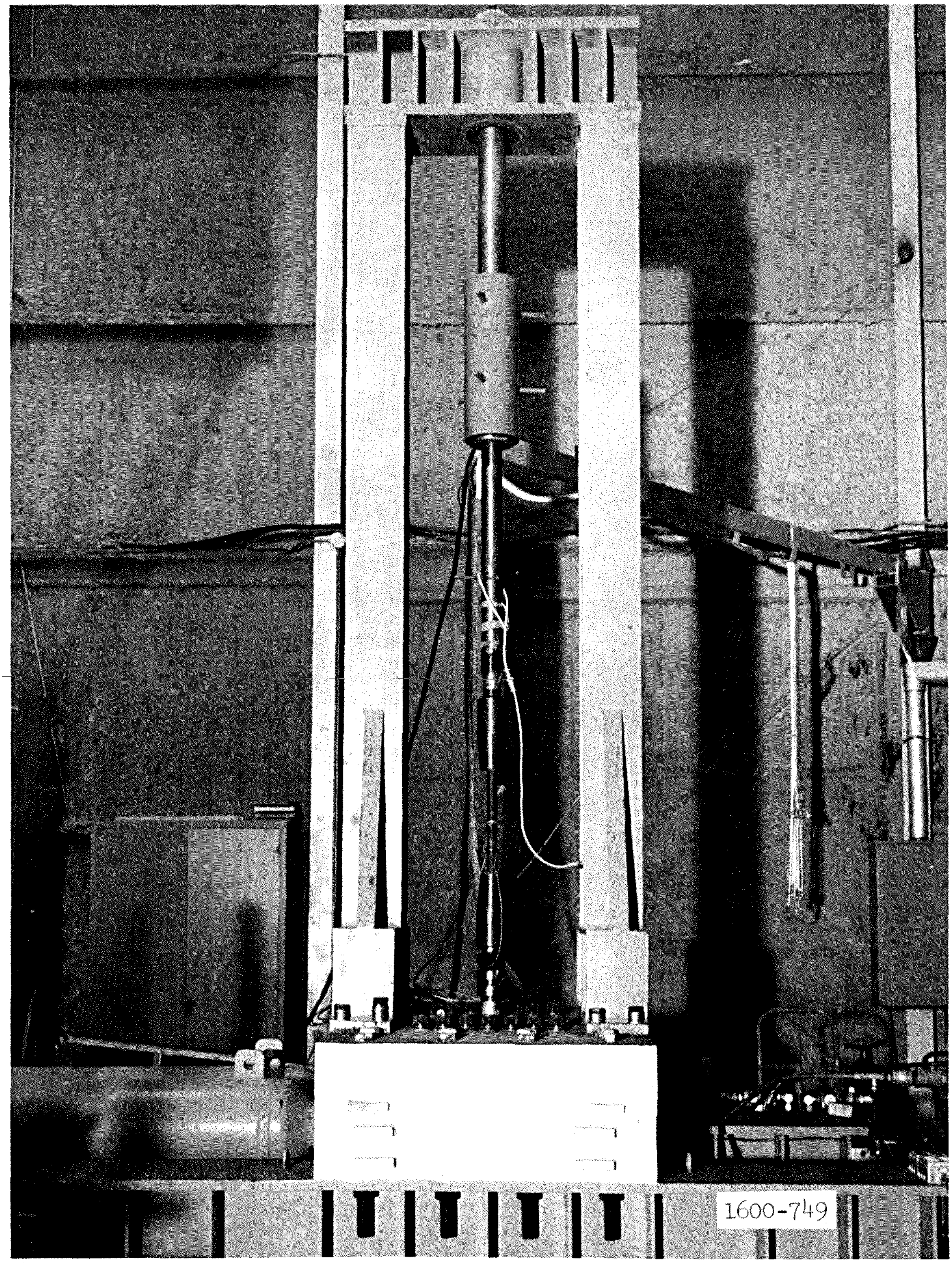


Figure 2.8 Sample in 200-kip-capacity loader ready for tension testing.

CHAPTER 3

TEST RESULTS AND DISCUSSION

Summaries of the results obtained during the tests are presented in Tables 3.1 and 3.2. The loading equipment, transducers, and electronic recording equipment functioned properly throughout the test series. An arithmetic average of the measured loads from the upper and lower load cells was used to determine the stress in the bars. A nominal area of 1.56 in^2 was used in computing stress. An arithmetic average of the measured strain values was used to plot stress-strain curves. At the loading rates used in these tests, there was no appreciable influence due to inertial effects. All the tension-tested samples exceeded minimum specifications for yield strength (75,000 psi) and tensile strength (100,000 psi) as set forth in Reference 7. All the concrete-encased samples, two of the bronze-brazed samples, and all of the extensively preheated bronze-brazed samples failed to meet minimum ASTM Specifications for elongation (5 percent). Summaries of the test results for each type of sample are presented in the following sections. Since only limited tests were conducted on the as-rolled bars, a section is not included for them. However, results of static and dynamic tests on the as-rolled bars are presented in Figure 3.1.

3.1 CONCRETE-ENCASED SAMPLES

Shear load versus time plots for Tests 209 and 210 are presented in Figure 3.2. Stress-strain curves are presented in Figure 3.3 for Tests 211, 212, and 213. In Test 209, the steel bar was sheared off at a load value of 51.1 kips. Posttest views of this sample are shown in Figures 3.4 and 3.5. The initial combined load of 51.1 kips shear and bending caused by the 3-inch moment arm did not exceed the strength of the bar. The bar failed in this test because of concrete failure that occurred on the brazed side of the steel plate. As the concrete cracking became well established, the stresses in the bar caused by the loading moment increased to values great enough to break the bar.

Failure occurred 2.7 seconds after the full load was applied to the test sample and after a geometric readjustment of the concrete took place that resulted in high bending moments. After the test, dye penetrant was applied (Figure 3.6) and indicated a leak between the bar and brazed joint.

In Test 210, a maximum shear load of only 22.3 kips was applied to Sample 2. No visible signs of cracking or distortion were observed during posttest investigations.

Test 211, a pull test of Sample 1, resulted in failure of the No. 11 bar at the brazed joint. The bar was stressed to a maximum of 94.7 ksi, which is below the minimum ASTM specification (Reference 7) for tensile strength (100 ksi). Final elongation of this bar was 0.8 percent. A posttest view of this sample is shown in Figure 3.7. Dye penetrant testing of the brazed joint showed it to be sound. Test 212 was a 60.8-ksi tension test of Sample 2. The bar was strained to 0.27 percent elongation and did not yield. No sign of cracking was visible on the posttest sample. Since yielding did not occur, an additional tension test (Test 213) at 96.2-ksi stress was performed on Sample 2. In this test, the bar yielded at 0.5 percent elongation, but did not break. After removal of the concrete, the brazed joint passed the dye penetrant test.

A special sample (bronze-brazed and not concrete-encased) was prepared from the same type steel and using the same brazing techniques as used for the concrete-encased samples. This sample was tested (Test 214) at 89.0-ksi stress for comparison with a concrete-encased sample (Test 211). A plot of stress versus strain for the Test 214 bronze-brazed sample is given in Figure 3.8. The sample broke at an elongation of 2.5 percent. The yield and tensile strengths of the Test 211 and 214 samples were high enough to pass minimum ASTM specifications. The relatively small elongations of the bars at rupture (0.8 and 2.5 percent) contradict the results of a prior test series (Reference 1). In an effort to investigate this apparent difference of results, dye penetrant tests were performed on two untested bronze-brazed samples that were surplus to the Reference 1 tests. Both samples failed the dye penetrant test, indicating a poor bond between the brazing material and the steel. These specimens had been prepared under field conditions at a construction site in North Dakota and furnished by HND, and it is believed that insufficient heat was used to obtain a sound brazed joint; hence, no decrease in ductility occurred.

Cooling of the material from brazing temperatures to ambient condition could possibly have caused the steel to become brittle if the cooling rate was too fast. Embrittlement could have been caused by the formation of a very hard material called martensite or by induced quenching strains. Both of these conditions can best be minimized by preheating and/or postheating the steel. To determine the hardening effect of brazing a control specimen, one of the WES-prepared joints was sawed and the hardness level determined. The results of this test are given in Table 3.3. The hardness levels gave no clue as to the type of failure experienced. The average hardness in the as-rolled bar was 99 on the Rockwell B (RB) scale. The maximum hardness measured in the brazed zone was 106 RB. Results of a chemical analysis of both types of steel used in these tests are presented in Table 3.4.

3.2 BRONZE-BRAZED SAMPLES

The average elongation for the three bronze-brazed bars tested statically was 5.4 percent, and that for the three bronze-brazed bars tested dynamically was 7.9 percent (see Table 3.5, which presents a comparison of test results). Both of these values indicate some degradation of the bar elongation when compared with that of the statically tested as-rolled bars (10.4 percent). The difference between the static and dynamic test results is explained by a greater heat input being applied to the statically tested bars when they were brazed. Although an accurate temperature measurement was not made at the point of brazing, thermocouples were placed 1/4 inch and 2 inches below the plate. Both of the gages showed a higher temperature when the bars that were to be tested statically were brazed. The average brazing time for the bars for dynamic testing was 4 minutes, and that for the bars for static testing was 6 minutes. Both the longer brazing time and higher temperature indicate that the bars for static testing were subjected to more heat input when being brazed. Using the temperature measurements made at the two gage locations as an indication of the temperature level reached at the point of brazing, the supposition is made that the brazing temperature during the static test was greater. A temperature versus time plot for Test 3 is shown in Figure 3.9. Stress versus strain curves for the dynamically tested samples are shown in Figure 3.10. Only one of the dynamically tested bronze-brazed samples was broken. All of the samples failed the dye penetrant tests.

3.3 EXTENSIVELY PREHEATED BRONZE-BRAZED SAMPLES

The three static tests performed on this type sample (Tests 4, 5, and 6) resulted in an average elongation of only 3.8 percent. These samples were subjected to the greatest heat input because of the longer time required for the process, i.e. approximately 4 minutes for preheating and 4 minutes for brazing. The average peak temperature at the gage located 1/4 inch below the plate was 1,215 F, the highest temperature average recorded during the entire test series. A plot of temperature versus time for Test 6 is given in Figure 3.11. All test samples failed the dye penetrant tests.

3.4 ALLOY-BRAZED SAMPLES

An average elongation of 8.7 percent was recorded for both the statically and dynamically tested samples. All the static test samples were broken, but none of the dynamic test samples were. The elongation of these bars was slightly greater than that for the bronze-brazed bars and approximately the same as that for the Cadweld-spliced bars. The heat input during brazing, as indicated at both thermocouple locations (Figure 3.12), was approximately the same as that recorded for the bronze-brazed bars. Stress versus strain plots for both the statically and dynamically tested alloy-brazed bars are shown in Figure 3.13. A cracked alloy-brazed joint is shown in Figure 3.14. This type separation of the braze joint is typical of that which occurred on the bronze-brazed bars. All of the alloy-brazed bars failed the posttest dye penetrant test.

3.5 CADWELD-SPLICED SAMPLES

Average elongations of 8.2 and 9.3 percent, respectively, were recorded on the statically and dynamically tested Cadweld-spliced bars. Only the Test 223 bar was not broken. The Test 15 sample fractured in the center of the splice sleeve, as shown in Figure 3.15. The final elongation of this bar was 5.1 percent. At the point of fracture, the hot-pour metal seemed to have melted into the rebar, causing some weakening of the steel. All other fractured bars failed outside the sleeve of the splice. The splice sleeve on the Test 14 sample was not completely full of pour material because of a leak that occurred during the splicing operation. Dye penetrants placed on the samples before the tension tests did not show any leaks until after the bars had failed. On two of the statically tested samples, the plates came loose from the sleeve after the bars had failed due to the inertial forces developed by the large plate mass during bar failure. A typical separation is shown in Figure 3.16. Stress versus strain plots for both the statically and dynamically tested Cadweld-spliced bars are shown in Figure 3.17. All the dynamically tested samples passed the dye penetrant test at the plate-sleeve joint after the rebars had been tension-tested.

An hour after the tension tests had been performed, dye penetrant leaked through the sleeve-rebar connection on two of the statically tested samples. After sitting overnight following a test, all the samples leaked dye penetrant through the sleeve. The penetrant was applied about 10 minutes prior to a tensile test. None of the joints leaked before any load was applied.

That the completed splicing sleeve will reinforce a continuous bar during tensile loading is shown by the results presented in Table 3.6. The average bar elongation for the Cadweld-spliced samples was 8.73 percent, while the average elongation of the bar across the splice was only 5.5 percent.

3.6 SUMMARY OF RESULTS

Although no direct temperature measurements were made on the specimens prepared from the Laclede steel, it is felt that the reason for the low final elongations (1.7 percent average) of these samples was excessive brazing temperatures. The relatively low elongation (3.8 percent) produced on the extensively preheated bronze-brazed bars (North Star steel) substantiates this because the temperatures on these bars were the highest recorded.

The greatest average elongation (8.8 percent) was produced on the Cadweld-spliced samples. The low-temperature, alloy-brazed samples elongated 8.7 percent, which is slightly greater than that for the bronze-brazed specimen (6.6 percent). Plots of temperature at Gages 1 and 2 versus elongation for the bronze-brazed, extensively preheated bronze-brazed, and alloy-brazed samples are shown in Figure 3.18.

It is felt that a minimum elongation of 5 percent can be obtained on bronze-brazed Grade 75 bars when an experienced welder uses the procedure outlined in Appendix A. At a field construction site, few controls will be available to determine if the brazing temperature is excessive; therefore, the quality of the joint will depend, to a great degree, on the skill of the welder. Neither visual observation of the bar color nor temperature-indicating crayons are adequate controls. Since there is a natural tendency to excessively heat the steel bar during brazing, every effort must be made to impress upon the welders making this type of joint the requirement to avoid excessive heating. Before the use of brazing is allowed as a field option, definitive quality-control procedures must be developed and a comprehensive welder certification program established.

TABLE 3.1 SUMMARY OF RESULTS OF TESTS ON CONCRETE-ENCASED SAMPLES

Test No.	Sample No.	Maximum Load	Loading Rate	Maximum Stress[a] σ_m	Yield Stress[b] σ_y	Yield Strain ϵ_y	Time to Yield t_y	Strain Rate $\dot{\epsilon}$	Final Elongation[c]	Remarks
		kips	kips/sec	ksi	ksi	in/in	seconds	in/in/sec	percent	
Shear Tests:										
209	3	51.1	488	--	--	--	--	--	--	Bar sheared off; concrete was severely cracked; joint failed dye penetrant test
210	2	22.3	188	--	--	--	--	--	--	No visible signs of cracking
Pull Tests:										
211	1	--	--	94.7	87.5	0.0053	0.11	0.042	0.8	Bar broke at braze point; joint passed dye penetrant test
212	2	--	--	60.8	NA[d]	NA[d]	NA[d]	0.026	NA[d]	Bar was not broken and did not yield
213	2	--	--	96.2	95.0	0.0048	0.25	0.022	0.5	Bar did not break; joint passed dye penetrant test

---

[a] A nominal cross-sectional area of 1.56 in^2 is common to all bars.

[b] All bars showed a pronounced yield point (computed using 0.2 percent offset method presented in Reference 6).

[c] Elongation was measured over an 8-inch gage length.

[d] NA--not applicable.

TABLE 3.2 SUMMARY OF RESULTS OF TENSION TESTS

Test No.	Sample Type	Maximum Stress[a] σ_m	Yield Stress[b] σ_y	Yield Strain ϵ_y	Final Elongation[c]	Stress at Which Joint Failed Dye Penetrant Test	Strain Rate $\dot{\epsilon}$	Time to Yield t_y	Remarks[d]
		ksi	ksi	in/in	percent	ksi	in/in/sec	seconds	
Static Tests:[e]									
1	Bronze-brazed bar	121.2	89.0	--	6.5	NA[f]	--	--	Braze joint was broken after bar failed
2	Bronze-brazed bar	121.3	85.4	--	5.5	NA[f]	--	--	Braze joint failed dye penetrant test before bar failed
3	Bronze-brazed bar	118.0	84.0	--	4.3	103	--	--	--
4	Extensively preheated bronze-brazed bar	110.0	83.6	--	3.4	109	--	--	--
5	Extensively preheated bronze-brazed bar	116.0	83.3	--	4.5	114	--	--	--
6	Extensively preheated bronze-brazed bar	112.0	84.5	--	3.5	103	--	--	--
7	As-rolled bar	127.6	84.0	--	12.5	NA[f]	--	--	Bar broke at gripper
8	As-rolled bar	127.6	80.0	--	8.3	NA[f]	--	--	Bar broke at gripper
9	As-rolled bar	127.6	84.0	--	10.4	NA[f]	--	--	Bar broke at gripper
10	Alloy-brazed bar	124.0	84.6	--	7.3	120	--	--	--
11	Alloy-brazed bar	126.6	84.3	--	10.0	116	--	--	--
12	Alloy-brazed bar	120.6	78.0	--	8.9	117	--	--	--
13	Cadweld-spliced bar	134.0	84.8	--	9.3	After failure	--	--	Bar broke 1/2 inch below sleeve
14	Cadweld-spliced bar	128.0	80.0	--	10.0	Passes dye test	--	--	Faulty splice; bar failed 8 inches below sleeve
15	Cadweld-spliced bar	125.0	84.0	--	5.1	After failure	--	--	Bar and splice broke at center of splice
Dynamic Tests:									
214	Bronze-brazed bar	115.7	89.0	0.0051	2.5	--	0.058	0.080	Bar broke, but joint passed dye penetrant test
215	As-rolled bar	127.0	94.0	0.0030	8.5	--	0.050	0.065	Bar broke; dye penetrant test not conducted
216	Bronze-brazed bar	134.0	89.0	0.0031	8.8	--	0.058	0.065	Bar broke, and joint failed dye penetrant test
217	Bronze-brazed bar	134.0	91.0	0.0027	6.5	--	0.040	0.070	Bar did not break, but joint failed dye penetrant test
218	Bronze-brazed bar	144.0	96.0	0.0035	8.4	--	0.057	0.063	Bar did not break, but joint failed dye penetrant test
219	Alloy-brazed bar	132.0	89.0	0.0031	8.8	--	0.061	0.055	Bar did not break, but joint failed dye penetrant test
220	Alloy-brazed bar	131.0	87.0	0.0031	8.8	--	0.060	0.055	Bar did not break, but joint failed dye penetrant test
221	Alloy-brazed bar	128.0	88.0	0.0032	8.6	--	0.060	0.055	Bar did not break, but joint failed dye penetrant test
222	Cadweld-spliced bar	131.0	90.0	0.0033	10.0	--	0.062	0.055	Bar broke at gripper, but joint passed dye penetrant test
223	Cadweld-spliced bar	136.0	90.0	0.0034	9.5	--	0.064	0.055	Bar did not break, and joint passed dye penetrant test
224	Cadweld-spliced bar	135.0	92.0	0.0036	8.3	--	0.067	0.055	Bar broke at gripper, but joint passed dye penetrant test

---

[a] A nominal cross-sectional area of 1.56 in^2 is common to all bars.

[b] All bars showed a pronounced yield point (computed using 0.2 percent offset method presented in Reference 6).

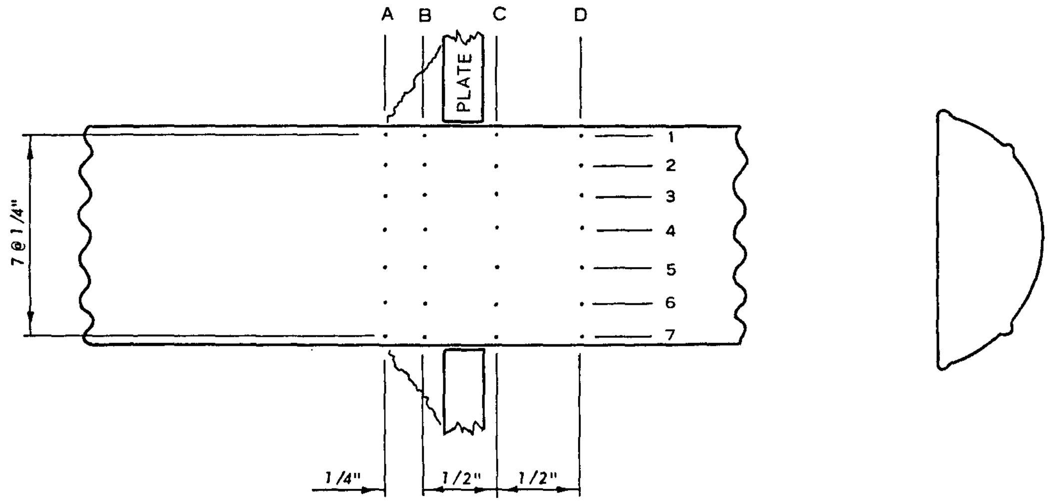
[c] Elongation was measured over an 8-inch gage length except in Tests 222 through 224 in which elongation was measured over a 4-inch gage length.

[d] All broken bars failed at braze joint; all statically tested bars failed.

[e] Static tests were performed at an average time to yield strength of 5 minutes.

[f] NA--not applicable.

TABLE 3.3 RELATION OF ROCKWELL HARDNESS TO TENSILE STRENGTH



Point[a]	Column A		Column B	
	Hardness on Rockwell B Scale	Tensile Strength	Hardness on Rockwell B Scale	Tensile Strength
		ksi		ksi
1	98	111	103	127
2	98	111	100	116
3	98	111	98	111
4	98	111	99	114
5	97	108	97	108
6	96	105	99	114
7	106	138	104	130

	Column C		Column D	
	Hardness on Rockwell B Scale	Tensile Strength	Hardness on Rockwell B Scale	Tensile Strength
		ksi		ksi
1	101	120	91	90
2	101	120	102	124
3	98	111	103	127
4	100	116	99	114
5	99	114	100	116
6	99	114	102	124
7	94	98	104	130

---

[a] See drawing above.

TABLE 3.4 RESULTS OF INDEPENDENT CHEMICAL ANALYSIS

Element	Chemical Composition of Indicated Bars			
	Grade 75[a]	Sample 1[b]	Sample 215[b]	Sample 216[b]
	percent	percent	percent	percent
Carbon	0.40	0.44	0.44	0.44
Manganese	0.93	1.33	1.33	1.34
Phosphorus	0.017	0.031	0.033	0.032
Sulfur	0.029	0.032	0.034	0.032
Silicon	0.32	0.55	0.62	0.62
Nickel	0.07	0.10	0.10	0.10
Chromium	0.88	0.10	0.10	0.09
Molybdenum	0.13	0.01	0.02	0.02
Copper	0.28	0.24	0.24	0.25

[a] Prepared from Laclede steel.

[b] Prepared from North Star steel.

TABLE 3.5 COMPARISON OF TEST RESULTS

Type Sample	Average Elongation	Average Peak Temperature at Gage 1	Average Peak Temperature at Gage 2	Average Brazing Time
	percent	°F	°F	minutes
Static Tests:				
As-rolled bars	10.4	--	--	--
Bronze-brazed bars	5.4	960	550	6
Extensively preheated bronze-brazed bars	3.8	1,215	676	7.3
Alloy-brazed bars	8.7	875	450	5.3
Cadweld-spliced bars	8.2	--	--	--
Dynamic Tests:				
As-rolled bars	8.5	--	--	--
Bronze-brazed bars	7.9	833	516	4
Alloy-brazed bars	8.7	--	--	--
Cadweld-spliced bars	9.3	--	--	--

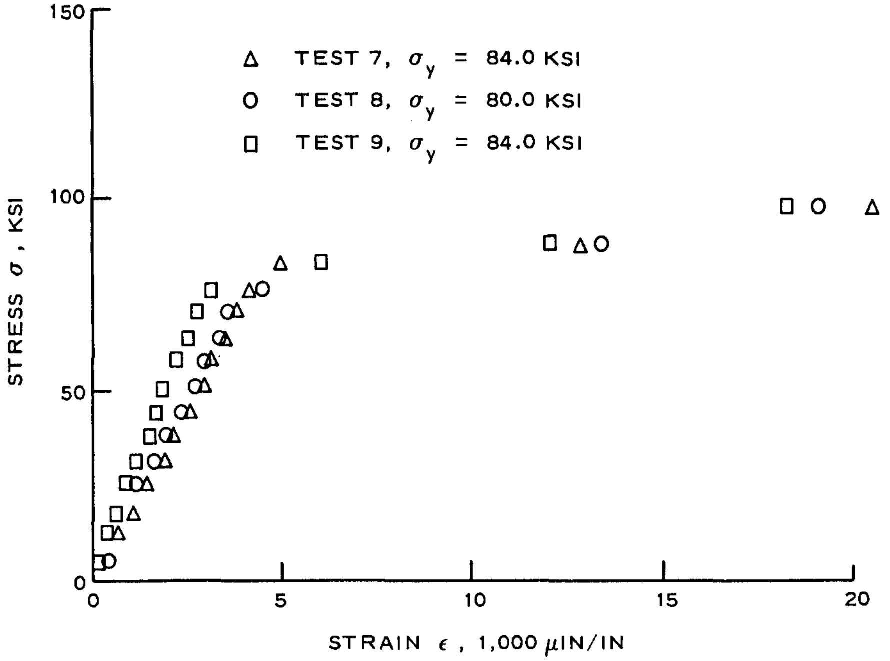
TABLE 3.6 ELONGATION OF CADWELD-SPLICED BARS

Test No.	Elongation of Material	Elongation Across Splice	Test No.	Elongation of Material	Elongation Across Splice
	percent	percent		percent	percent
13	9.3[a]	5.5[a]	222	10.0[c]	4.8[a]
14	10.1[a]	7.9[a]	223	9.5[c]	5.0[a]
15	5.1[a]	NA[b]	224	8.3[c]	4.1[a]
			Average	8.73	5.5

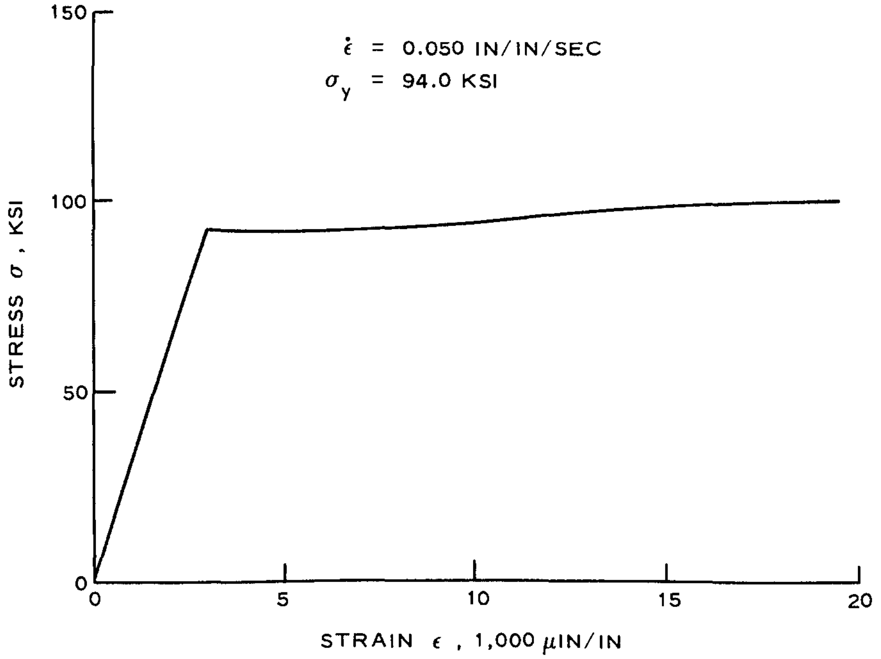
[a] Measured along 8-inch gage length.

[b] NA--not applicable

[c] Measured along 4-inch gage length.

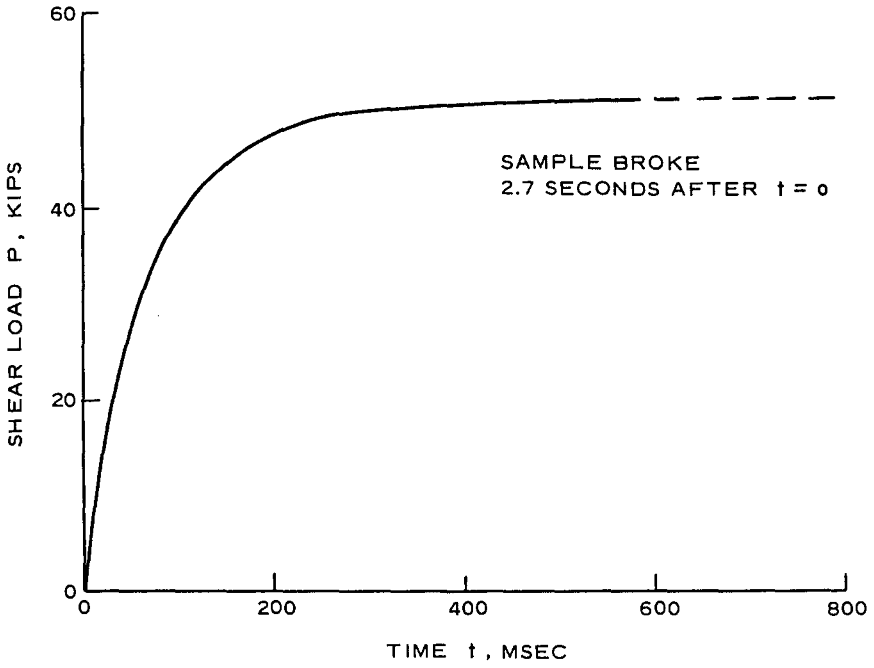


a. STATIC TESTS 7, 8, AND 9

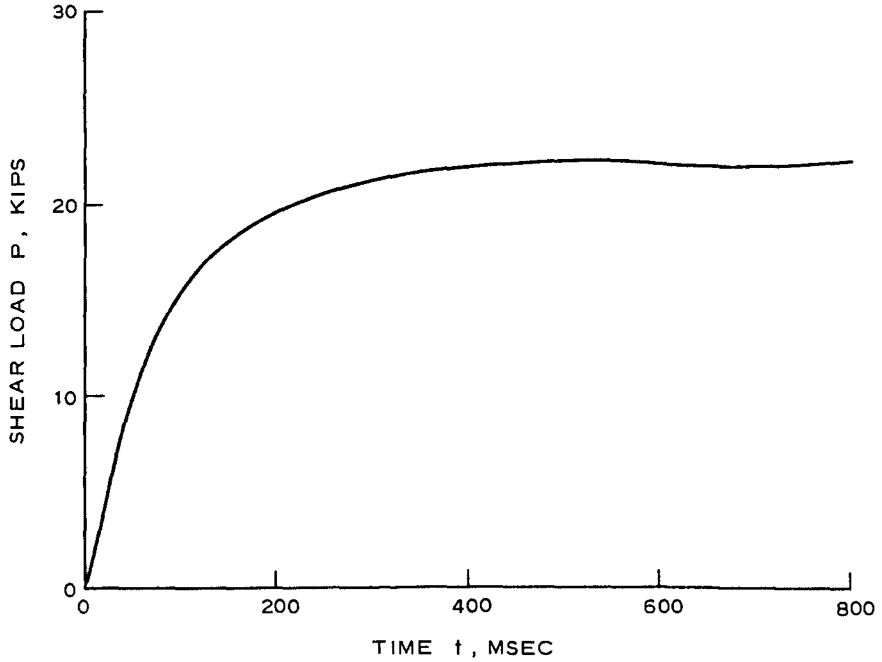


b. DYNAMIC TEST 215

Figure 3.1 Stress versus strain, static Tests 7, 8, and 9 and dynamic Test 215 (as-rolled bars).

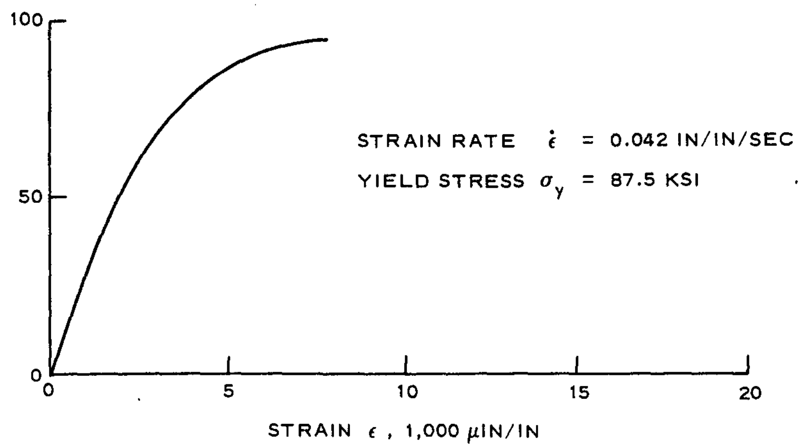


a. TEST 209

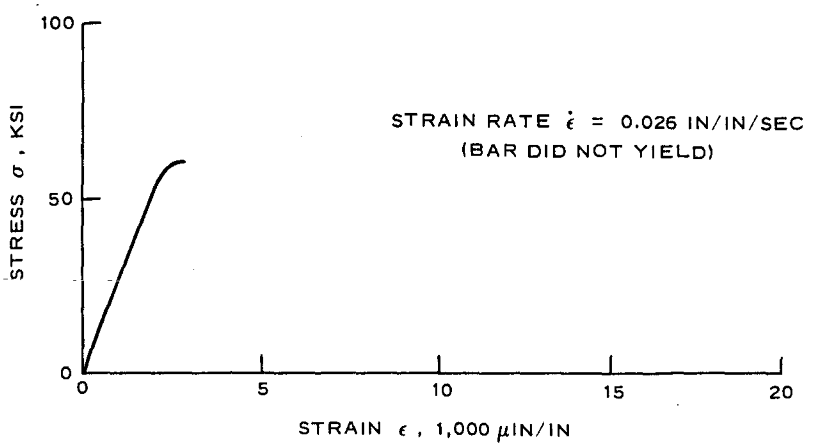


b. TEST 210

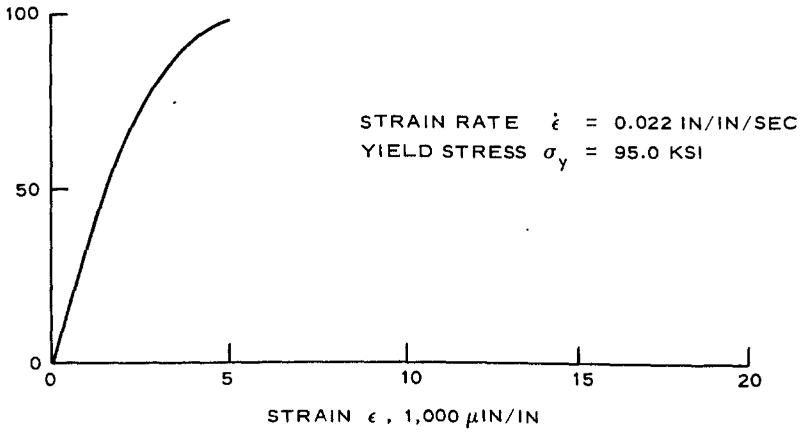
Figure 3.2 Shear load versus time, Tests 209 and 210 (concrete-encased bars).



a. TEST 211



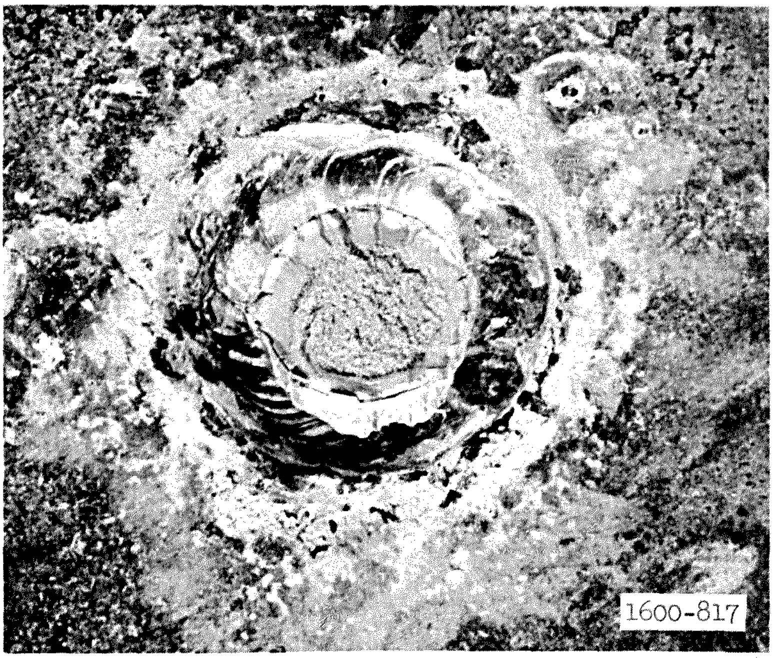
b. TEST 212



c. TEST 213

Figure 3.3 Stress-strain curves, Tests 211, 212, and 213 (concrete-encased bars).

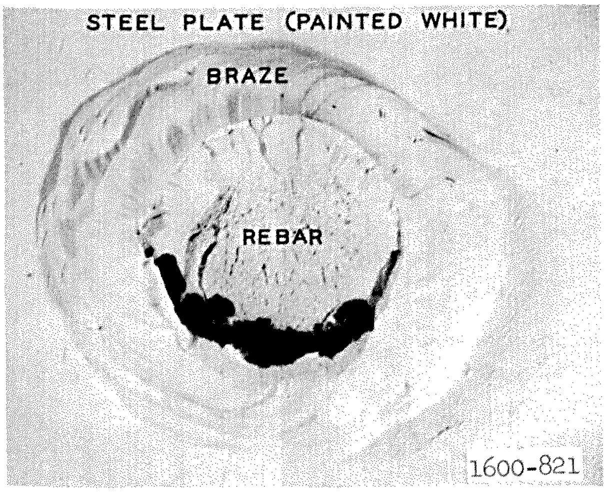
a. Failure on bar side.



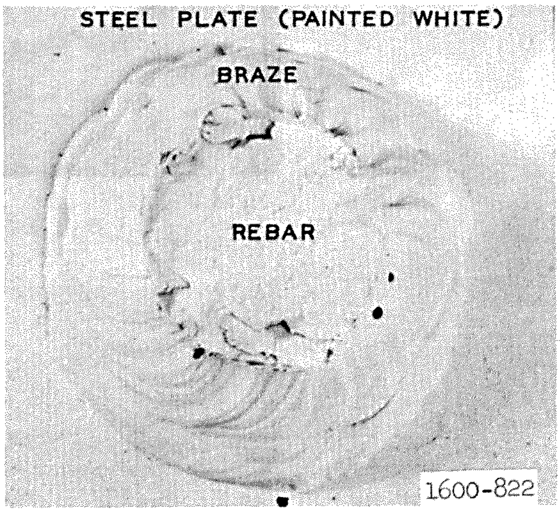
b. Failure on plate side.

Figure 3.4 End views of failed rebar, Test 209 (concrete-encased bar).

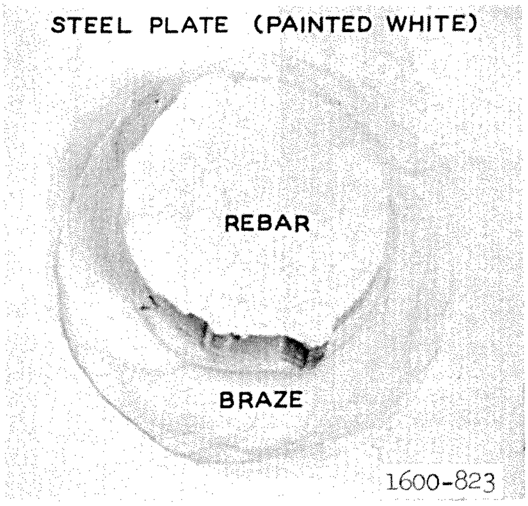
Figure 3.5 Posttest view showing concrete failure that occurred on brazed side of steel plate, Test 209 (concrete-encased bar).



a. Test 209.



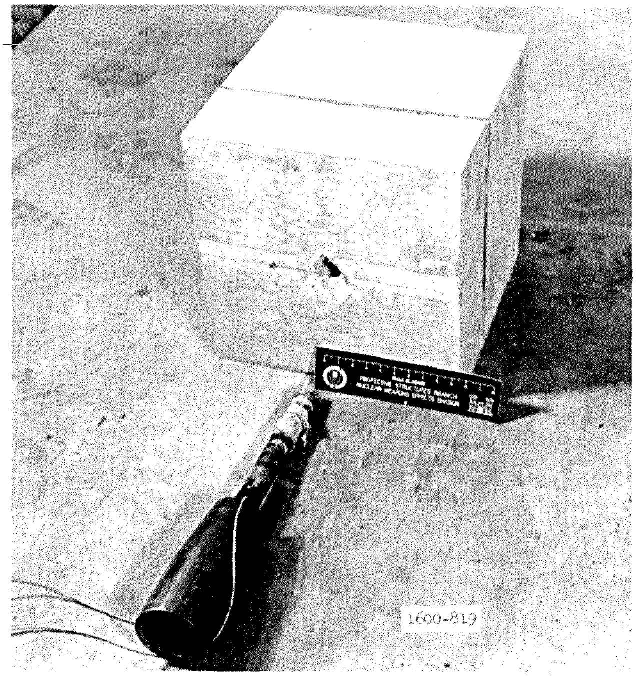
b. Test 211.



c. Test 213.

Figure 3.6 Results of dye penetrant tests conducted after shear Test 209 and pull Tests 211 and 213 (concrete-encased bars). Dark areas are areas where dye has penetrated splice joint.

a. Bar fracture.



b. Failed sample.

Figure 3.7 Bar fracture and failed sample, Test 211 (concrete-encased bar).

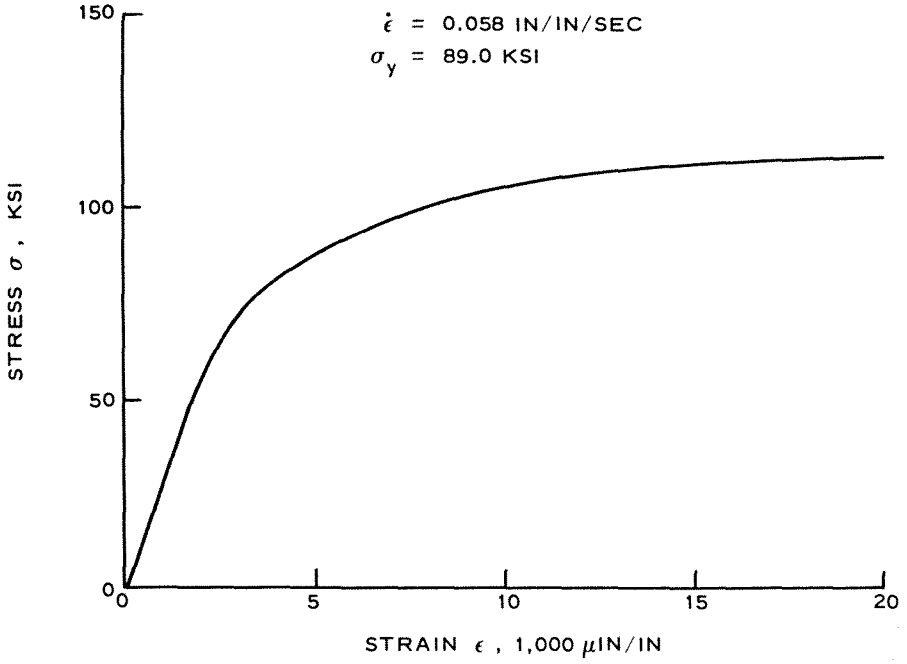


Figure 3.8 Stress versus strain, Test 214 (bronze-brazed bar).

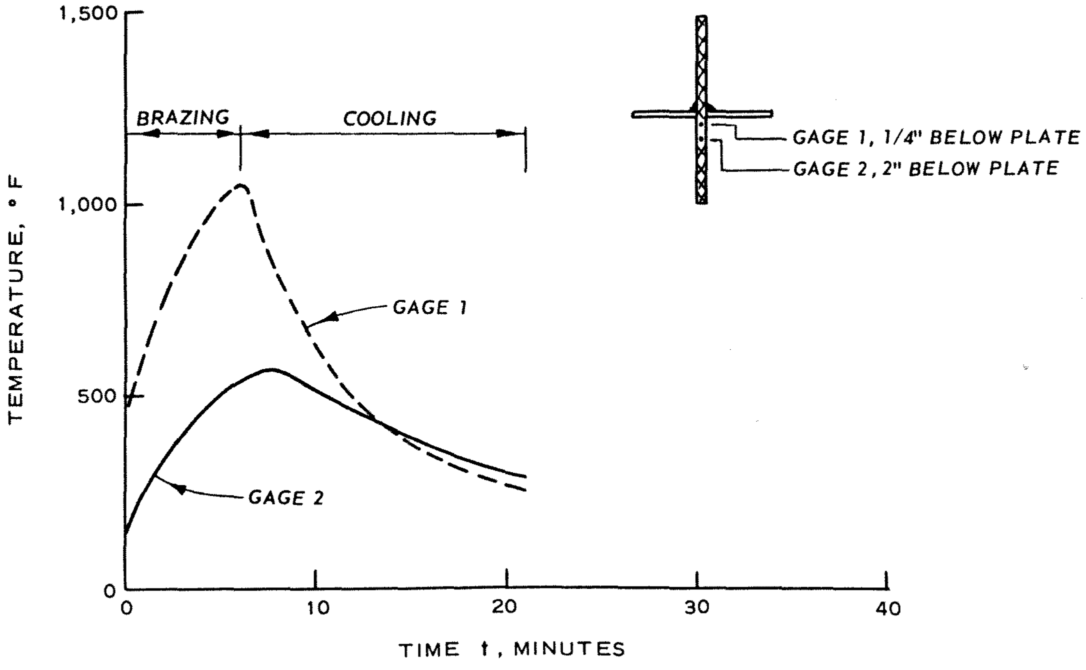
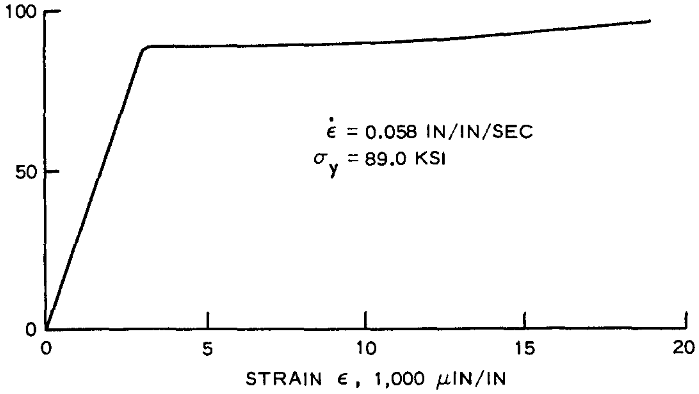
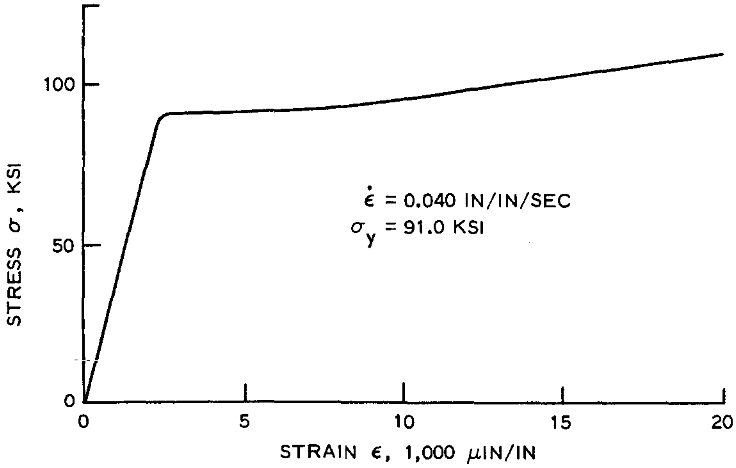


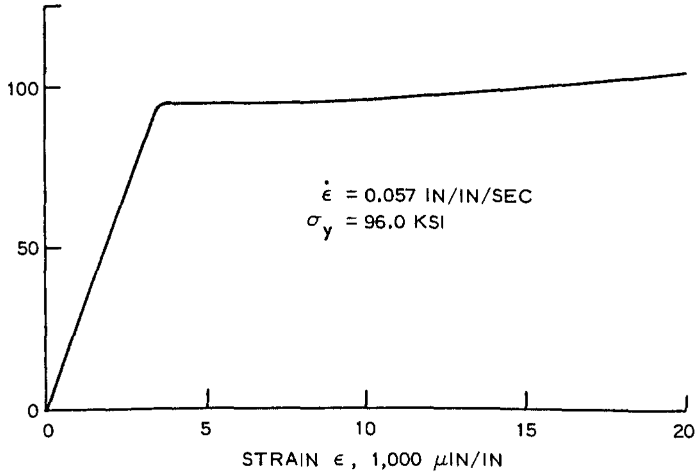
Figure 3.9 Temperature versus time, bronze-brazed bar, Test 3.



a. TEST 216



b. TEST 217



c. TEST 218

Figure 3.10 Stress versus strain, Tests 216, 217, and 218 (bronze-brazed bars).

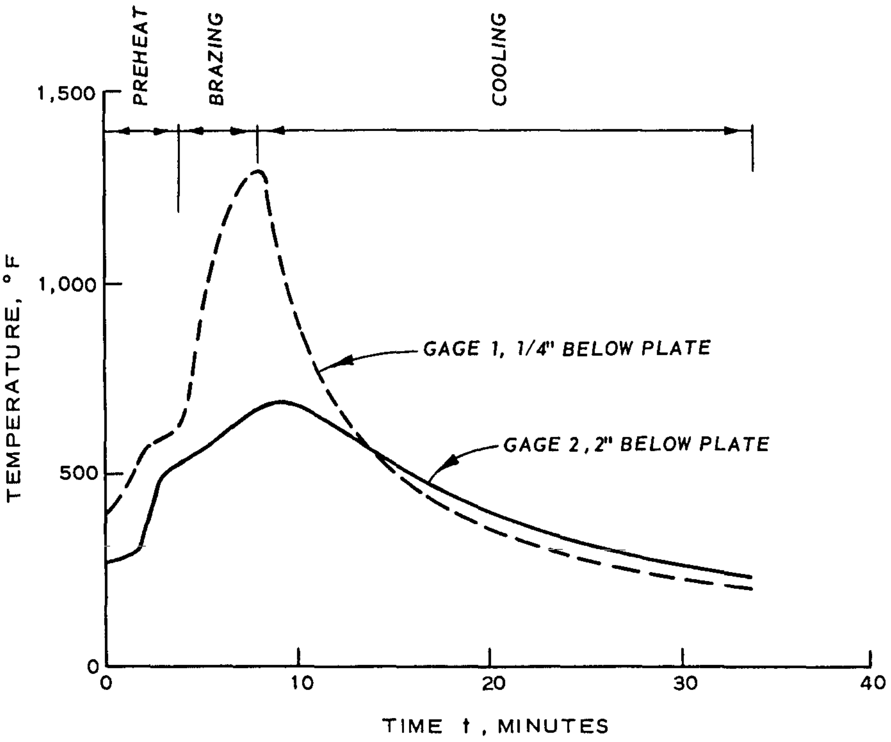
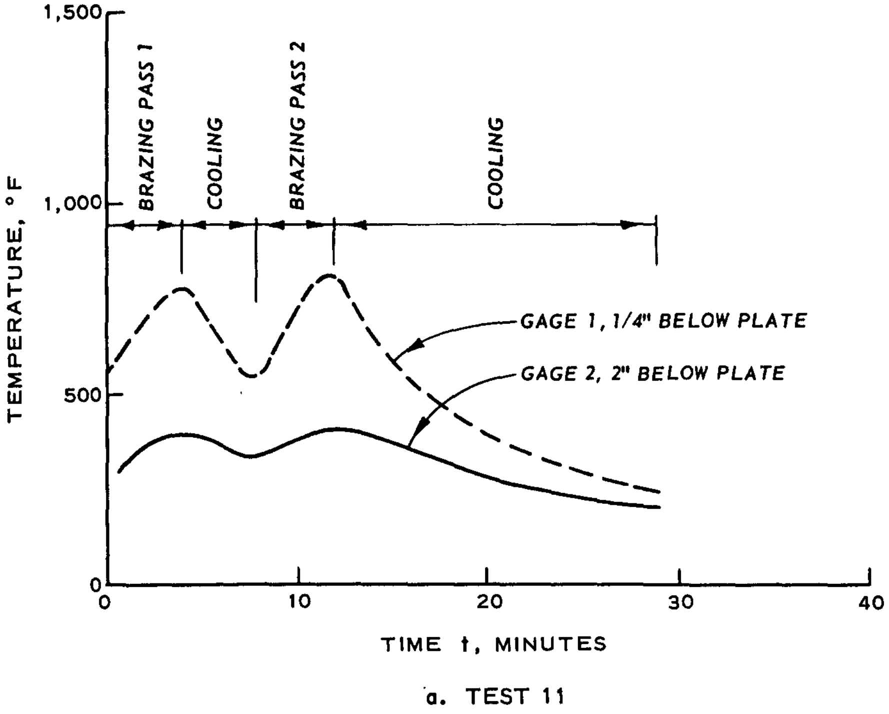


Figure 3.11 Temperature versus time, Test 6 (extensively preheated bronze-brazed bar).



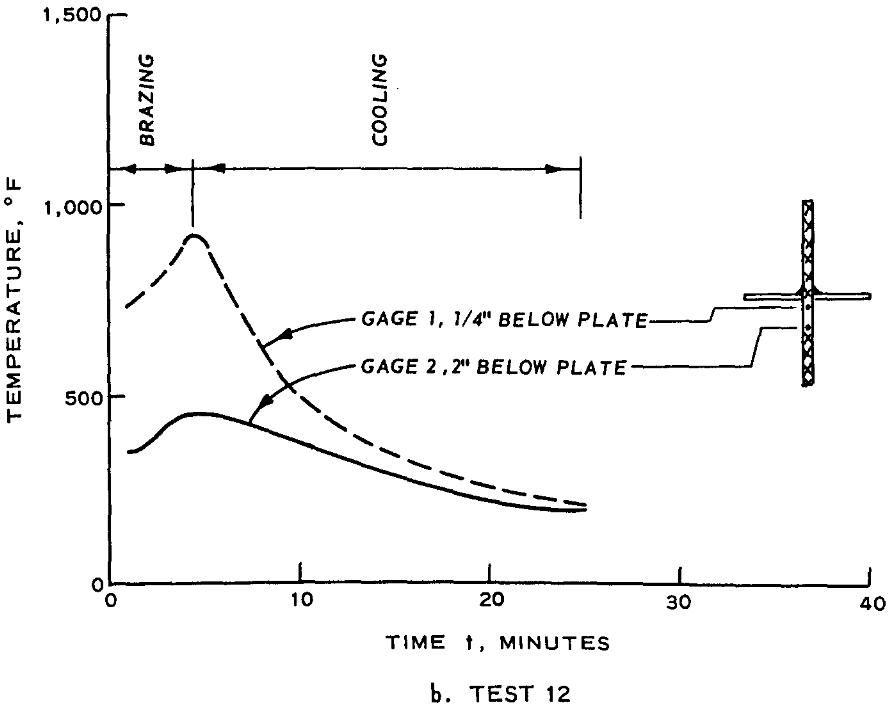
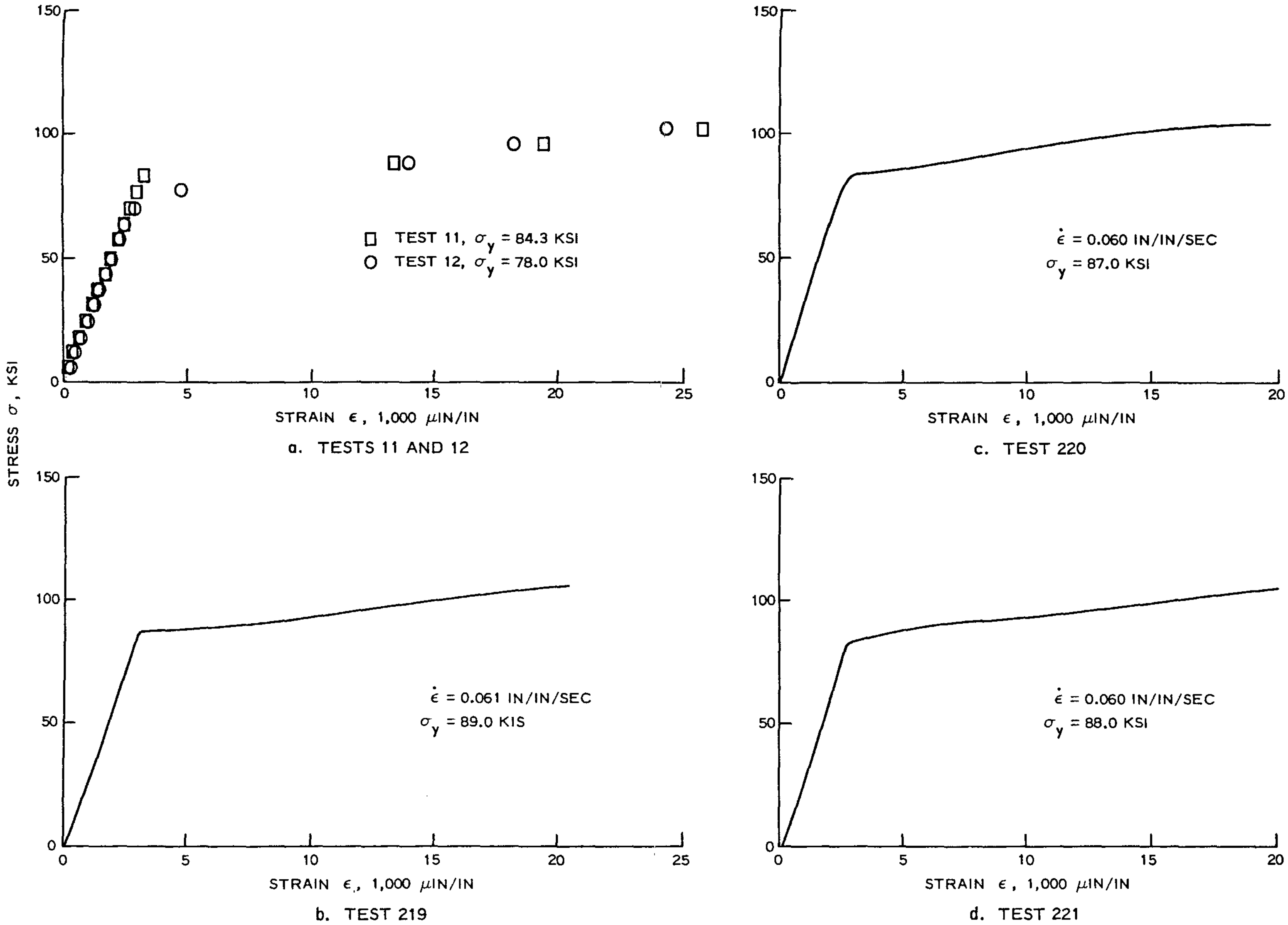


Figure 3.12 Temperature versus time, Tests 11 and 12 (alloy-brazed bars).



a. TESTS 11 AND 12

c. TEST 220

b. TEST 219

d. TEST 221

Figure 3.13 Stress versus strain, Tests 11, 12, 219, 220, and 221 (alloy-brazed bars).

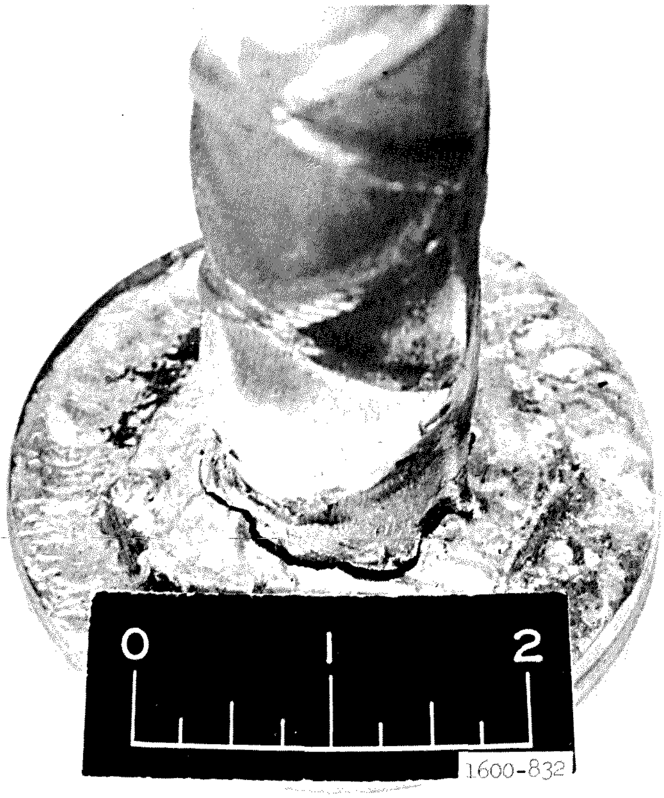


Figure 3.14 Cracked alloy-brazed joint, Test 221.

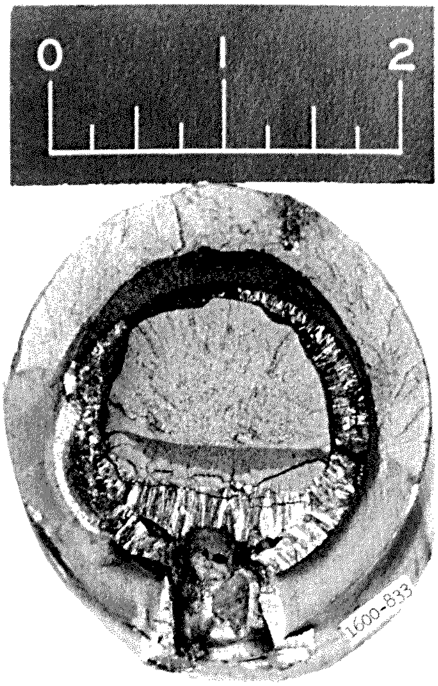
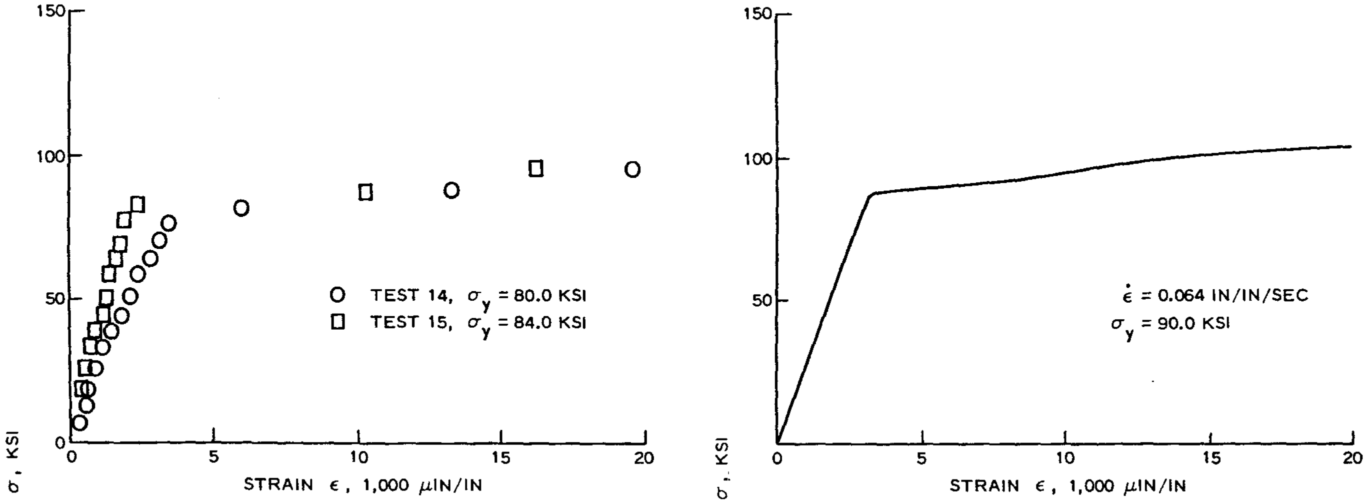


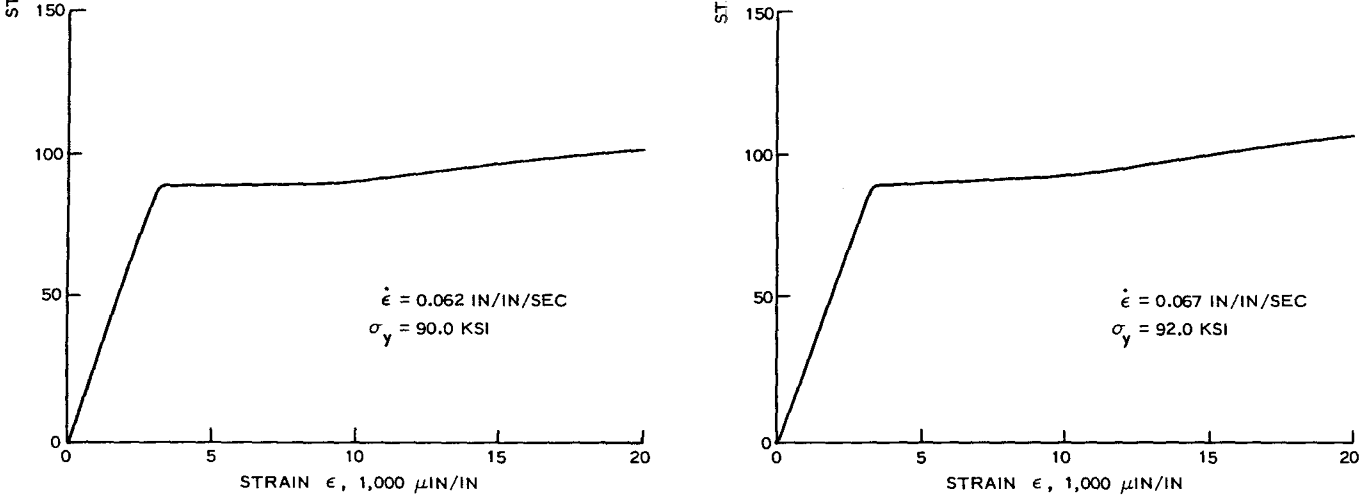
Figure 3.15 Fracture in center of splice sleeve, Test 15 (Cadweld-spliced bar).

Figure 3.16 Separation of joint from Cadweld sleeve, Test 13 (Cadweld-spliced bar).



a. TESTS 14 AND 15

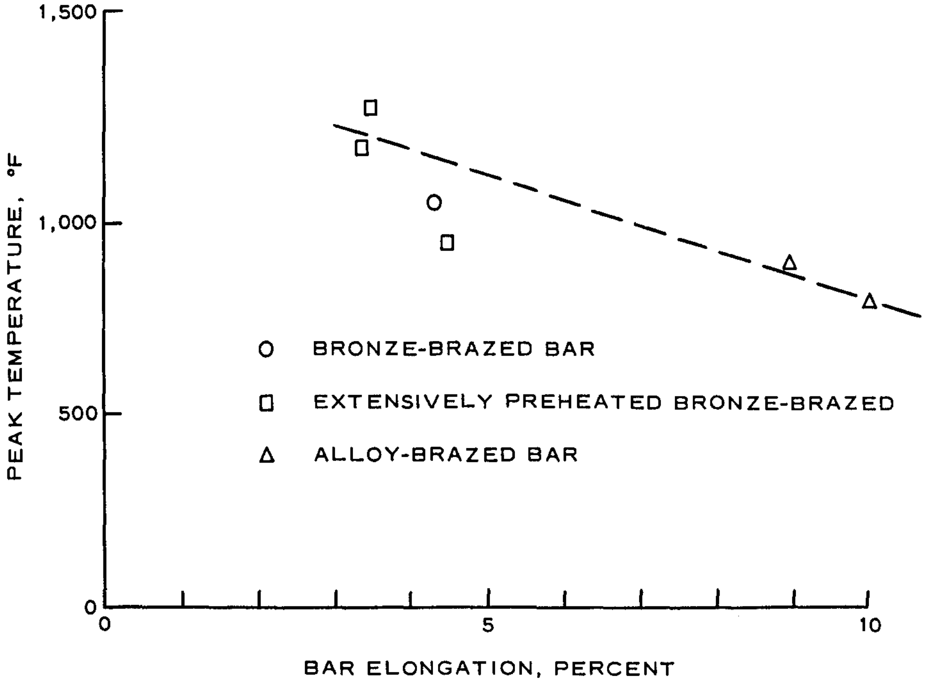
c. TEST 223



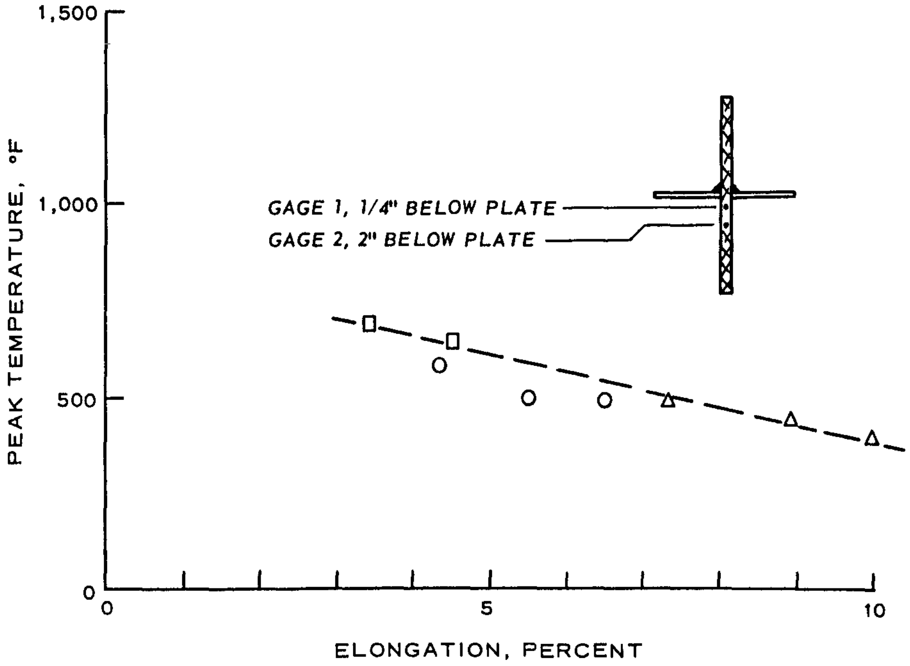
b. TEST 222

d. TEST 224

Figure 3.17 Stress versus strain, Tests 14, 15, 222, 223, and 224 (Cadweld-spliced bars).



a. GAGE 1



b. GAGE 2

Figure 3.18 Peak brazing temperature at Gages 1 and 2 versus final elongation of bronze-brazed, extensively preheated bronze-brazed, and alloy-brazed bars.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Based on the results of this study, the following conclusions are believed warranted:

1. Bronze-brazed reinforcing bar penetrations appear to have sufficient mechanical strength to resist forces of the magnitude expected in a PARB for design loading conditions.

2. Bronze-brazed Grade 75 rebars prepared in accordance with the procedure presented in Appendix A will result in bar elongation in excess of 5 percent before rupture. Hence, these bars as brazed will meet ASTM minimum standards.

3. The Cadweld-spliced samples were capable of the greatest elongations prior to rupture.

4. After a bronze-brazed rebar has been strained approximately 2.5 percent, the brazed joint will fail a dye penetrant test, thus indicating leakage.

5. A Cadweld-spliced joint will leak dye penetrant a few hours after the application of a generous amount of dye.

4.2 RECOMMENDATIONS

Based on the results of this study, the following recommendations are made:

1. The procedures outlined in Appendix A should be followed in order to obtain sound brazed joints. A thoroughly clean surface is critical and the use of sandblasting is recommended as one of the best means of achieving the necessary degree of surface cleanliness. The different deformation patterns in use make cleaning techniques such as wire brushing not universally effective.

2. When it is critical that bar ductilities be greater than

2 percent, the Cadweld-splice method of sealing EMP shield rebar penetrations should be used if experienced welders are not available and quality-control inspection is difficult.

APPENDIX A

PROCEDURE FOR BRAZING A REBAR THAT PENETRATES A STEEL PLATE

A.1 BRAZING ROD

A 1/8-inch-diameter, flux-coated, high-strength bronze brazing rod should be used. The rod (35) manufactured by National Cylinder Gas or similar should conform to specifications AWS-ASTM-RCuZn-C or QQ-R-5712, Type 1, Class FS-RCuZn-2 (Reference 4). The chemical composition is 58 percent copper, 0.9 percent tin, 0.7 percent iron, 0.08 percent manganese, 0.08 percent silicon, and a zinc balance.

A.2 PROCEDURES

Brazing procedures are as follows:

1. Thoroughly clean the surfaces to be brazed and clean off any mill scale on the steel plate. Sandblasting is the best method of cleaning the reinforcing bars.

2. Select a welding tip that produces a semiblunt type of cone; this permits a wide-coverage heat pattern. (The welding tip used in tests conducted at the U. S. Army Engineer Waterways Experiment Station (WES) was a Victor No. 4-T1 tip with a 0.073-inch-diameter orifice.)

3. Adjust the oxyacetylene flame to a neutral type and adjust the volume of gas to produce a soft flame. A harsh, blast-type flame is injurious to bronze and forms deposits that are difficult to control.

4. Heat the bar and plate in the area to be brazed, maintaining an even heat distribution around the bar. When the heated bar becomes blood (dark) red, melt some flux from the rod onto the base metal in the joint area.

5. Heat the base metal around the flux deposit, but avoid playing the flame directly on the deposited flux. When the heat of the base metal causes the flux to melt, employ the flame to deposit a drop of the alloy onto the plate.

6. Deposit metal on the joint while playing the torch across the deposited metal in a weaving motion. Point the rod in the direction of

travel. Watch the deposit, and dip the rod in and out of the molten pool so that additional alloy will be fed into the joint evenly and in constant supply.

7. While building up the bronze joint, focus the welding tip so as to establish the heat source in the 1/4-inch-thick plate as much as possible. Keep the temperature in the bar as low as possible, but maintain a good band of heat around the bar. If a medium reddish glow exists in the bar material immediately above the deposited alloy, then the temperature of the bar is greater than necessary. Several trial welds may be necessary for a welder to develop the technique.

8. Use as small a fillet joint as possible (a 3/8- by 1/2-inch fillet was used at WES). If a larger fillet is necessary, two passes should be used.

9. If two brazing passes are necessary, allow 5 minutes between passes for the rebar to cool.

10. Complete each brazing pass in 4 minutes or less.

APPENDIX B

ADDITIONAL STATIC TESTS

Three additional static tests were performed on Cadweld-spliced samples. These samples were prepared in a manner similar to that described in Section 2.2.5, but the steel plates were manually shielded metal, arc-welded to the Cadweld splices rather than brazed. Samples 1 and 3 were welded with a low-hydrogen electrode (trade name Speedex HTS), AWS classification E 7018, at 25 to 80 volts dc and 190 amperes. Sample 2 was welded with an AWS E 6011 electrode (trade name Fleetweld No. 35) at 25 to 80 volts dc and 145 amperes.

Temperature measurements were made on the rebars during the splicing operation. The temperature-sensing thermocouple was placed on the rebar at the end of the Cadweld sleeve and under the asbestos packing. During the splicing of the Cadweld sleeve, a maximum temperature of 500 F was measured on the rebar. All of the Cadweld splices seemed to be sound. A dye penetrant check was performed on the completed samples prior to conduct of the tension test. Approximately 2 hours after the application of a generous amount of dye penetrant, leaks between the Cadweld splice and the rebar were observed on all three samples, as shown in Figure B.1. The dye did not penetrate the welded connection between the sleeve and the steel plate. The plate-splice connections also remained sound after the tension tests of the bars. The strain measurements presented in Figures B.2 through B.4 were recorded from two strain gages mounted on the rebars. The strain measurements presented in Figure B.5 were recorded with an 8-inch-long mechanical extensometer. A summary of these test results is presented in Table B.1.

TABLE B.1 RESULTS OF TENSION TESTS ON ARC-WELDED CADWELD SPLICES

Test No.	Maximum Stress[a] σ_m	Yield Stress[b] σ_y	Final Elongation of Bar[c]	Final Elongation Across Splice[c]
	ksi	ksi	percent	percent
1	119.5	76.0	8.7	5.0
2	125.8	83.3	9.2	4.0
3	124.3	83.0	8.7	5.8

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[a] A nominal cross-sectional area of 1.56 in^2 is common to all bars.

[b] All bars showed a pronounced yield point.

[c] Elongation was measured over an 8-inch gage length.

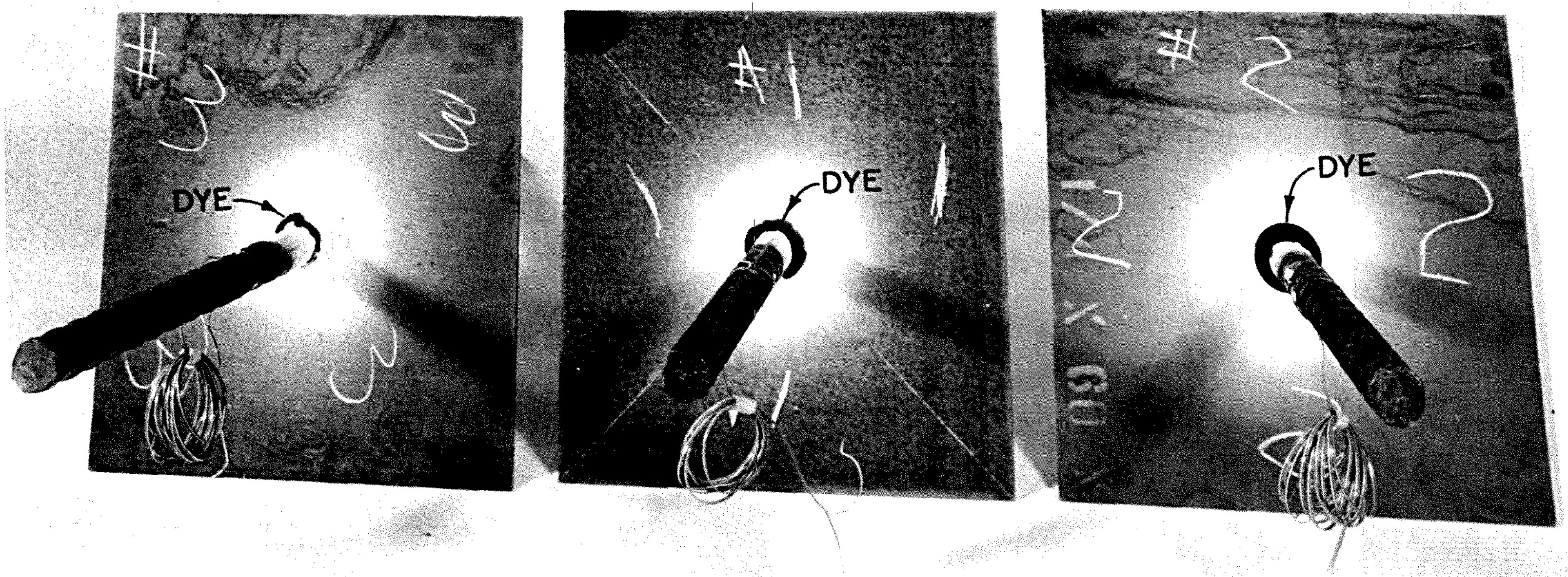

Figure B.1 Dye penetrating arc-welded joints of samples prior to tension tests.

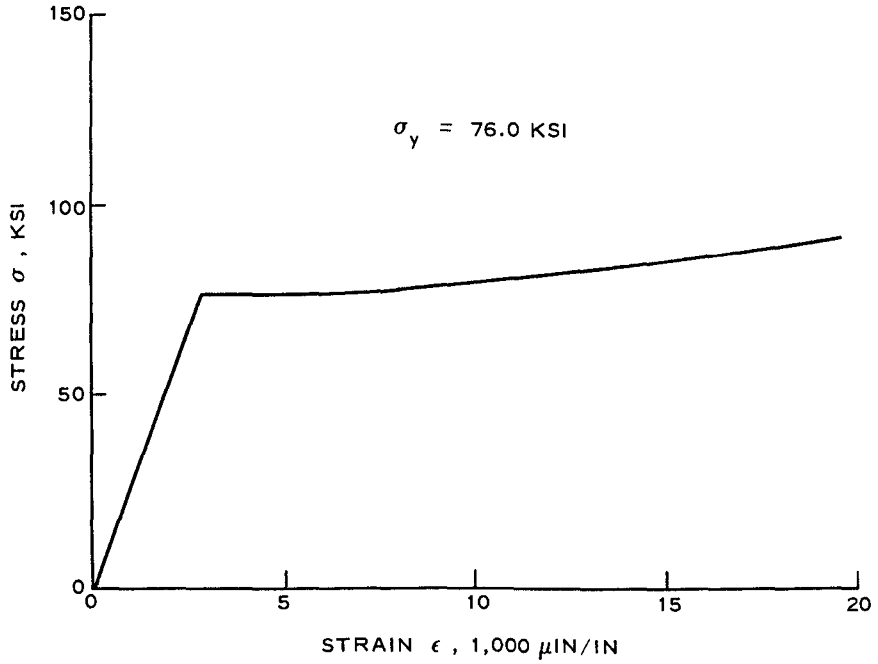

Figure B.2 Stress versus strain, static Test 1 (arc-welded Cadweld splice). Measurements recorded from two strain gages.

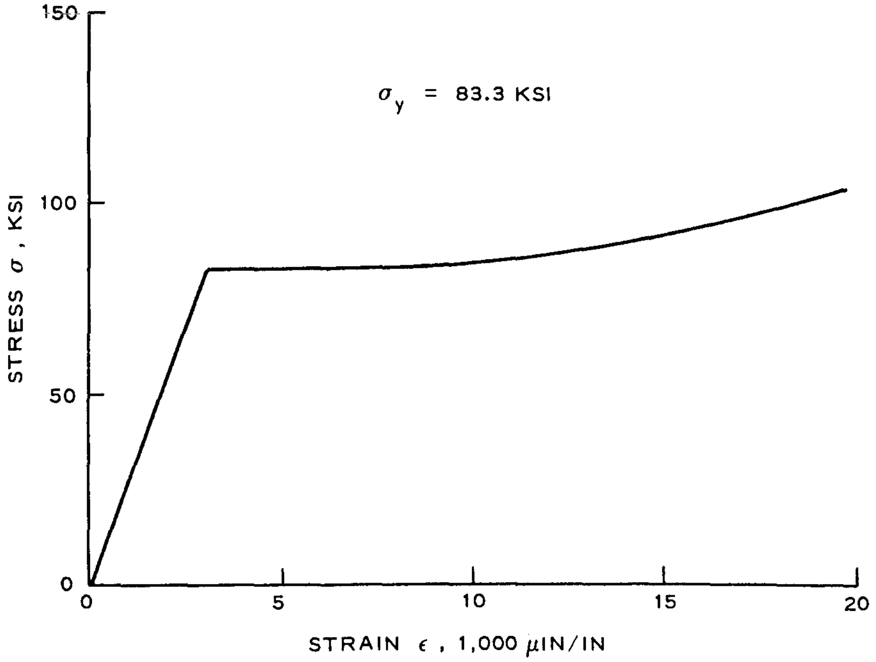

Figure B.3 Stress versus strain, static Test 2 (arc-welded Cadweld splice). Measurements recorded from two strain gages.

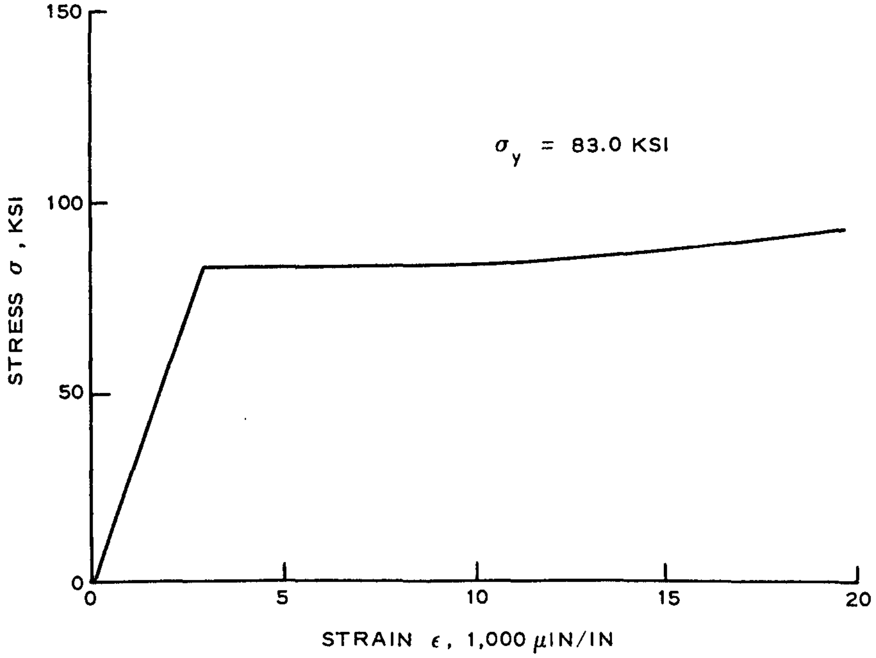

Figure B.4 Stress versus strain, static Test 3 (arc-welded Cadweld splice). Measurements recorded from two strain gages.

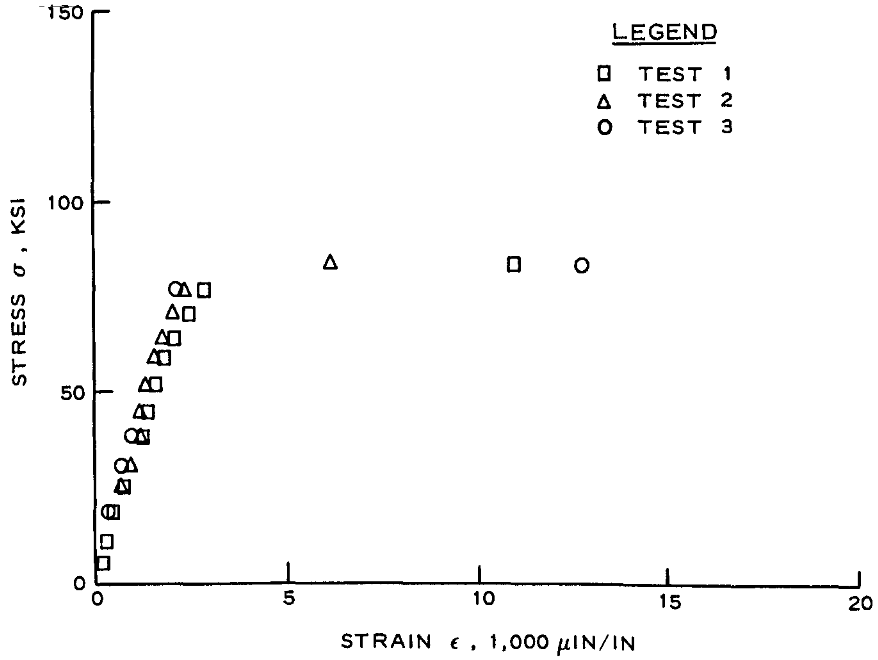

Figure B.5 Stress versus strain, static Tests 1, 2, and 3 (arc-welded Cadweld splices). Measurements made with 8-inch-long extensometer.

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13. ABSTRACT

The objective of this study was to determine whether bronze brazing could be used to seal steel reinforcing bar penetrations through the electromagnetic pulse (EMP) shields of Perimeter Acquisition Radar Buildings (PARB) when such seal joints are required to withstand design loads without degradation of the EMP shielding properties or of the mechanical properties of the reinforcing bars. Initially, five tests were performed on three concrete-encased bars that represented full-scale penetrations of reinforcing bars (No. 11, Grade 75) through 1/4-inch-thick steel plates that represented the EMP shield. After completion of each test, the concrete was removed from the brazed joint, and dye penetrant was used to examine the joint for cracking. During this initial series of five tests, it became evident that a significant degradation in bar ductility had occurred as a result of the brazing process. Consequently, 26 tension tests were performed on No. 11 bars with a 1/4-inch-thick steel plate attached by four different methods, i.e. bronze braze, preheated bronze braze, alloy braze, and Cadweld splice, to determine a brazing technique that did not degrade bar ductility. All samples were tested at static or dynamic (intermediate) loading rates. The time to yield at the intermediate loading rate was about 0.10 second (approximately 0.08 in/in/sec). Transient load and strain measurements were recorded during the tests. The results of the full-scale penetration tests indicated that it is possible for a brazed penetration of the type tested to withstand shear and tensile loads of a magnitude expected in a PARB. The test results, however, indicated that the brazing process caused a significant reduction in the ductility of the reinforcing bar. All tension-tested samples exceeded the American Society for Testing and Material's minimum requirements for tensile and yield strength; however, the test results indicated that brazing of the Grade 75 reinforcing bars can result in a considerable loss of ductility (elongation at rupture being less than 1 percent) if during brazing the temperature is excessive. If the brazing procedure outlined in Appendix A is used by an experienced and certified welder, bar elongations greater than 5 percent can be obtained. The Cadweld-spliced samples produced the greatest final elongation (8.5 percent). Test results showed that the brazed joint between the bar and plate leaked dye penetrant at approximately 2.5 percent bar elongation. Thus, it is possible that the EMP shielding properties will be significantly degraded at bar elongations above 2.5 percent.

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