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Button Welding for Structural Steel Connections

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BUTTON WELDING FOR STRUCTURAL

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This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and acceptable as meeting the thesis requirements for this degree; but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Advisor

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INTRODUCTION

Structural steel joints in bridges and buildings have considerable effect upon the costs of fabrication and erection. In the past, rivets were considered reliable and could be easily tested for satisfactory performance. Riveted joints require large amounts of equipment and skilled workmen. Noise created by riveting processes is very objectionable.

Some structural connections have been bolted; but, until recent years, there has not been a fully reliable bolted joint. The development of special bolts coupled with controlled torque wrenches have made structural bolting feasible.

Welding is also used, but field welding is subject to many uncertainties. Welder operators must be highly skilled individuals and are required to be certified.

Recently there has been developed a carbon-dioxide-shielded arc welding process which utilizes pure dry carbon-dioxide gas as a shielding medium around an arc established between the work piece and a bare wire electrode. The electrode is fed continuously into the molten arc weld pool with high current density. With the addition of a cycle timer and specially designed nozzle fittings, this equipment produces "button welds" of quality at a high rate of production. The consumable electrode, which adds filler metal to the weld, leaves the finished weld with a rivet-like head or "button" appearance.

This thesis concerns the investigation of single button welded lap joints utilized to join two specimens of structural steel. More

specifically, it reports on the static load-carrying capabilities of this type joint. The objectives of this study are: (1) to study the button welds produced by carbon-dioxide shielded metal arc welding equipment, (2) to determine the static strength characteristics of button welds, (3) to determine whether these welds can be considered statically reliable for structural applications.

Research, in line with these objectives, was conducted in connection with the effect of the various electrical controls of the equipment on the weld strength. Essentially, this included a series of shear tests with all joints being made at 208 volts input to the equipment utilizing 1/4 inch thick material. Two other series of tests with 230 volts input were also conducted utilizing 3/16 inch and 1/4 inch thick material. Riveted joints in like material were tested for comparison with the button welded joints. Tension tests on the button welds comprised another series. Several joints were sawed transversely, polished, and etched. Photomicrographs were taken, with Rockwell hardness tests being made on the weld cross section. All data obtained are set forth in Tables I through XI. Figures 12 through 21 give a graphical representation of the tests conducted. From the test data, it is apparent that button welds can be made with considerable consistency and that the feasibility of button welded joints in structural steel is a possibility.

DEFINITION OF TERMS

In all technical reports the use of certain words and phrases is necessary to describe certain qualities of the observed phenomenon. The following terms will be used throughout the remainder of this thesis without subsequent explanation.

Arc welding - A non-pressure or fusion welding process wherein the welding heat is obtained from an arc between the base metal or weld metal and the electrode.

Arc weld pool - The molten metal pool surrounding the electrode during the welding operation.

ASTM - American Society for Testing Materials.

Bare electrode - A metal electrode with no coating or with a light coating that is incidental to the drawing of the wire.

Button weld - A finished weld that resembles a button or rivet head.

Constant potential welding equipment - Equipment which makes use of a relatively flat volt-ampere curve wherein a small change in arc length (and arc voltage) will cause a large change in current and burnoff rate.

Contact tube - A replaceable metal tube mounted in the welding gun to provide electrical contact to the wire electrode and guide the electrode to the weld area.

CO_2 welding process - An arc welding process wherein coalescences are produced by heating with an electric arc between a metal electrode and the work. Shielding is obtained by introducing CO_2 gas around the electrode as welding progresses.

<u>Duty cycle</u> - The percentage of a ten minute period that welding equipment can operate at its rated current without exceeding proper operating temperatures.

<u>Faying surface</u> - That surface of a member which is in contact with another member to which it is to be joined.

<u>Heat affected zone</u> - That portion of the base metal which has not been melted, but whose mechanical properties or microstructures have been altered by the heat of welding.

<u>Lap joint</u> - A joint between two overlapping members.

<u>Manifold</u> - A multiple header for connecting several CO_2 cylinders to CO_2 welding equipment.

<u>Quenching</u> - Rapid cooling by immersion in liquids or gases, or by contact with metal.

HISTORICAL REVIEW OF IRON AND STEEL FABRICATION

The nineteenth century was predominantly a transportation century, with the railroad greatly influencing man's progress. The major engineering triumphs were in railroad location and railroad bridges.[1] Prior to this period, in the late eighteenth century, a comparatively untried material, iron, began to replace wood and stone in bridge structures. The first iron bridge of record was a cast iron arch design which was erected in 1779 at Ironbridge, England. Although the stone masonry arch was superior in beauty and durability, the metal bridge gave greater strength in proportion to the weight of the structure, and it was capable of being built more quickly and economically. Accordingly, being better adapted to keep pace with the accelerated activity of railroad construction, it began to supplant the stone and wooden structures almost entirely. Wrought iron was first used in this country for vertical tension members of the "Howe" truss in 1840, and in inclined tension members of the "Pratt" truss about 1845. The use of wrought iron tension members with wood or cast iron compression members continued until about 1860 when the riveted lattice bridge, built entirely of wrought iron, was introduced. In rapid succession other types of truss design followed.

Perhaps the most significant step leading to more economical design was the development of a rational method of truss analysis by Squire Whipple in 1847. This initiated a modern era of bridge analysis and

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[1]J. K. Finch. "A Hundred Years of American Civil Engineering, 1852-1952," Transactions, vol. CT, 28-96, American Society of Civil Engineers: New York, New York, 1953.

design. This made possible, for the first time, the computation of stresses for assumed loads with truss members designed accordingly.

With the advent of the Bessemer process in 1860, steel, which had been considered uneconomical, became plentiful. This made it possible to fabricate trusses with members of rolled steel. History relates that the first all steel bridge was constructed over the Missouri River at Glasgow, Missouri, in 1879.[2] Thereafter steel railroad bridges became common throughout the United States, practically all spans being built on the general lines of the "Pratt" truss, with vertical compression members and inclined tension members, or, on the lines of the "Warren" truss, with all main web members inclined. However, in recent years the constantly increasing weight of the rolling stock in use has tended toward the use of heavier and more rigid structures with long panels and as few members as possible, more substantial details, solid floors, and stiff lateral and vibration bracing.

Structural steel, with a safe working strength 20 per cent greater than wrought iron, came into general use about 1890. In less than five years, it was used exclusively for bridges.

> The rapidly increasing capacity of American bridge-building shops and their ability to fabricate and handle single members of sizes impossible to obtain a few years ago, has enabled the American engineer to design bridges with practically no shop limitations, and he has thus been free to make designs solely with the idea of producing a structure with the maximum strength and rigidity and the minimum weight of material.[3]

The members of a truss are designed to resist forces or loads

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[2]Ibid.

[3]Henry W. Hodge, "Railway Bridge Designs," The Encyclopedia Americana, vol. 4, 520, Americana Corporation: New York, New York, 1946.

which it supports. These loads tend to lengthen or shorten the members. A truss member, resisting a tendency to lengthen, sustains a stress known as tension, while one resisting a tendency to shorten sustains a stress known as compression. The structural joints must be designed to resist shear, that is, the tendency of a member to pull away from or slide through the joint.

In the early days of steel bridge construction, the pin connected structure was the more suitable for all but the shortest spans. However, as locomotives became heavier and faster and haulage increased, it became evident that pin-connected trusses were "loose-jointed" and subject to excessive vibration.[4]

Riveted wrought iron beams were used as early as 1831.[5] Riveted joints also became common in trusses after 1860. Riveted trusses have their members joined together directly by rivets, or by means of joining each member to a common special connecting plate, or plates, known as gusset plates. Such a joint has great stiffness which gives the structure considerably more rigidity than pin-type connections.

The application of welding to mass production of machines, structures, and equipment dates only from about the time of World War I. During this period arc welding, although discovered in 1887, was used by the United States Navy to salvage the wrecked machinery of German

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[4]Finch, loc. cit.

[5]Richard Kirby and Philip Gustave Laurson, Early Years of Modern Civil Engineering: Yale University Press, New Haven, Connecticut, 1932.

ships. The importance of structural welding to the Navy can be seen in its reliance upon arc welding for ship construction. In the construction of steel ships, welding has largely replaced riveting. During World War II, it was stated in a report to the Secretary of the Navy--"that without welding it would have been impossible to build in such a short time, the enormous fleet of ships which played such a vital part in winning the war."

Shortly following 1920, there were introduced into this country from Europe special electrodes that produced far better results than the previous bare metal electrodes. These electrodes consisted of a metal rod coated with a material to provide arc stabilization and improve the quality of the weld metal. Such electrodes have been steadily improved to the present day. They make possible greater welding speed, higher weld strengths, and improved operator efficiency.[6]

Immediately following World War II, after considerable effort by the welding industry, inert-gas-shielded metal-arc welding was introduced. This process utilized a consumable metal electrode, with the gas shielding introduced through an inverted cup around the electrode. Initially, either argon or helium was used as the shielding gas. It was found that this type of shielding protected the electrode, the arc stream, and the molten metal from the adverse effects of oxygen and nitrogen in the air. More recently, however, carbon-dioxide has been

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[6] W. J. Chaffee, Practical Arc Welding, Hobart Trade School, Incorporated: Troy, Ohio, 1942.

utilized as a shielding agent.[7] The advantages of this process are as follows: (1) high quality weld metal, (2) high rates of deposition, (3) deep penetrating arc, (4) open and visible arc, and (5) ease of adaption to button welding.

The new button welding process is a precision method of welding. It is now being used to replace or augment resistance spot welding or riveting in light gage material. It has extensive usage in turning out components for the automobile industry. With the new button welding methods, one plant makes five welds in a small area on thin gage material to fasten a reinforcement bracket. On another job, an operator button welds a cover plate to a control arm at a rate of 4800 pieces per shift, compared to a former 2200 pieces with manual arc welding. Reliability of weld quality, even on uncleaned steel; extreme flexibility; and low cost of operation make button welding a valuable new high speed production tool. This would seem to indicate that application of this type of welding has some potential in the fabrication of light-weight structural steel.

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[7] R. J. Keller, "Carbon-Dioxide-Shielded Metal-Arc Welding of Carbon Steel Plate," Welding Journal, vol. 38, American Welding Society: New York, New York, January, 1959.

EQUIPMENT AND MATERIAL USED

Constant Potential Welder with C-O Manual Attachments[8]

This unit consists of an A. O. Smith Model A6000CP Constant Potential welder complete with C-O Manual equipment as shown in Figure 1. The welder is rated at 600 amperes at 40 volts output and 100% duty cycle for automatic and semi-automatic use. It features a 0 to 50 volt output range with built-in 230/110 volt power supply and superior voltage regulation. Further, as opposed to conventional arc welders, it provides constant voltage with variable current depending upon the arc length utilized. By merely shortening the arc length, the operator can increase considerably the amount of weld metal laid down.

The C-O Manual equipment consists of the following: an electrode wire drive unit which contains all the necessary circuit controls and the wire drive motor; a lightweight well-balanced hand gun for easy welding operation; and a button weld attachment which produces timed welds with speed and quality.

The wire drive unit contains the wire drive motor, gas and water solenoid valves, pressure switch, purge timer, and control relay. The wire drive motor speed is electro-mechanically controlled by a heavy duty governor which compensates for normal voltage variation and load conditions. Wire speed settings are changed manually by moving the wire feed speed dial to the desired setting which indicates the speed of wire in inches per minute. The speed dial indicates approximately the welding

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[8]A. O. Smith Corporation, Operator's Manual for C-O Manual, A. O. Smith Corporation: Milwaukee, Wisconsin, 1959.

current when using 1/16 inch diameter electrode wire, and it can be varied from 120 inches up to 620 inches per minute. This approximates a variation from 120 to 620 amperes.

The flow of gas and water to the welding hand gun is controlled by electrically operated solenoid valves. These valves are energized and opened on the start of a weld cycle. The valves remain open after the finish of a weld cycle to purge the weld area with carbon-dioxide gas and continue the flow of cooling water through the hand gun nozzle for approximately five seconds.

The pressure switch and its normally open contact prevents the start of a weld cycle unless the water supply has been turned on and the water pressure is 25 pounds per square inch. The minimum flow of coolant required to cool the gun and power cable assembly is one pint per minute.

A thermal type time delay relay is used to time the five second purge cycle at the finish of each weld.

The control relay is energized when the welding gun trigger is depressed. Its purpose is to control properly the wire drive unit, water solenoids, and purge timer.

The hand gun assembly includes the hose and wire feed cable. The gun is lightweight, well-balanced, and its pistol grip design provides good control and arc visibility. Replacement of the contact tube and nozzle tip can be made quickly and easily.

The contact tube shown in Figure 1 provides electrical contact between the power source and the welding electrode wire within the

confines of the hand gun itself. Such contact tubes are required to be clean and smooth in order to provide good electrical contact and minimum friction to the feeding of the wire.

To prevent freeze-up of the regulator, carbon-dioxide gas is supplied from dually manifolded CO_2 gas cylinders as shown in Figure 2. CO_2 gas used in welding must be welding grade, which has a controlled low moisture content. Excessive moisture causes porosity in the weld metal.

The button weld attachment consists of a cycle timer that is installed on the wire drive unit and several button weld nozzles which can be fitted to the hand gun for all common joint designs. The cycle timer can be set to the number of cycles desired for a given weld. The number of cycles divided by 60 represents the time setting in seconds.

Operator skill or training is not necessary to make consistent, reliable button welds. The operator merely places the nozzle of the hand gun in position manually, or into a fixture which guides the nozzle to the desired weld area. When the trigger is depressed, it actuates the wire feed; and the arc is struck as the electrode touches the work piece. The weld continues until the pre-set time cycle has expired. The result is a finished weld that resembles a rivet or button head. The button size and penetration of the weld can be varied to suit the application by changing the arc voltage, weld current, and length of weld time.

Lap Joint Welding Jig

Shown in Figure 3 is the special welding jig designed and

constructed for consistent fabrication of lap joints. It includes fit-up plates which are interchangeable for material 3/16 inch or 1/4 inch thick. Good electrical ground is provided through a securely attached ground cable and hold-down studs. An added feature of the hold-down studs is the insurance of good fit-up and alignment of the work pieces. A guide for proper positioning of the welding gun nozzle is also provided.

Shear and Tension Testing Equipment

All tension and shear tests were conducted with a hydraulically operated Tinius Olesen universal testing machine, type "L", 60,000 pound capacity, shown in Figure 4. Calibration of this machine was checked with a proving ring, and its dial readings were found to be within one percent of the proving ring values.

Materials Used

The principle materials used in fabricating the joints to be tested consisted of flat bar stock steel meeting ASTM designation A242 and A. O. Smith CO_2 automatic tri-oxidized welding electrode wire CO-86. The chemical content of this steel and wire was determined by the Twin City Testing and Engineering Laboratory, St. Paul, Minnesota. This analysis is shown in Table I.

Three-eighths inch diameter cold rivets and one-half inch diameter structural steel rivets were used for riveted joints with the one-half inch rivets meeting ASTM designation A 141-39.[9]

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[9] American Institute of Steel Construction, *Steel Construction Manual*, pp. 333-335, American Institute of Steel Construction: New York, New York, 1959.

PREPARATION OF TEST SPECIMENS

The program of tests shown in Table II is arranged according to specimen number, joining material used, and purpose of the test. All joined specimens tested were single lap joints fabricated from structural steel meeting the specification ASTM designation A242. Tensile test data for the steel utilized are shown in Table III.

All specimens were purposely joined with mill scale faying surfaces to simulate shop and field fabricating conditions.

The welding jig in Figure 3 was used to obtain proper alignment and fit-up of all button welded lap joints.

Upon installation of the welding equipment, only 208 volts input was available. However, a series of tests was run on specimens welded at that voltage to simulate low voltage conditions. Upon installation of 230 volts service, all specimens were fabricated at that input voltage.

Joint specimens were fabricated by unskilled operators with not more than two hours of preliminary instruction on the operation of the welding equipment utilized. Special emphasis was placed upon maintaining the starting position of the electrode wire at an equal distance above the work pieces prior to the weld cycle. In addition, the operating pressure of the CO_2 gas was checked frequently.

<u>Specimens No. 21 - 128</u>

These specimens were of type J1 as detailed in Figure 6. Three were made for each setting of the welding equipment. Input voltage was 208 volts. Output voltage was varied from 44 to 46 volts. Amperage

settings were varied in steps of 10 from 380 to 410 amperes. Welding time ranged from 184 to 209 cycles. Contact tube height was maintained at 5/8 inch.

Specimens No. 201 - 281

These specimens were also of the type J1, as detailed in Figure 6. Input voltage was 230 volts. Output voltage was varied from 45 to 47 volts. Amperage settings were varied in steps of 10 from 390 to 410 amperes. Welding time ranged from 180 to 190 cycles. Contact tube height was maintained at 5/8 inch with three specimens being fabricated for each setting of the welder.

Specimens No. 401 - 481

These specimens were of the type J2, as detailed in Figure 7. Three were fabricated for each welder setting. Input voltage was 230 volts. Output voltage was varied from 41 to 43 volts. Amperage settings were varied in steps of 10 from 450 to 470 amperes. Welding time ranged from 80 to 100 cycles. Contact tube height was maintained at 5/8 inch.

Specimens No. 501 - 515

These specimens were of the type J1 fabricated according to the detail in Figure 6. The input voltage was 230 volts, and the welder settings were maintained at 46 volts, 400 amperes, and 180 cycles with the contact tube height being varied from 1/2 inch to 1 inch.

Specimens No. 601 - 609

These specimens were of the type J3, as detailed in Figure 8. The

input voltage was 230 volts. The output voltage and amperage were maintained at 46 volts and 390 amperes, respectively. The welding time was varied in steps of five from 180 to 190 cycles. Contact tube height was 5/8 inch.

Specimens No. 610 - 612

These specimens were of the type J1, except that 3/8 inch cold rivets were used to fabricate the lap joint with the rivet being placed in the center of the lap area.

Specimens No. 613 - 615

These specimens also were of the type J1 with 1/2 inch hot rivets being used to fabricate the lap joint. The rivets were located at the center of the lap area.

Specimens No. 616 - 618

These specimens, designated J4, were made using one work piece as detailed in Figure 9. Button welds were centered on the stock material at one inch intervals. Input voltage was 230 volts with the welder being set at 37 volts, 350 amperes, 30 cycles, and 5/8 inch contact tube height.

Specimens No. 616A - 618A

These specimens consisted of a single, flat piece of stock material with dimensions 7" x 1 1/2" x 1/4".

Specimens No. 619 - 621

These specimens, designated J5, were made using one work piece as detailed in Figure 10. One button weld was centered on the stock material

from one direction and then repeated from the opposite direction. After welding, the specimens were machined to the size indicated.

Specimens No. 622 - 630

These specimens duplicated Specimens No. 214, 244, and 262. They were of the type J1 with three of each being fabricated. Upon completion, each specimen was sawed in a transverse direction through the button weld and stock material. All were then carefully polished and etched for metallurgical examination and hardness testing.

TEST PROCEDURES AND DATA

Since this is the first known attempt to obtain test data on button welded structural steel joints, standard test specimens and procedures had not been adopted. However, a uniform rate of loading was maintained for all shear and tension tests according to the rate specified by the American Society for Testing Materials.

Before testing, all button welded specimens were allowed to air cool to room temperature. They were then tested in the Tinius Olesen universal testing machine with the specimen being properly centered and gripped. In the testing of lap joints, the grips of the testing machine were shimmed for proper alignment of the test specimen.

Tension Tests of Steel and Weld Metal

Tension tests were conducted on Specimens No. 616A - 618A and No. 616 - 618. The material used for Specimens No. 616A - 618A was plain flat steel bar stock 7" x 1 1/2" x 1/4". Specimens No. 616 - 618 were identical except for button welds which were placed one inch center to center along the center line of the bar. Button heads were then machined down flush with the steel bar. Before testing, a two inch gage length was scribed on the center of the specimen for the purpose of determining the per cent of elongation of the material. Each specimen was then placed in the testing machine and tested in tension for yield and ultimate strength. The yield and ultimate stresses, per cent of elongation, and per cent of reduction in cross sectional area are shown in Table III.

Tension tests were also made on the button weld metal for yield

and ultimate stresses. These specimens included No. 619 - 621. The data for these tests are tabulated in Table X.

__Shear Testing of Lap Joints__

Two hundred seventy specimens were tested to determine the effect of the various welding equipment control settings on the shear resistance of the single button welds to statically applied loads. These were tested to failure by applying tension to the joined specimen in a direction perpendicular to the axis of penetration of the button weld. Test data for Specimens No. 21 - 128 are given in Table IV; that for Specimens No. 201 - 281 in Table V; and that for Specimens No. 401 - 481 in Table VI.

Fifteen additional specimens were similarly tested to determine the effect of contact tube height on the shear strength. The test data for these specimens, No. 501 - 515, are tabulated in Table VII.

__Tension Testing of the Button Welds__

Nine tests of button welds in the stock material were conducted to determine the direct tension effect of a static load applied in the direction of the button weld's penetration axis. These tests were run on Specimens No. 601 - 609, with the data appearing in Table VII. The special fixture shown in Figure 5 was used in conjunction with the Tinius Olesen universal testing machine. By placing one of the specimens in the fixture and applying a compressive load, the button weld material was subjected to direct tension.

Hardness Tests

A Rockwell Hardness Tester was utilized to obtain hardness cross sections of Specimens No. 622 - 630. Initial polishing of the nine specimens indicated that all specimens were of sound weld. Therefore, three specimens, namely, No. 623, 626, and 629, were selected for hardness testing. These represented one specimen for each welder setting. Hardness tests were then made at specified distances from the weld center line as indicated in Figure 22. The data for these tests are set forth in Table XI. Relative hardness for Specimen No. 623 is shown in Figure 23. The Rockwell Hardness Test was also conducted upon a cross section of the work pieces before welding. The average value thus obtained was B68.0, indicating an approximate tensile strength of 60,000 pounds per square inch.

A photomacrograph of the weld area for Specimen No. 623 is shown in Figure 24.

Figure 25 illustrates the typical microstructure of the steel used in the work pieces. This represents a magnification of 100X.

Fourteen photomicrographs shown in Figures 26 to 39 were made of the weld area for the relative positions indicated in Figure 22. All photomicrographs represent a magnification of 100X.

ANALYSIS OF TESTS

An understanding of the behavior of materials under the action of applied loads is of prime importance to all engineers. Safety and economy are the two most important factors for which an engineer accepts responsibility. Complete analysis of materials should include: operating temperatures; applied loads; and mechanical, physical, and chemical properties.[10]

This investigation was conducted with statically applied loads at room temperatures. The mechanical properties considered were tension, shear, and yield strengths. The physical properties considered were hardness and weld quality. Chemical analysis of the material was obtained in order to compare the weld material with the work pieces and to verify the type of structural steel used.

The effect of dynamic loading on button welds was not considered in this particular study. However, research in that area is presently being conducted.

It was apparent from preliminary tests that a good electrical ground and a good joint fit-up were prerequisites for consistent strength of button welds. Each of these factors substantially affected the penetration characteristics of the button weld.

Consistency of button welds for a particular welder setting appeared to be good. Welds were completely free of slag, and there was

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[10] John J. Chyle, "Factors in the Selection of Welding Processes," The Welding Journal Research Supplement, American Welding Society: New York, New York, July 1953.

little evidence of porosity in the weld metal. Static tests indicated that ultimate strengths of the weld were within plus or minus 10% of the mean value as calculated for each series of three button welded joints.

Operator skill or special training was not necessary. This factor appears to have great economic potential since manual arc welding and riveting of structural connections requires certified or skilled operators. Other economic factors favoring button welding were the low equipment maintenance costs and the high production rates.

Preliminary tests indicated that the surface condition of the steel being welded does not seriously affect the weld quality. Button welding was conducted with good results through mill scale surfaces. It is understood that equally good results may be expected through oiled or greased surfaces.[11]

Because of the gas shielded arc, CO_2 welding can not be done in extremely drafty or windy areas.[12] This limits the potential of such welding equipment for field use. However, this should not be disadvantageous for shop fabrication.

The dial of the button weld timer was calibrated non-linearly. This made it difficult to set the welding cycle accurately for a preselected time which happened to fall between the dial numbers. However, a more advanced equipment design features an electronic timer with fine control which insures accurate settings.

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[11]Ted Metaxas, "Wider Use of CO_2 Welding," Mill & Factory: New York, New York, November 1959.

[12]Keller, loc. cit.

It was noted that increasing the output voltage flattened the appearance of the button weld. Reducing the output voltage increased the weld penetration. The amperage setting materially affected the weld strength, and an increase in the weld cycle increased the strength of the button weld.

The strength graphs contained in this investigation were plotted utilizing the average load values tabulated for each series of three joints fabricated with identical equipment control settings. These graphs are shown in Figures 12 to 21.

Effect of Tension on Structural Steel and Weld Metal

It is apparent from Table III that the welding operation had little effect upon the ultimate strength of the structural steel used. It is also noted that the tension tests of the structural steel bars, designated Specimens No. 616A - 618A, indicated an average elongation of 44.8% for a two inch gage length and an average reduction in area at the failure cross section of 51.3%. On the other hand, the button welded Specimens No. 616 - 618 indicated an average elongation of 29.1% with an average reduction in area of 35.9%. Figure 11 shows the effect of tension on these two types of specimens. The hardening effect of the welding process is evident. However, it should be noted that failure in the button welded specimen took place between two welds indicating the absence of a "net tension" effect.

The data in Table X indicate that the weld metal was approximately 50% stronger in ultimate tension than the structural steel used. However, a standard ASTM test was conducted on a specimen of the weld

metal with the following results: yield stress - 58,600 psi.; ultimate stress - 74,500 psi.; elongation in two inch gage length - 26.5%; and reduction in area - 27.5%. These values are very close to the company specifications for this type of electrode wire.

__Effect of Shear on Button Welded Lap Joints__

Shear tests indicated that the shear strength of button welds increases with penetration of the weld. This can be attributed to the bowl shape of the arc weld pool during the welding process which causes the cross section of the weld at the juncture of the joined pieces to increase with weld penetration.[13] The strongest button welds were those with penetration just short of "burn through". Near "burn through" was determined by the appearance of a discolored "hot spot" on the back side of the button welded joint. The limit of penetration for button welds in the type of structural steel used appeared to be slightly in excess of 1/2 inch.

In the conduct of all shear tests on button welded joints, it was found that the faying surfaces offered little or no resistance to the applied loads. Therefore, it was assumed that the load was carried entirely by the button welds.

The data of Table IV indicates the results of the first series of shear tests. These were conducted at 208 volts welder input, utilizing 1/4 inch thick work pieces. Figures 12, 13, and 14 show that 45 volts

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[13] Roger W. Tuthill, "Dip Transfer, Carbon-Dioxide Welding," __Weld-Journal__, vol. 38, p. 979, The American Welding Society: New York, New York, 1959.

output, 390 to 400 amperes, and 209 cycles gave the strongest welds.

Figures 15, 16, and 17 represent graphically the data of Table V. These tests were conducted on 1/4 inch thick material at 230 volts input. Results indicate that 47 volts output, 390 to 400 amperes, and 190 cycles were the most satisfactory.

It is evident from the tests conducted on specimens fabricated at 208 volts and 230 volts input that the input voltage differential can be compensated by changes in the welder control settings. Therefore, with this in mind, it would seem that low voltage conditions in the field or shop would have very little effect on button weld strengths. However, it was noted that the 230 volts input produced greater button weld penetrations with maximum penetrations exceeding 1/2 inch.

The graphs of Figure 18, 19, and 20 were obtained from the information contained in Table VI. These tests involved 3/16 inch thick work pieces utilizing 230 volts input. The best welds were produced with settings of 42 volts input, 460 amperes, and 100 cycles.

Figure 21 is a graph of the data shown in Table VII. It is noted that the contact tube height had a definite effect on the strength of the button welds. The curve indicates that the 1/2 inch height gave the best strength; however, this setting caused occasional welding of the contact tube to the electrode wire. Although weld strengths were somewhat reduced, it was found that a contact tube height of 5/8 to 3/4 inch virtually eliminated fusion of the contact tube with the electrode.

Table IX shows the results of shear on single 3/8 inch and 1/2 inch diameter rivets used with 1/4 inch thick work pieces. By comparing these data and the button weld data for 1/4 inch material it can be seen

that the load carrying capabilities for button welds in shear compares favorably with that of rivets. For example, in Table V, the average load for Specimens No. 261 - 263 was 8,417 pounds with an average shear stress of 50,800 pounds per square inch. For 1/2 inch hot rivets, the computed average load from Table IX was 9,400 pounds with an average shear stress of 47,900 pounds per square inch. Of course, it must be remembered that this comparison involves rivets of 0.500 inch diameter; whereas, the average diameter of the button welds was 0.462 inches.

Effect of Tension on Button Welds

The data of Table VIII indicate that the direct tension capabilities of button welds were materially changed by varying the welder equipment controls. It is also noted that the direct tension qualities of button welds compare favorably with those of rivets. Although the special fixture of Figure 5 was utilized, it was not possible to entirely eliminate a slight peeling effect caused by bending in the vicinity of the weld. However, it was apparent from these tests that button welds could be fabricated with good tensile quality.

Button Welds and Hardness

Rockwell Hardness test data are shown in Table XI. Figure 23 is a graph of the hardness in and around the weld area. From this it can be seen that the hardness of the button weld was greatest along the penetration axis. Conversely, the hardness decreased as the distance from the penetration axis increased. Also, the hardness of the work pieces in the vicinity of the heat affected zone was increased by the welding operation. This condition was probably caused by the quenching

effect of the surrounding mass of cold steel.

By examining Figure 24 it can be seen that button welding gives a good quality weld with excellent fusion between the work pieces and the weld metal. Close examination of typical weld cross sections revealed practically no slag or graphite inclusions. Also, it was noted that the weld cross sections were consistent in appearance and exhibited little or no porosity.

Figures 25 through 39 are photomicrographs of the work pieces and the weld area. It appears that the pearlite area decreases as the axis of the weld is approached. Apparently, the welding operation diminishes the carbon content of the steel depending upon the distance from the hottest portion of the arc weld pool. This should tend to make the weld more resistant to fatigue stresses. However, it must be remembered that this advantage would be partially offset by the increased hardness in and around the weld area.

Inspection of Button Welded Connections

Inspection of manually welded connections in steel bridges and buildings is of necessity mostly visual. Such inspection consists of gaging dimensions, checking specified tolerances, and examining for slag inclusion and incipient cracking in the weld. In addition, the inspector should review the welding procedure used and examine the qualifications of the welding personnel.

The visual inspection of button welded steel connections would be aided materially by the knowledge of the consistency of these welds. Button welds are consistent from several standpoints. These include the

weld penetration and strength for a given equipment setting, the absence of slag, the good quality of the weld metal and fusion, and the consistent operating method used in button welding.

Occasional spot checking of welds may be used to supplement visual inspection, if desired. Several methods are available. These include X-ray or gamma-ray, flourescent dye penetrant inspection, magnetic particle testing, hardness testing, probing and sampling of the weld area.[14]

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[14]American Welding Society, Welding Handbook, Section One, American Welding Society: New York, 1957.

CONCLUSIONS

From the discussion presented in this thesis, the following conclusions seem justified:

1. A good electrical ground between the welding equipment and the work pieces is necessary.

2. A tight fit-up between the work pieces provides stronger button welds.

3. CO_2 shielded welding assures excellent weld metal quality. Fusion with the work pieces provides a good quality button weld that is relatively free of inclusions. In addition, the surface of the weld is completely slag free.

4. Operator skill or training is not necessary. For a given welder setting, button welds are consistent.

5. Button welds can be produced with low welding equipment maintenance costs.

6. Button welding provides high production rates.

7. The timer utilized on the button welding equipment lacks precision.

8. With a given amperage setting, increasing the output voltage flattens the appearance of the button welds. Reducing the output voltage increases the penetration of the welds.

9. For a given voltage and weld cycle, increasing the amperage increases the weld strength.

10. For a given voltage and amperage, increasing the weld cycle increases the button weld strength up to the point of "burn through".

11. The quenching effect of the steel mass causes a hardening of the steel in and around the weld area.

12. The button welding process burns out the carbon in and around the weld area.

13. Shear and direct tensile strength increase with penetration to the point of "burn through". The strongest button welds are those that are just short of "burn through".

14. For the type of equipment and electrode utilized, the limit of button weld penetration is slightly in excess of 1/2 inch.

15. In single button welded lap joints, the faying surfaces of the work pieces offer little or no resistance to the applied load.

16. Low welder input voltage can be compensated for by changes in the welder control settings.

17. For 1/4 inch work pieces, the best weld strengths were obtained with a welder control setting of 47 volts output, 390 to 400 amperes and 190 cycles.

18. The contact tube height affects the strength of the button welds. For 1/4 inch work pieces the most efficient height appears to be 5/8 inch to 3/4 inch.

19. The static load carrying capabilities of button welds compares favorably with that of hot rivets.

20. Knowledge of the consistency of button welds greatly aids in their inspection.

21. From the standpoint of static loads, button welds are reliable for structural applications. However, in view of the limited

amount of research in this area to date, it is believed that such structural applications should be confined initially to secondary stress members.

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APPENDIX I

TABLE I. CHEMICAL ANALYSIS OF STEEL AND ELECTRODE

Specimen	As Specified By	As Tested By	C	Mn	Si	P	S	Al
			%					
Steel	ASTM No. A242		.22	1.25	---	---	.05	---
		Twin Cities Testing Lab.	.19	.66	.05	.01	.04	---
Electrode	A. O. Smith Company		.15	1.10	.30	.025	.03	.60
		Twin Cities Testing Lab.	.15	1.05	.41	.01	.02	Trace

TABLE II. PROGRAM OF TESTS

Specimen Number	Type	Faying Surface	Joint Material	Input Voltage	Purpose
21-128	J1	Mill scale	Button weld	208	Shear test
201-281	J1	Mill scale	Button weld	230	Shear test
401-481	J2	Mill scale	Button weld	230	Shear test
501-515	J1	Mill scale	Button weld	230	Contact tube ht.
601-609	J3	Mill scale	Button weld	230	Tension test
610-612	J1	Mill scale	3/8" cold rivet	---	Shear test
613-615	J1	Mill scale	1/2" hot rivet	---	Shear test
616A-618A	J4	Without Button welds		230	Steel tension test
616-618	J4	None used	Button weld	230	Steel tension test
619-621	J5	None used	Button weld	230	Weld metal tension
622-630	J1	Mill scale	Button weld	230	Metallurgy testing

TABLE III. TENSION TEST OF STEEL USED

Specimen Number	Yield Load (lbs)	Yield Stress (psi)	Ultimate Load (lbs)	Ultimate Stress (psi)	Elongation in 2" gage Length	Reduction in Area
616A	18500	49400	26200	69700	45.5%	51.7%
617A	18300	48800	25600	68200	46.0%	51.5%
618A	18800	50100	25800	68900	43.0%	49.9%
616	17500	46600	25600	68200	27.4%	33.6%
617	17200	45700	24500	65300	22.5%	29.6%
618	17400	46300	26200	69700	37.5%	44.6%

TABLE IV. SHEAR TEST, TYPE J1 SPECIMEN, 208 VOLTS INPUT

Joint Number	Volts	Amps.	Cycles	Load (lbs)	Ave. Load (lbs)	Shear Diameter (in)	Shear Stress (psi)	Remarks
21	45	400	194	9200		.443	59600	
22	45	400	194	7450	8217	.411	56100	
23	45	400	194	8000		.418	58300	
24	45	400	184	7600		.430	52300	
25	45	400	184	7300	7607	.420	52700	
26	45	400	184	7920		.405	61400	
27	45	400	209	9000		.449	56800	
28	45	400	209	9500	9020	.446	60800	
29	45	400	209	8560		.439	56500	
30	45	390	194	8600		.443	55800	
31	45	390	194	8580	8400	.439	56700	
32	45	390	194	8020		.431	54900	
33	45	390	184	7800		.439	51500	
34	45	390	184	8630	8203	.431	59100	
35	45	390	184	8180		.424	57100	
36	45	390	209	8850		.442	57900	
37	45	390	209	9120	8890	.451	57100	
38	45	390	209	8700		.436	62800	

TABLE IV. SHEAR TEST, TYPE J1 SPECIMEN, 208 VOLTS INPUT (Continued)

Joint Number	Volts	Amps.	Cycles	Load (lbs)	Ave. Load (lbs)	Shear Diameter (in)	Shear Stress (psi)	Remarks
39	45	410	194	7880		.446	50400	
40	45	410	194	7940	8007	.480	43900	
41	45	410	194	8200		.475	46200	
42	45	410	184	7400		.408	56600	
43	45	410	184	7640	7140	.406	59000	
44	45	410	184	6780		.417	49600	
45	45	410	209	8600		.445	55300	
46	45	410	209	8860	8713	.430	61000	
47	45	410	209	8680		.462	51800	
48	44	400	194	8100		.418	59500	
49	44	400	194	7440	7753	.402	58600	
50	44	400	194	7720		.421	55400	
51	44	400	184	7300		.398	58700	
52	44	400	184	7650	6923	.415	56600	
53	44	400	184	5820		.368	54700	
54	44	400	209	7680		.416	55900	
55	44	400	209	8900	8127	.441	58200	
56	44	400	209	7800		.420	56300	
57	44	390	194	8100		.444	52300	
58	44	390	194	7660	7960	.424	54200	
59	44	390	194	8120		.427	56700	
60	44	390	184	6510		.400	51800	
61	44	390	184	7650	6837	.412	57000	
62	44	390	184	6350		.372	58400	
63	44	390	209	8100		.399	64800	
64	44	390	209	8180	8313	.407	62881	
65	44	390	209	8660		.437	58200	
66	44	410	194	8200		.421	58900	
67	44	410	194	7850	7983	.437	52300	
68	44	410	194	7900		.418	57600	
69	44	410	184	7680		.398	61700	
70	44	410	184	7780	7666	.409	59200	
71	44	410	184	7540		.406	58200	

TABLE IV. SHEAR TEST, TYPE J1 SPECIMEN, 208 VOLTS INPUT (Continued)

Joint Number	Volts	Amps.	Cycles	Load (lbs)	Ave. Load (lbs)	Shear Diameter (in)	Shear Stress (psi)	Remarks
72	44	410	209	9300		.470	53600	
73	44	410	209	8360	8420	.426	58600	
74	44	410	209	7600		.431	52100	
75	46	400	194	8050		.424	57000	
76	46	400	194	7880	7977	.434	53200	
77	46	400	194	8000		.441	52400	
78	46	400	184	6500		.414	52100	
79	46	400	184	7860	7570	.430	54100	
80	46	400	184	8350		.435	56200	
81	46	400	209	8900		.462	53100	
82	46	400	209	8700	8107	.455	53500	
83	46	400	209	6720		.403	52700	
84	46	390	194	8180		.439	54000	
85	46	390	194	6720	7733	.427	46900	
86	46	390	194	8300		.441	54300	
87	46	390	184	7280		.415	53800	
88	46	390	184	7070	7383	.427	49800	
89	46	390	184	7800		.445	50100	
90	46	390	209	8900		.484	48400	
91	46	390	209	9050	8883	.451	56600	
92	46	390	209	8700		.450	54700	
93	46	410	194	8000		.452	49800	
94	46	410	194	8330	7976	.444	53800	
95	46	410	194	7600		.424	53800	
96	46	410	184	7630		.413	57400	
97	46	410	184	6600	7450	.426	46300	(1)
98	46	410	184	8120		.430	56900	
99	46	410	209	8300		.436	55600	
100	46	410	209	8600	8300	.462	51300	
101	46	410	209	8000		.450	54200	
102	46	380	184	6600		.445	42400	
103	46	380	184	6400	7100	.409	52500	
104	46	380	184	8300		.440	54575	

TABLE IV. SHEAR TEST, TYPE J1 SPECIMEN, 208 VOLTS INPUT (Continued)

Joint Number	Volts	Amps.	Cycles	Load (lbs)	Ave. Load (lbs)	Shear Diameter (in)	Shear Stress (psi)	Remarks
105	46	380	194	8400		.440	55200	
106	46	380	194	7880	7970	.440	51800	
107	46	380	194	7600		.424	53800	
108	46	380	209	7120		.417	52100	
109	46	380	209	7200	7600	.462	43000	
110	46	380	209	8450		.461	50600	
111	45	380	184	7350		.408	56200	
112	45	380	184	6800	7230	.388	57500	
113	45	380	184	7550		.416	55500	
114	45	380	194	6800		.423	48400	
115	45	380	194	7640	7100	.428	53100	
116	45	380	194	6900		.400	54900	
117	45	380	209	7640		.405	59300	
118	45	380	209	6600	7300	.420	47600	
119	45	380	209	7640		.450	48000	
120	44	380	184	6700		.396	54400	
121	44	380	184	6800	7180	.398	54600	
122	44	380	184	8060		.461	48100	
123	44	380	194	7100		.420	51200	
124	44	380	194	7120	7130	.424	50400	
125	44	380	194	7220		.418	52600	
126	44	380	209	7000		.418	51000	
127	44	380	209	8330	7500	.434	56300	
128	44	380	209	7200		.418	52900	

(1) Poor fit up.

TABLE V. SHEAR TEST, TYPE J1 SPECIMEN, 230 VOLTS INPUT

Joint Number	Volts	Amps.	Cycles	Load (lbs)	Ave. Load (lbs)	Shear Diameter (in.)	Shear Stress (psi)	Remarks
201	45	390	180	7500		.425	52900	
202	45	390	180	8240	8010	.431	56500	
203	45	390	180	8290		.435	56800	
204	45	390	185	8130		.442	53000	
205	45	390	185	7800	7943	.439	51500	
206	45	390	185	7900		.430	54390	
207	45	390	190	7530		.429	51900	
208	45	390	190	8500	7830	.443	55100	
209	45	390	190	7460		.434	48403	
210	45	400	180	7950		.441	52000	
211	45	400	180	7270	7527	.426	51000	
212	45	400	180	7360		.417	53900	
213	45	400	185	8360		.440	55400	
214	45	400	185	8000	8230	.436	53600	
215	45	400	185	8330		.435	56000	
216	45	400	190	7450		.434	50300	
217	45	400	190	7520	7523	.440	49400	
218	45	400	190	7600		.437	50700	
219	45	410	180	7900		.434	53400	
220	45	410	180	6900	7633	.440	45400	(1)
221	45	410	180	8100		.435	54500	
222	45	410	185	7200		.425	50800	
223	45	410	185	7950	7450	.428	55200	
224	45	410	185	7200		.424	51000	
225	45	410	190	8400		.463	49900	
226	45	410	190	7770	7923	.445	50300	
227	45	410	190	7600		.440	50000	
228	46	390	180	7000		.408	53500	
229	46	390	180	7560	7253	.417	55300	
230	46	390	180	7200		.425	50800	
231	46	390	185	7240		.420	52200	
232	46	390	185	8040	7770	.431	55100	
233	46	390	185	8030		.430	55300	

TABLE V. SHEAR TEST, TYPE J1 SPECIMEN, 230 VOLTS INPUT (Continued)

Joint Number	Volts	Amps.	Cycles	Load (lbs)	Ave. Load (lbs)	Shear Diameter (in.)	Shear Stress (psi)	Remarks
234	46	390	190	8200		.433	55700	
235	46	390	190	7840	8020	.438	52000	
236	46	390	190	8020		.444	51800	
237	46	400	180	8180		.446	56500	
238	46	400	180	7330	7527	.428	55000	
239	46	400	180	7070		.428	49100	(1)
240	46	400	185	8130		.435	54700	
241	46	400	185	7300	7650	.418	53000	
242	46	400	185	7520		.433	51100	
243	46	400	190	8200		.452	51100	
244	46	400	190	7900	8100	.435	53200	
245	46	400	190	8200		.443	53200	
246	46	410	180	7380		.443	47900	(1)
247	46	410	180	8370	7983	.440	55000	
248	46	410	180	8200		.430	56500	
249	46	410	185	7530		.428	52300	
250	46	410	185	7800	7577	.426	54700	
251	46	410	185	7400		.405	57400	
252	46	410	190	8140		.448	51600	
253	46	410	190	7860	7707	.428	54600	
254	46	410	190	7120		.440	46800	
255	47	390	180	8780		.455	54000	
256	47	390	180	8300	8073	.430	57100	
257	47	390	180	7140		.437	47600	(1)
258	47	390	185	8300		.450	52200	
259	47	390	185	6800	7433	.487	36500	
260	47	390	185	7200		.475	40600	
261	47	390	190	9250		.468	53800	
262	47	390	190	7900	8417	.470	45500	
263	47	390	190	8100		.449	53000	
264	47	400	180	8000		.449	50500	
265	47	400	180	8800	8313	.450	55300	
266	47	400	180	8140		.446	52100	

TABLE V. SHEAR TEST, TYPE J1 SPECIMEN, 230 VOLTS INPUT (Continued)

Joint Number	Volts	Amps.	Cycles	Load (lbs)	Ave. Load (lbs)	Shear Diameter (in.)	Shear Stress (psi)	Remarks
267	47	400	185	8350		.467	48700	
268	47	400	185	8160	7937	.458	44300	
269	47	400	185	7300		.458	44300	(1)
270	47	400	190	8220		.473	50500	
271	47	400	190	7900	8240	.463	47000	
272	47	400	190	8600		.465	50600	
273	47	410	180	8240		.452	51300	
274	47	410	180	7800	7847	.440	51300	
275	47	410	180	7500		.430	51600	
276	47	410	185	----		----	-----	(2)
277	47	410	185	7800	8085	.440	51300	
278	47	410	185	8370		.460	50400	
279	47	410	190	8020		.475	45300	
280	47	410	190	8360	7977	.464	49400	
281	47	410	190	7550		.460	45400	

(1) Poor fit up of work pieces.
(2) Weld burned through. Not included in computation of average load.

TABLE VI. SHEAR TEST, TYPE J2 SPECIMEN, 230 VOLTS INPUT

Joint Number	Volts	Amps.	Cycles	Load (lbs)	Ave. Load (lbs)	Shear Diameter (in.)	Shear Stress (psi)	Remarks
401	41	450	90	5200		.344	56000	
402	41	450	90	5040	5180	.335	57200	
403	41	450	90	5300		.342	57700	
404	41	450	100	5180		.330	60600	
405	41	450	100	5200	5247	.338	58000	
406	41	450	100	5340		.350	55500	
407	41	450	80	4620		.321	58100	
408	41	450	80	4530	4566	.320	56300	
409	41	450	80	4550		.314	58700	
410	41	460	90	4800		.332	55400	
411	41	460	90	5820	5266	.353	59500	
412	41	460	90	5180		.336	58400	
413	41	460	100	5060		.323	61800	
414	41	460	100	5720	5227	.350	59400	
415	41	460	100	4900		.332	56600	
416	41	460	80	5060		.314	65300	
417	41	460	80	4500	4787	.312	58900	
418	41	460	80	4800		.312	62800	
419	41	470	90	4820		.316	61200	
420	41	470	90	5260	5033	.328	62700	
421	41	470	90	5020		.326	60100	
422	41	470	100	5200		.333	59700	
423	41	470	100	5340	5400	.335	60500	
424	41	470	100	5660		.348	59500	
425	41	470	80	4900		.330	57300	
426	41	470	80	4640	4840	.344	50300	
427	41	470	80	4980		.336	56200	
428	42	450	90	6240		.360	61300	
429	42	450	90	5160	5427	.343	55900	
430	42	450	90	4880		.325	58800	(1)
431	42	450	100	5080		.346	54000	
432	42	450	100	5300	5347	.343	57700	
433	42	450	100	5660		.340	62300	

TABLE VI. SHEAR TEST, TYPE J2 SPECIMEN, 230 VOLTS INPUT (Continued)

Joint Number	Volts	Amps.	Cycles	Load (lbs)	Ave. Load (lbs)	Shear Diameter (in.)	Shear Stress (psi)	Remarks
434	42	450	80	4380		.310	58000	(1)
435	42	450	80	4960	4787	.334	56600	
436	42	450	80	5020		.340	55300	
437	42	460	90	4380		.325	52800	(1)
438	42	460	90	5440	4907	.350	61000	
439	42	460	90	4900		.329	57600	
440	42	460	100	5040		.350	52400	
441	42	460	100	5940	5413	.360	58300	
442	42	460	100	5260		.345	56300	
443	42	460	80	5140		.335	58300	
444	42	460	80	4540	5013	.309	60500	(1)
445	42	460	80	5360		.342	58300	
446	42	470	90	5380		.351	60400	
447	42	470	90	4800	4993	.360	47100	
448	42	470	90	4800		.345	51300	
449	42	470	100	5120		.340	56400	
450	42	470	100	5160	5167	.348	58500	
451	42	470	100	5220		.356	52400	
452	42	470	80	4980		.317	63100	
453	42	470	80	4560	4787	.344	49100	
454	42	470	80	4920		.330	57500	
455	43	450	90	5160		.326	61800	
456	43	450	90	5900	5460	.386	50400	
457	43	450	90	5320		.328	62900	
458	43	450	100	5400		.340	59500	
459	43	450	100	8420	5400	----	-----	(2)
460	43	450	100	8960		----	-----	(2)
461	43	450	80	7280		----	-----	(2)
462	43	450	80	8160	4960	----	-----	(2)
463	43	450	80	4960		.320	61700	
464	43	460	90	4520		.340	49800	
465	43	460	90	4930	4903	.347	56200	
466	43	460	90	5260		.350	54700	

TABLE VI. SHEAR TEST, TYPE J2 SPECIMEN, 230 VOLTS INPUT (Continued)

Joint Number	Volts	Amps.	Cycles	Load (lbs)	Ave. Load (lbs)	Shear Diameter (in.)	Shear Stress (psi)	Remarks
467	43	460	100	5100		.341	55800	
468	43	460	100	5880	5400	.366	55900	
469	43	460	100	5220		.358	51800	
470	43	460	80	4980		.320	61900	
471	43	460	80	5100	4907	.335	57900	
472	43	460	80	4640		.318	58400	
473	43	470	90	5300		.365	50700	
474	43	470	90	5100	5100	.350	53000	
475	43	470	90	4900		.345	52400	
476	43	470	100	5560		.365	53100	
477	43	470	100	3000	5830	.355	------	(3)
478	43	470	100	6100		.373	56300	
479	43	470	80	4800		.330	56100	
480	43	470	80	5700	5243	.365	54500	
481	43	470	80	5230		.347	55300	

(1) Poor fit up of work pieces.
(2) Oversize welds--cause unknown. Not included in computation of average load.
(3) Weld burned through. Not included in computation of average load.

TABLE VII. EFFECT OF CONTACT TUBE HEIGHT ON BUTTON WELD

Joint Number	Volts	Amps.	Cycles	Contact Tube Ht. (in.)	Load (lbs)	Ave. Load (lbs)	Shear Diameter (in.)	Shear Stress (psi)
501	46	400	180	1/2	7800		.457	47600
502	46	400	180	1/2	7640	7567	.456	46800
503	46	400	180	1/2	7260		.456	44500
504	46	400	180	5/8	7000		.425	49300
505	46	400	180	5/8	6100	6593	.414	45300
506	46	400	180	5/8	6680		.425	47100
507	46	400	180	3/4	6280		.399	50200
508	46	400	180	3/4	6260	6380	.397	50600
509	46	400	180	3/4	6600		.409	50200
510	46	400	180	7/8	6240		.390	52200
511	46	400	180	7/8	5880	5900	.388	49700
512	46	400	180	7/8	5580		.375	50500
513	46	400	180	1	4820		.359	51000
514	46	400	180	1	6280	5640	.382	54800
515	46	400	180	1	5820		.378	51800

TABLE VIII. TENSION TEST, TYPE J3 SPECIMEN, 230 VOLT INPUT

Specimen Number	Volts	Amps.	Cycles	Load (lbs)	Ave. Load (lbs)	Weld Diameter (in)	Tensile Stress (psi)	Remarks
601	46	390	180	8500		.411	64600	
602	46	390	180	8000	8593	.407	61500	(1)
603	46	390	180	9280		.419	67300	
604	46	390	185	8160		.452	54800	
605	46	390	185	8960	8466	.453	56000	
606	46	390	185	8280		.456	50700	
607	46	390	190	10500		.451	65700	
608	46	390	190	9300	9400	.446	59500	
609	46	390	190	8400		.430	57800	(1)

(1) Poor fit up of work pieces.

TABLE IX. SHEAR TEST OF SINGLE RIVET LAP JOINT

Joint Number	Rivet Diameter (in.)	Load (lbs)	Stress (psi)	Remarks
610	.375	6190	56100	Cold Rivet
611	.375	6440	58300	Cold Rivet
612	.375	6240	56600	Cold Rivet
613	.500	9500	48300	Hot Rivet
614	.500	9400	47900	Hot Rivet
615	.500	9350	47600	Hot Rivet

TABLE X. WELD METAL TENSION TEST, TYPE J5 SPECIMEN, 230 VOLTS INPUT

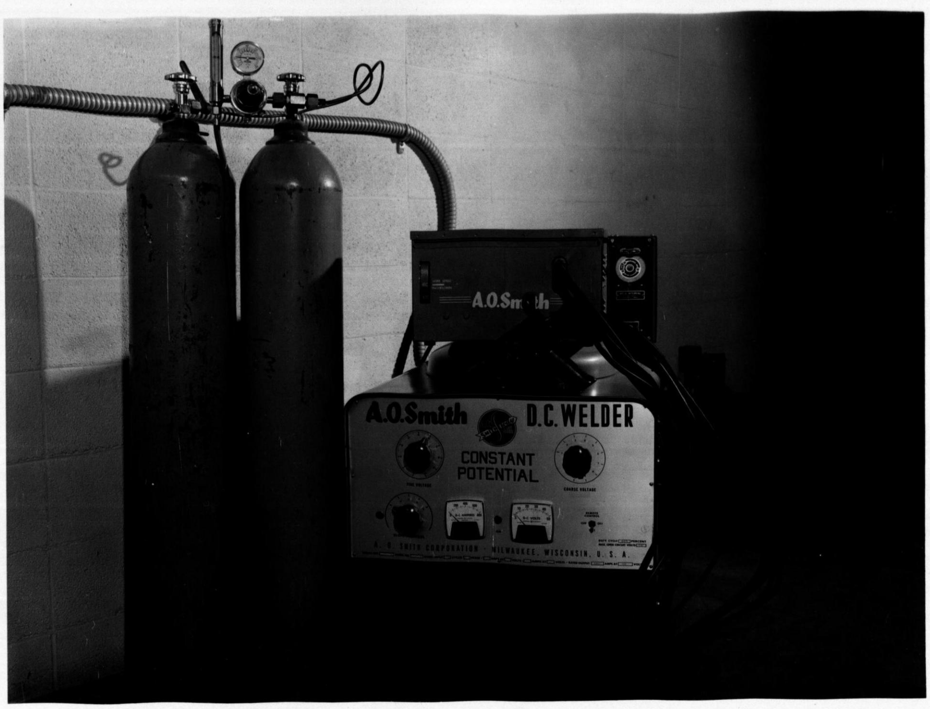
Specimen Number	Yield Load (lbs)	Yield Stress (psi)	Ultimate Load (lbs)	Ultimate Stress (psi)
619	5240	84000	5880	94000
620	5160	82500	5520	88500
621	5200	83300	5620	90000

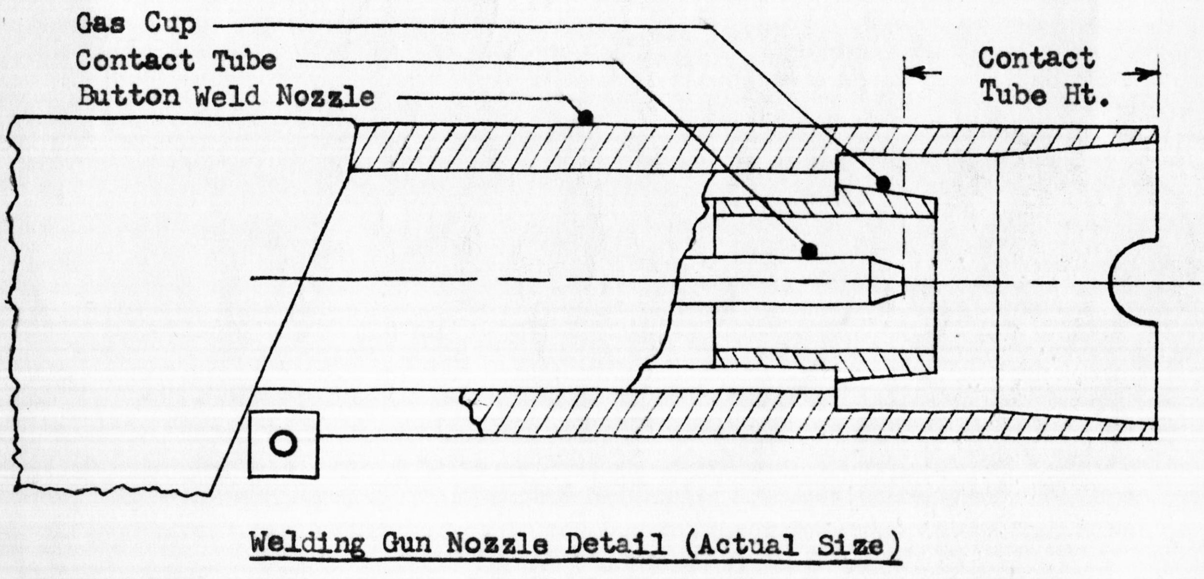
TABLE XI. HARDNESS TEST DATA, TYPE J1 SPECIMEN, 230 VOLTS INPUT

Point Number*	Rockwell Hardness		
	Specimen No. 623	Specimen No. 626	Specimen No. 629
1	B-67.0	B-75.0	B-78.5
2	B-51.0	B-60.0	B-56.0
3	B-78.5	B-77.3	B-70.5
4	B-82.5	B-82.0	B-77.0
5	B-81.0	B-76.3	B-74.2
6	B-69.4	B-67.1	B-68.0
7	B-81.4	B-77.8	B-73.3
8	B-84.2	B-82.7	B-79.2
9	B-84.0	B-75.6	B-79.0
10	B-61.5	B-40.8	B-62.0
11	B-70.5	B-70.0	B-70.0
12	B-81.5	B-83.2	B-78.0
13	B-68.0	B-69.0	B-75.0
14	B-63.0	B-64.3	B-60.0

*See Figure 22 for point location.

APPENDIX II





Welding Gun Nozzle Detail (Actual Size)

Figure 1. Button Welding Equipment.

Figure 2. Manifold Arrangement of CO_2 Cylinders.

Figure 3. Button Welding Jig.

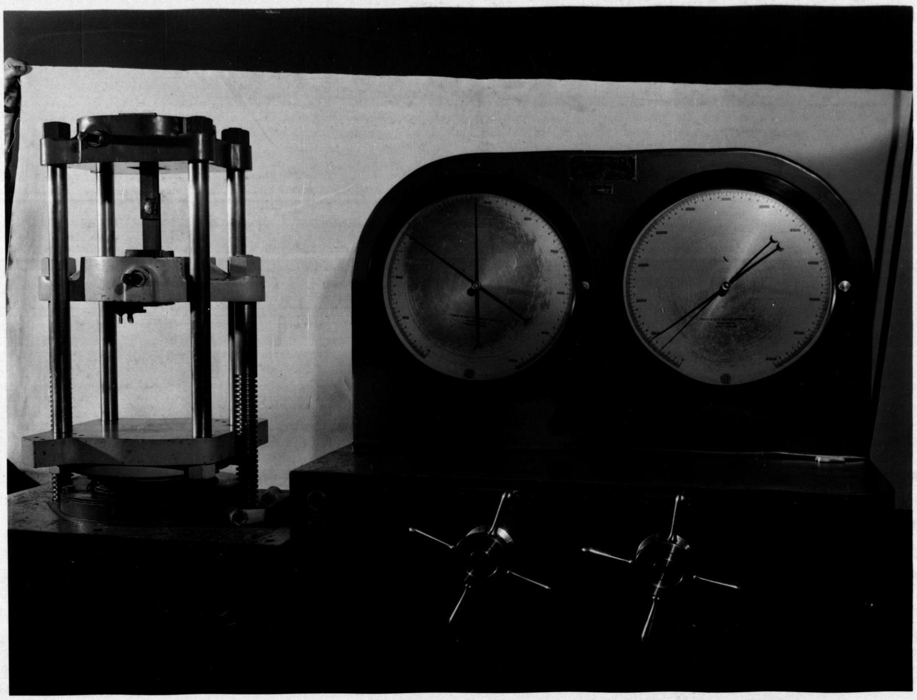


Figure 4. Tinius Olesen Universal Testing Machine.

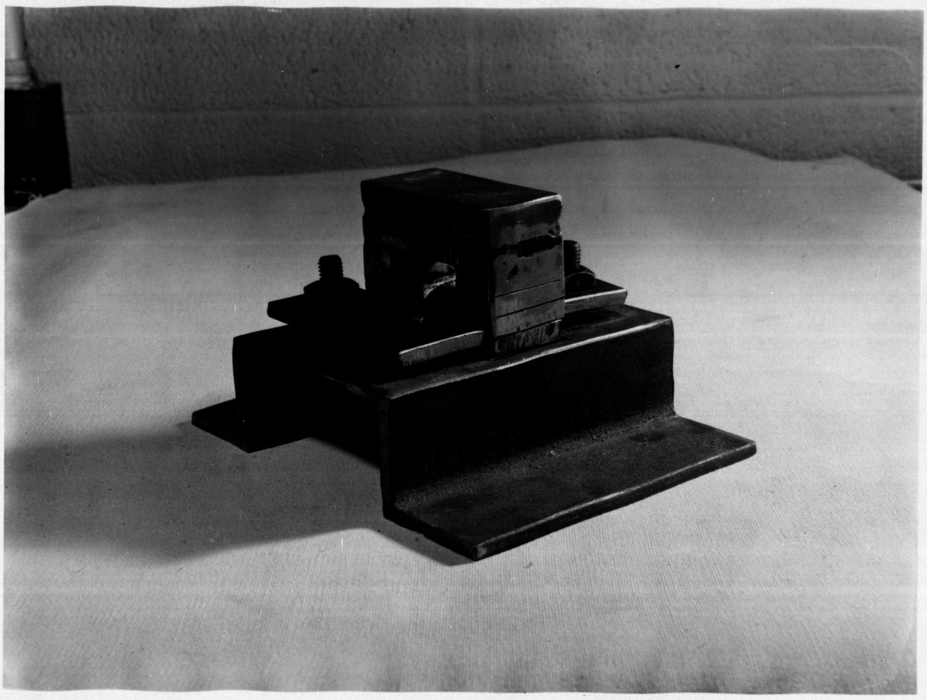
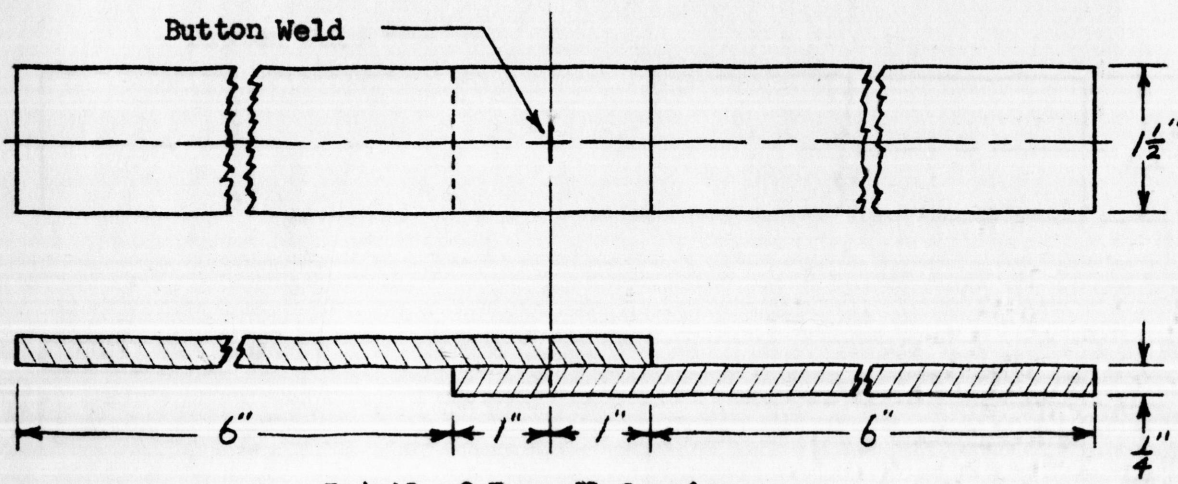
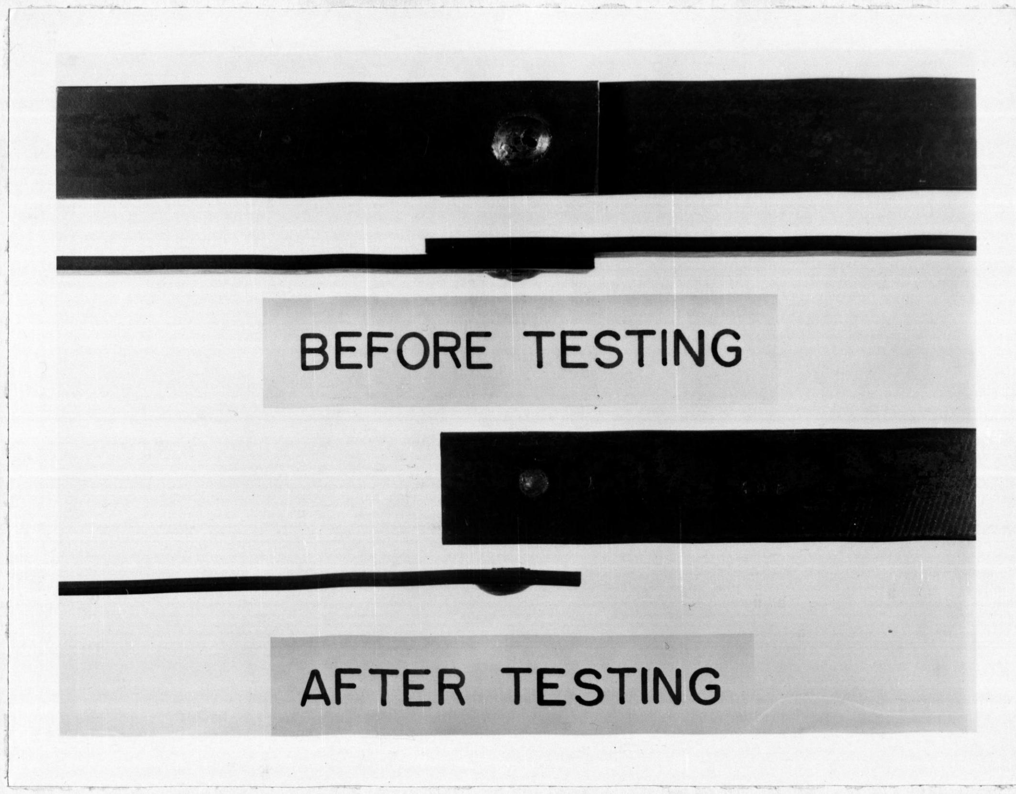


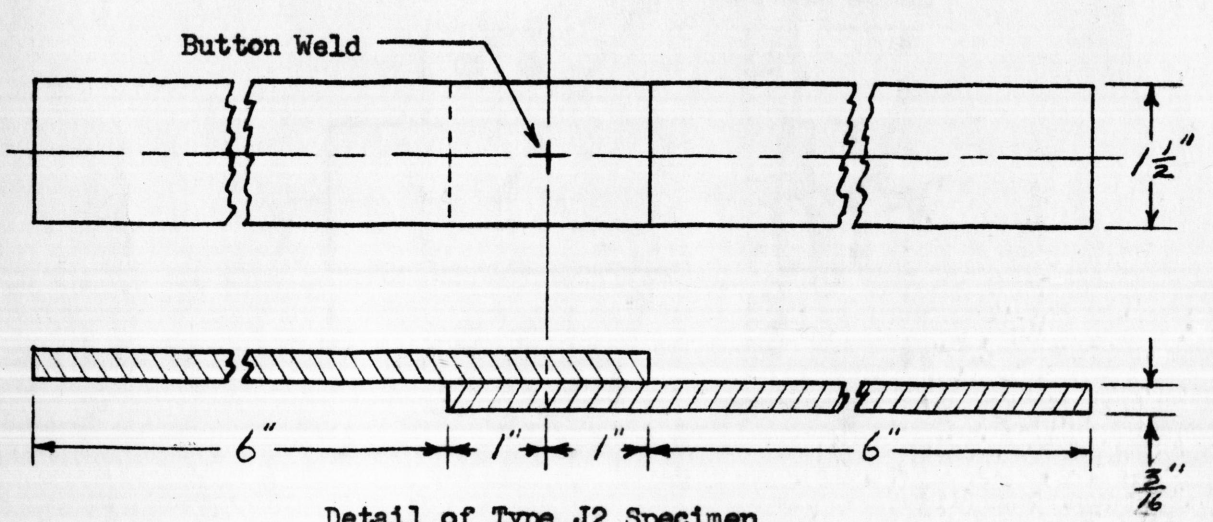
Figure 5. Button Weld Tension Testing Fixture.



Detail of Type J1 Specimen

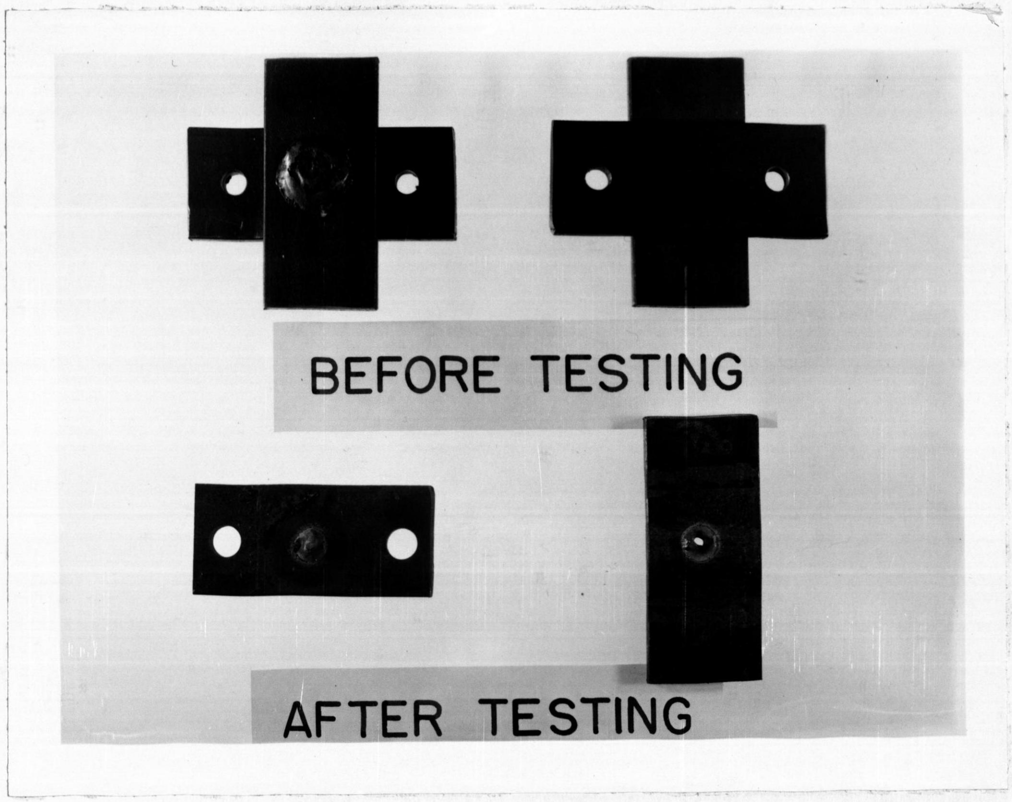
Figure 6. Type J1 Specimen.

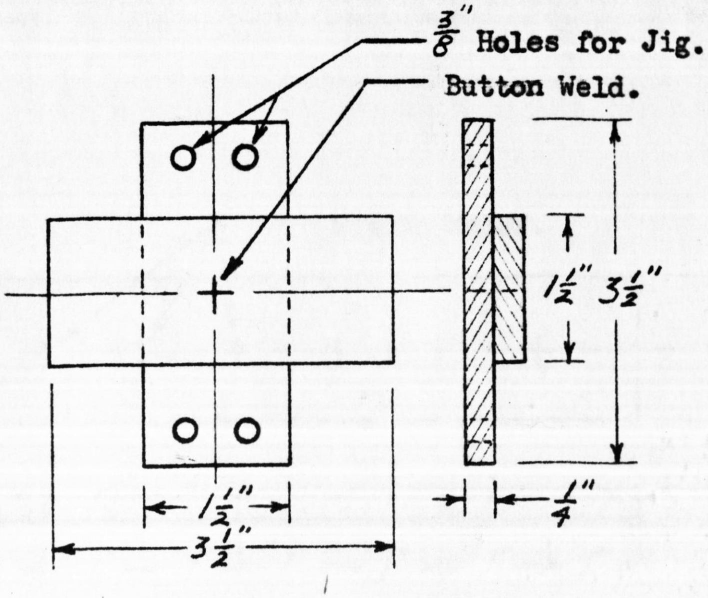




Detail of Type J2 Specimen

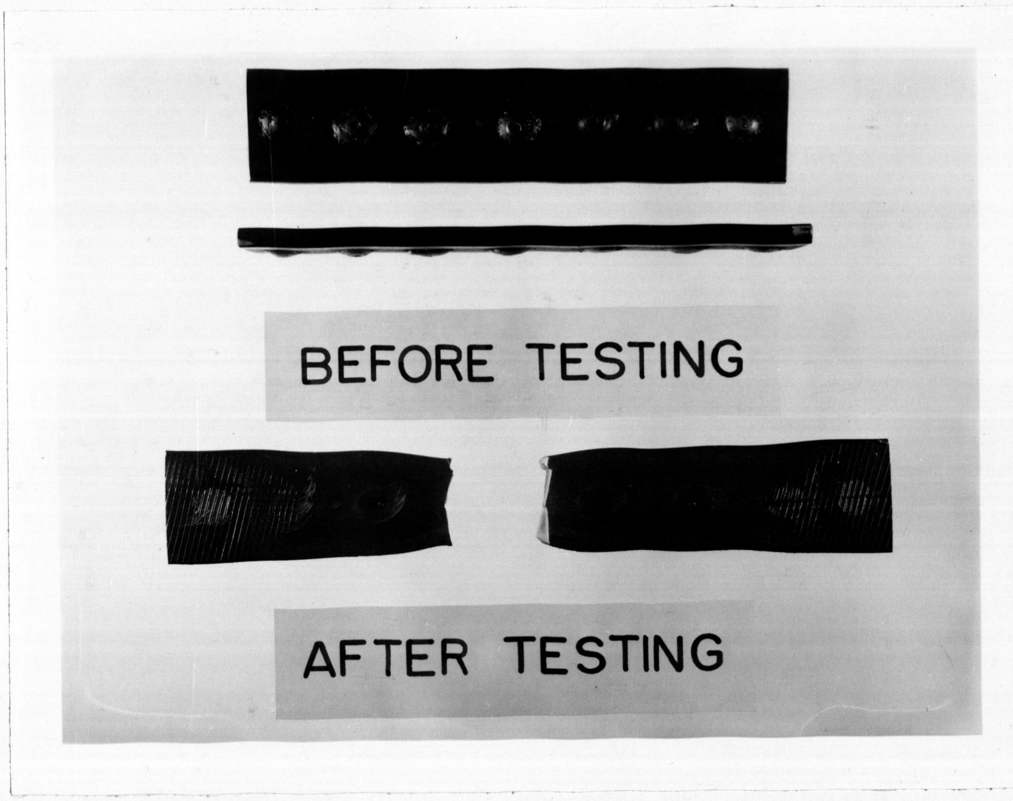
Figure 7. Type J2 Specimen.

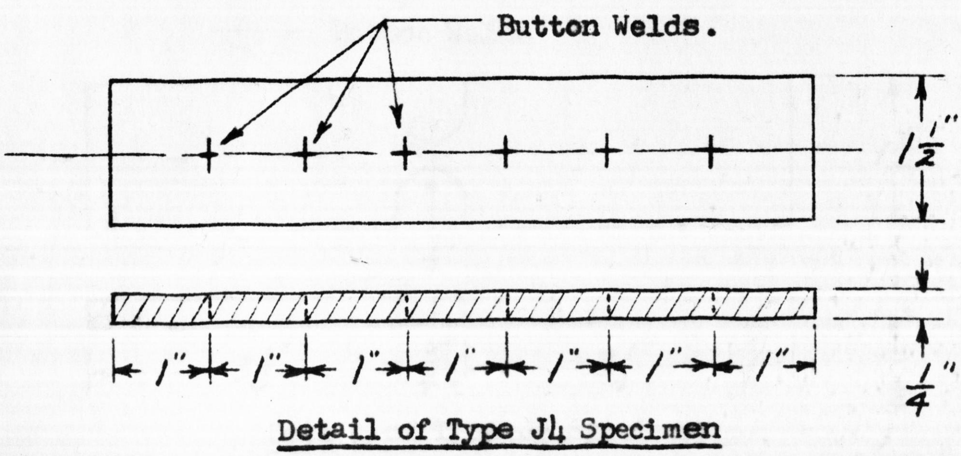




Detail of Type J3 Specimen

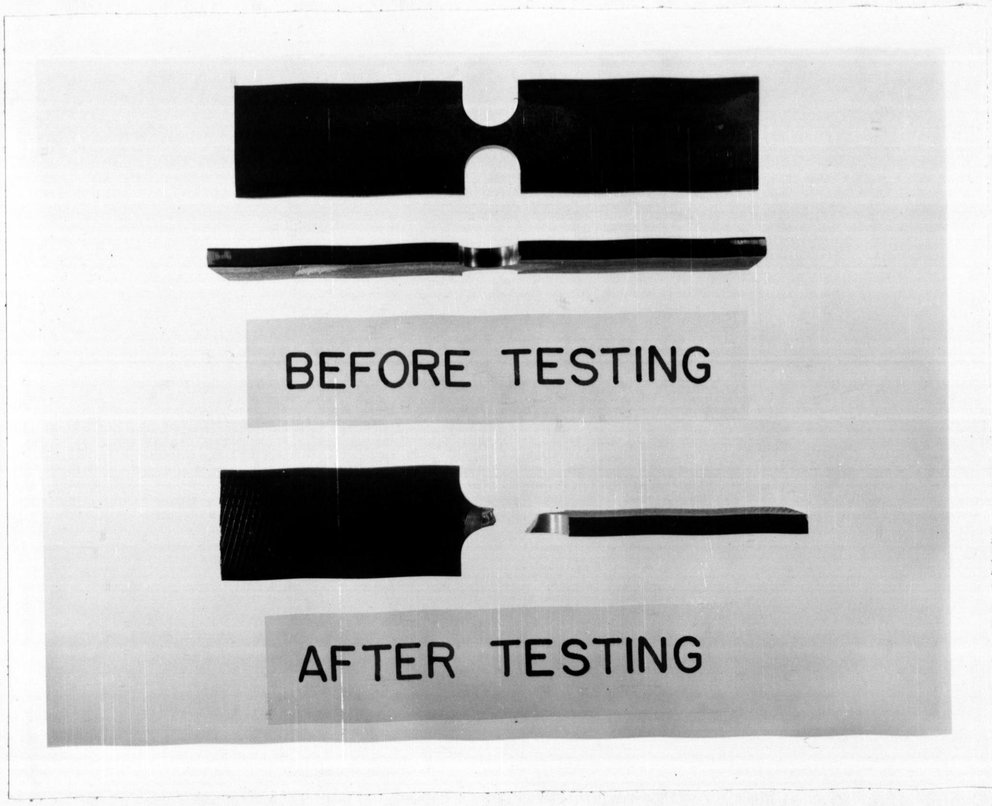
Figure 8. Type J3 Specimen.

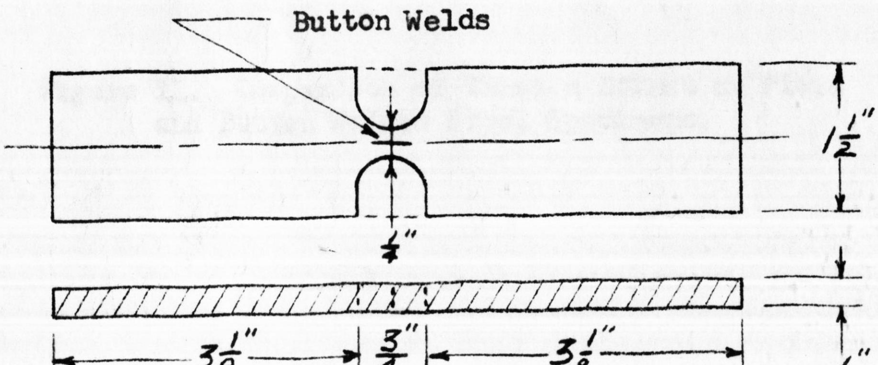




Detail of Type J4 Specimen

Figure 9. Type J4 Specimen.





Detail of Type J5 Specimen

Figure 10. Type J5 Specimen.

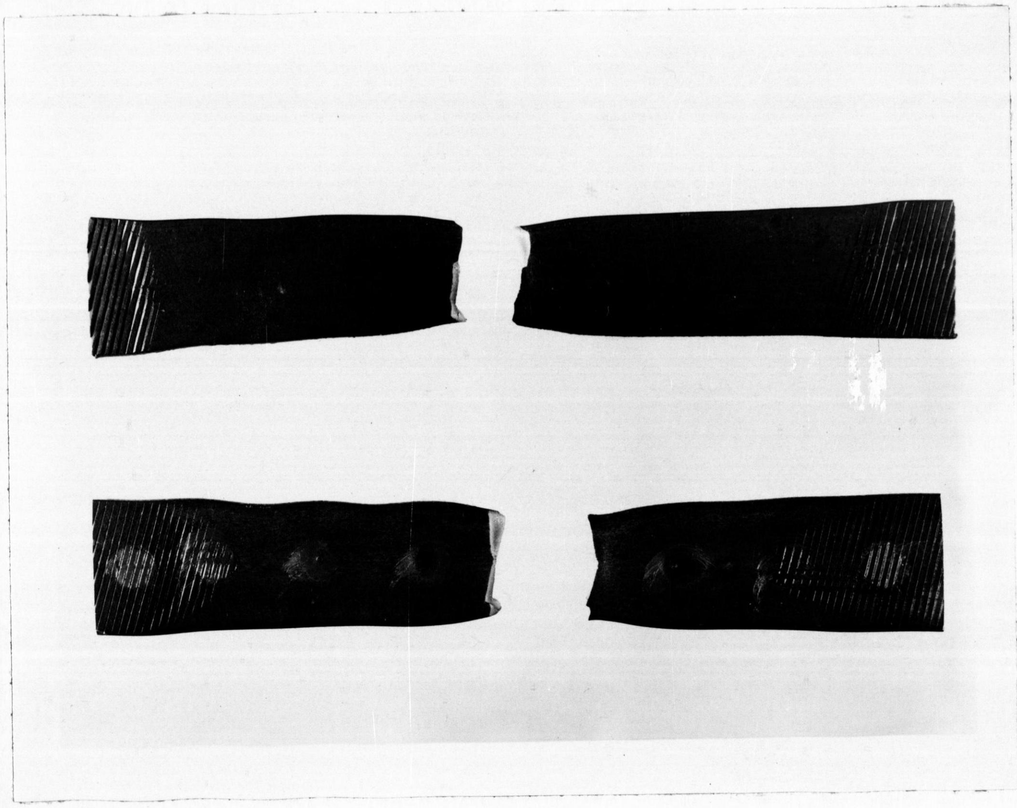


Figure 11. Comparison of Tension Effect on Plain and Button Welded Steel Specimens.

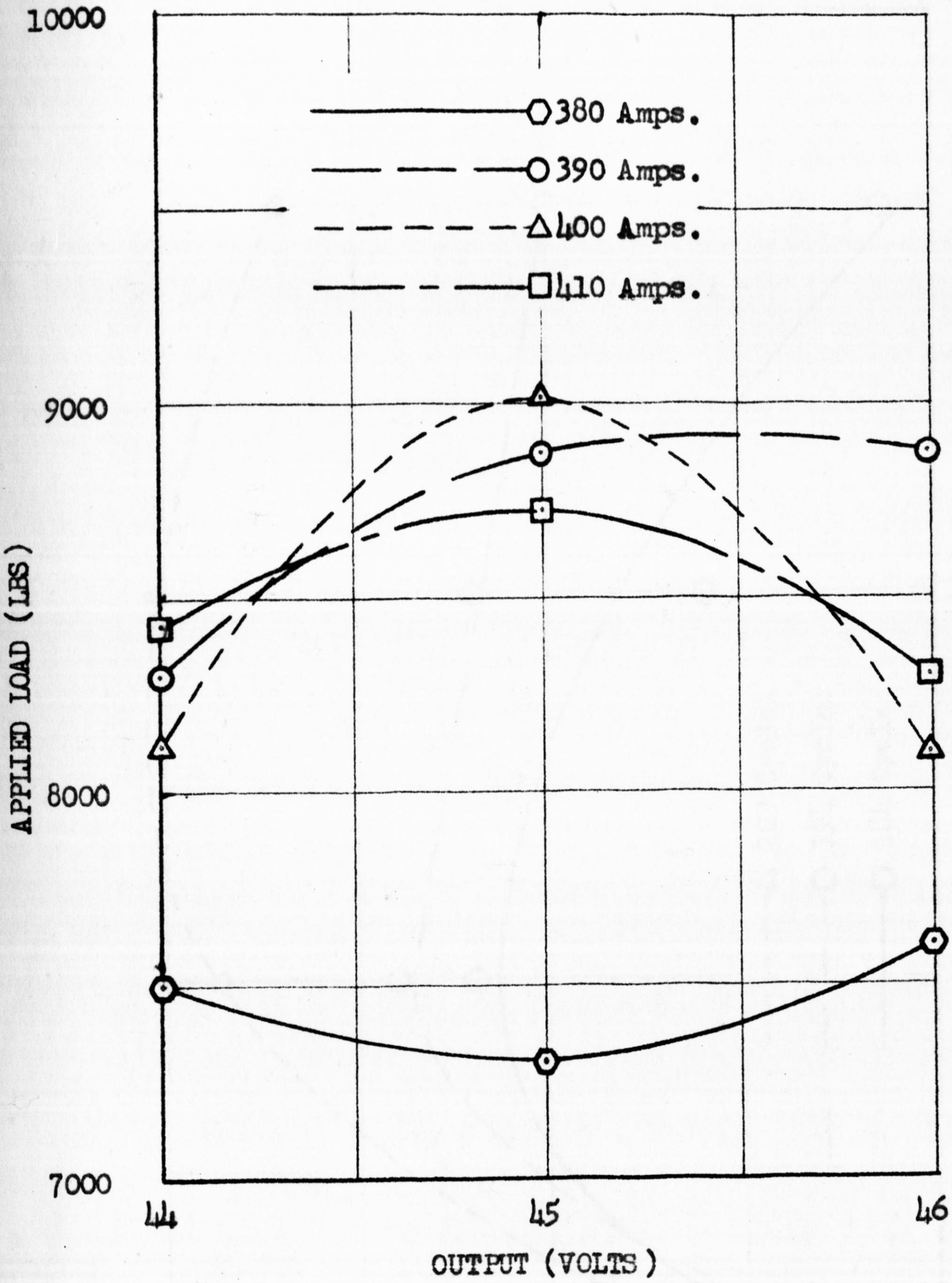


Figure 12. Effect of Amperage and Voltage on Load. Type J1 Specimen, 208 Volts Input, 209 Cycles Welding Time.

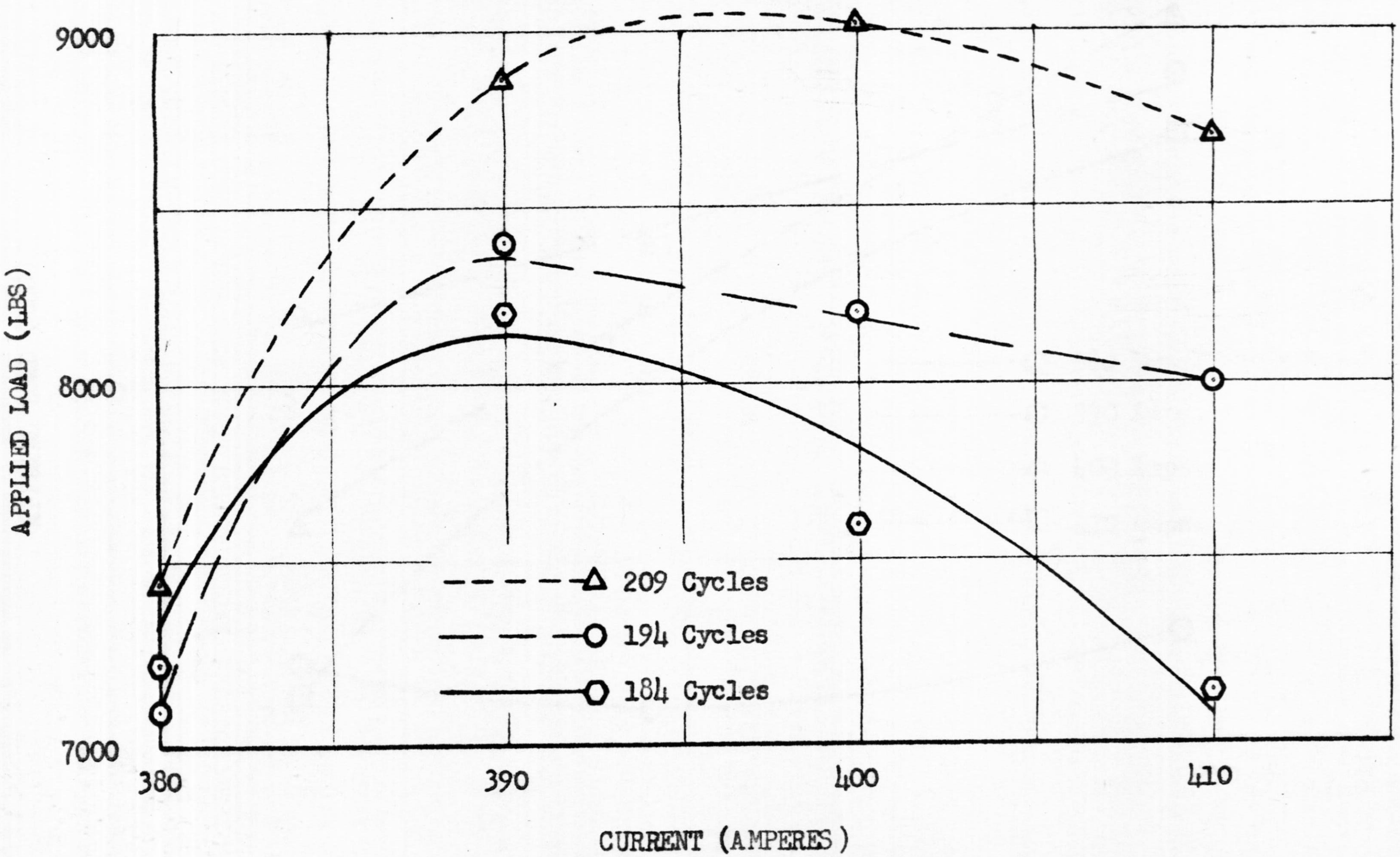


Figure 13. Effect of Time and Amperage on Load. Type J1 Specimens, 208 Volts Input, 45 Volts Out.

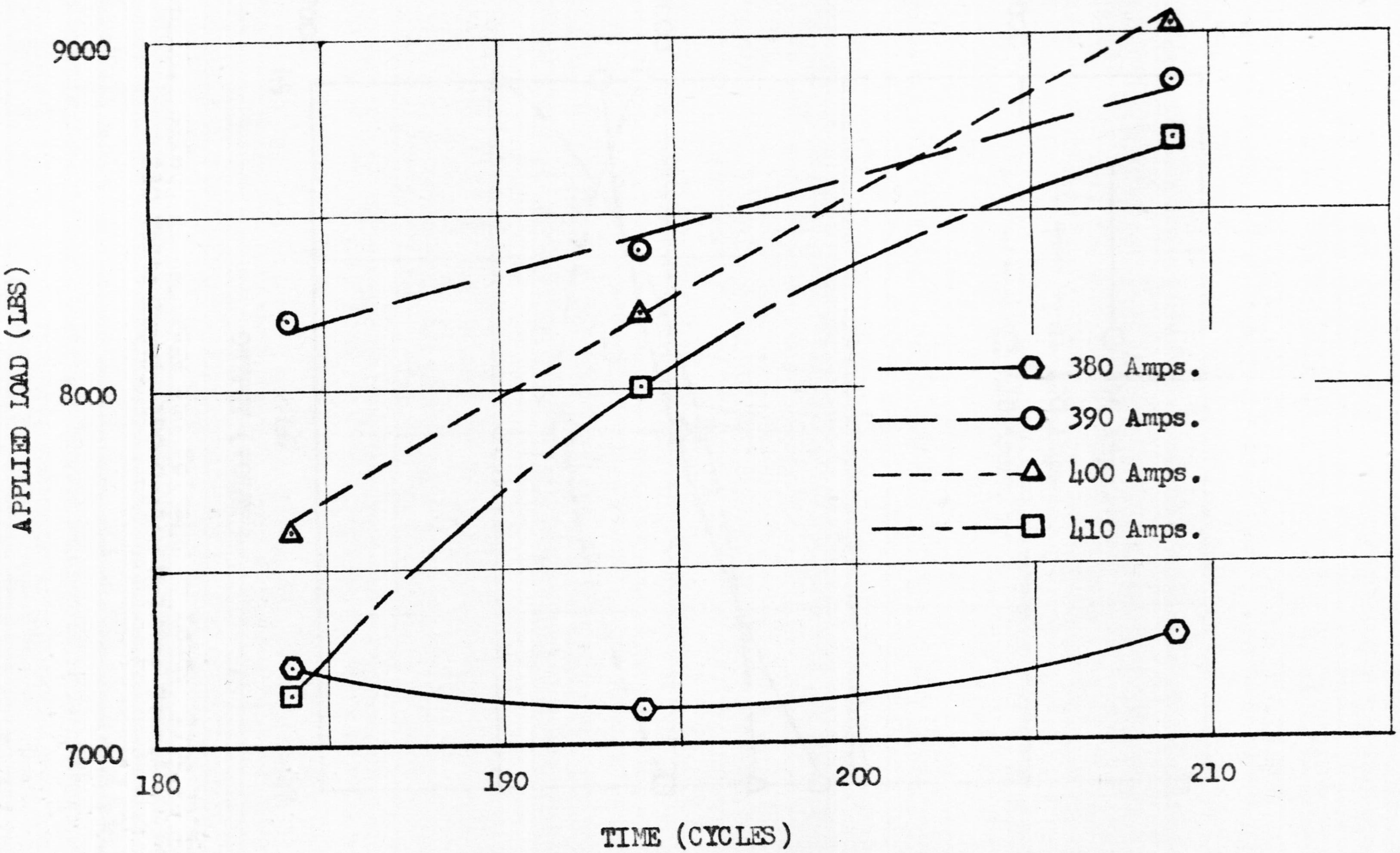


Figure 14. Effect of Time and Amperage on Load. Type J1 Specimens, 208 Volts Input, 45 Volts Out.

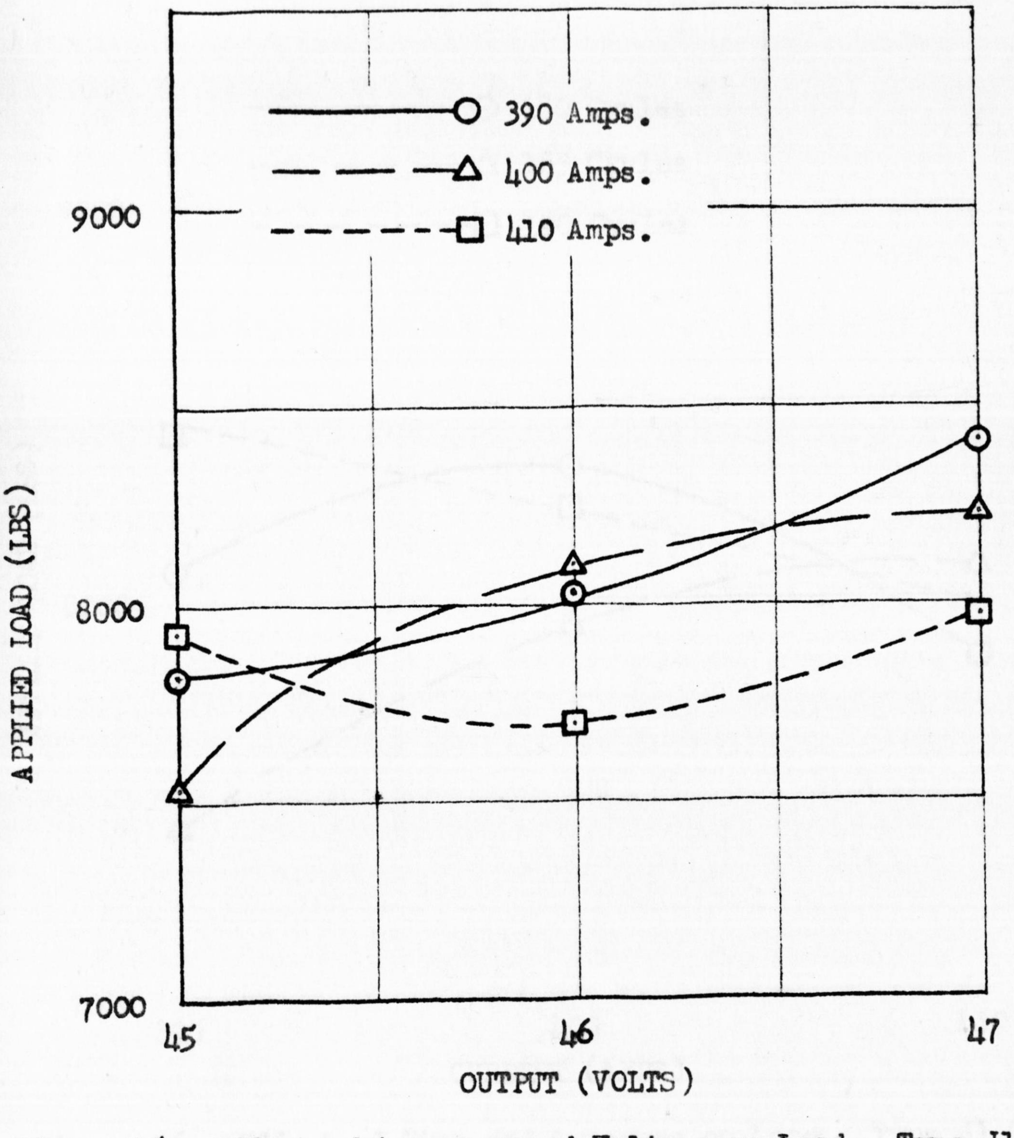


Figure 15. Effect of Amperage and Voltage on Load. Type J1 Specimen, 230 Volts Input, 190 Cycles Welding Time.

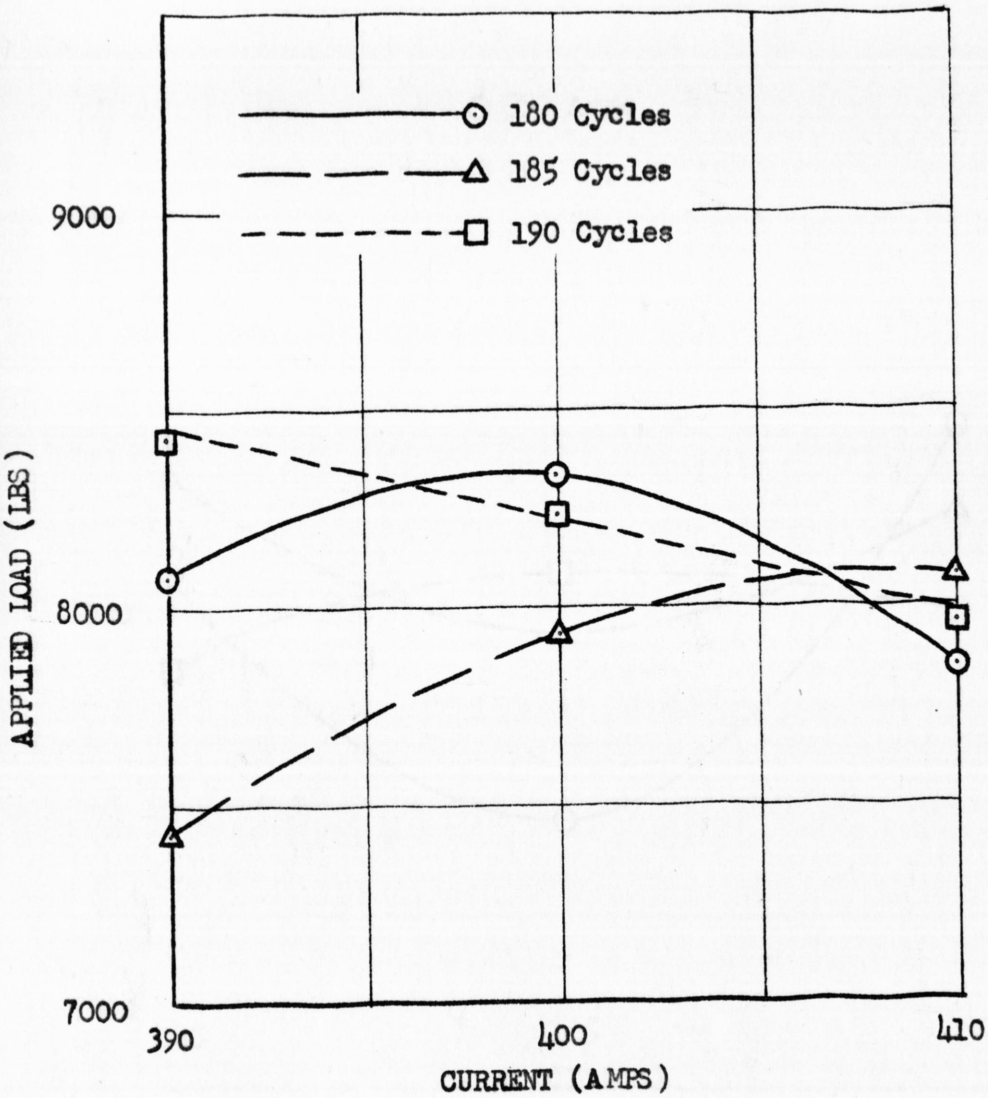


Figure 16. Effect of Time and Amperage on Load. Type J1 Specimens, 230 Volts Input, 47 Volts Output.

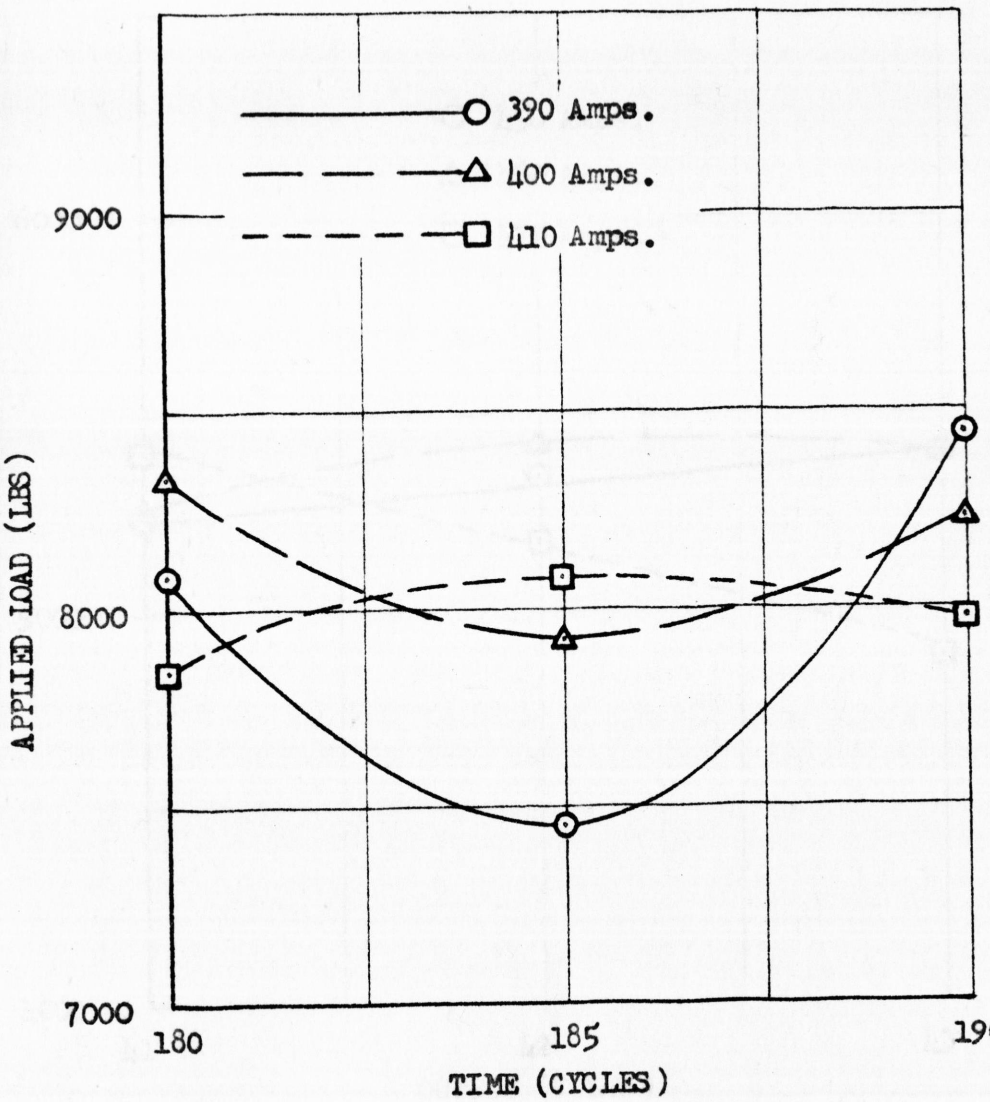


Figure 17. Effect of Time and Amperage on Load. Type J1 Specimens, 230 Volts Input, 47 Volts Output.

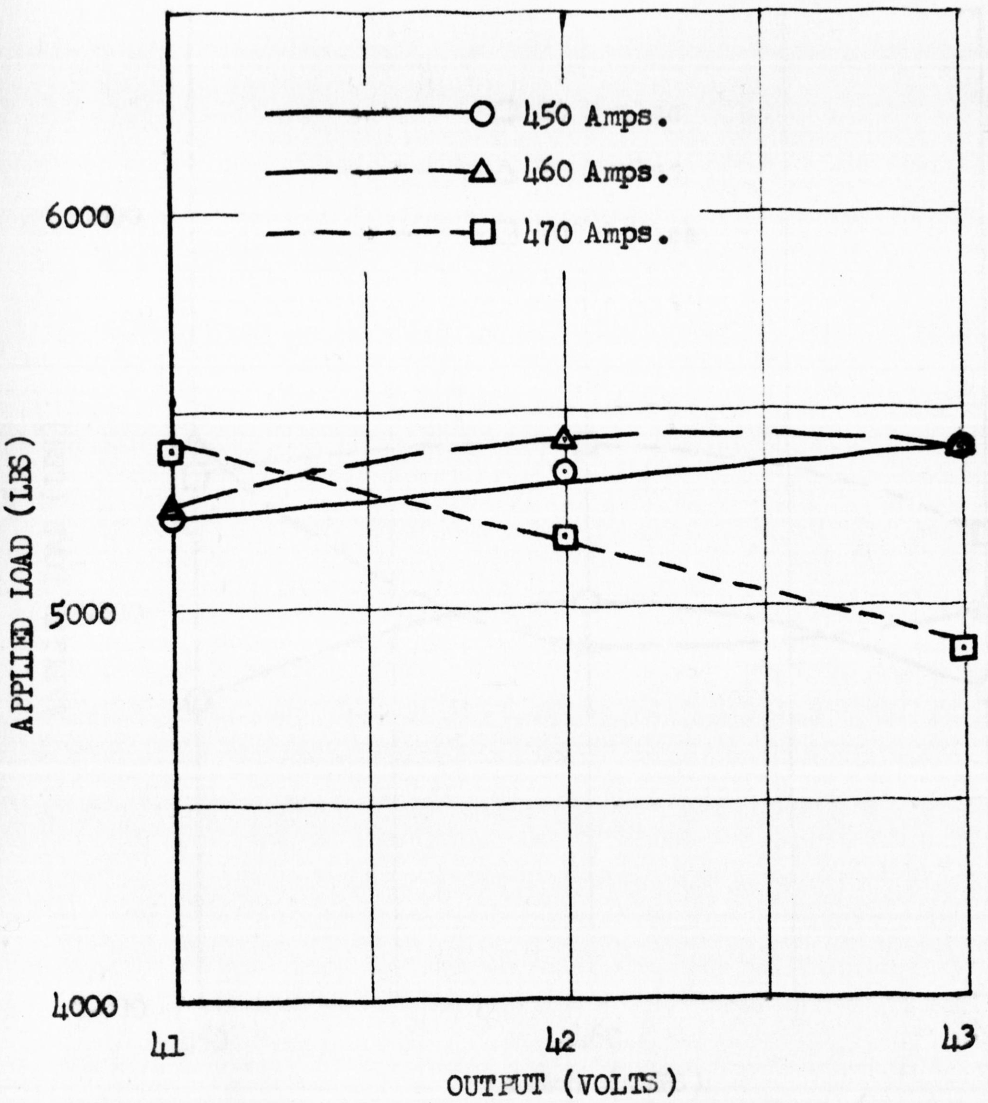


Figure 18. Effect of Amperage and Voltage on Load. Type J2 Specimen, 230 Volts Input, 100 Cycles Welding Time.

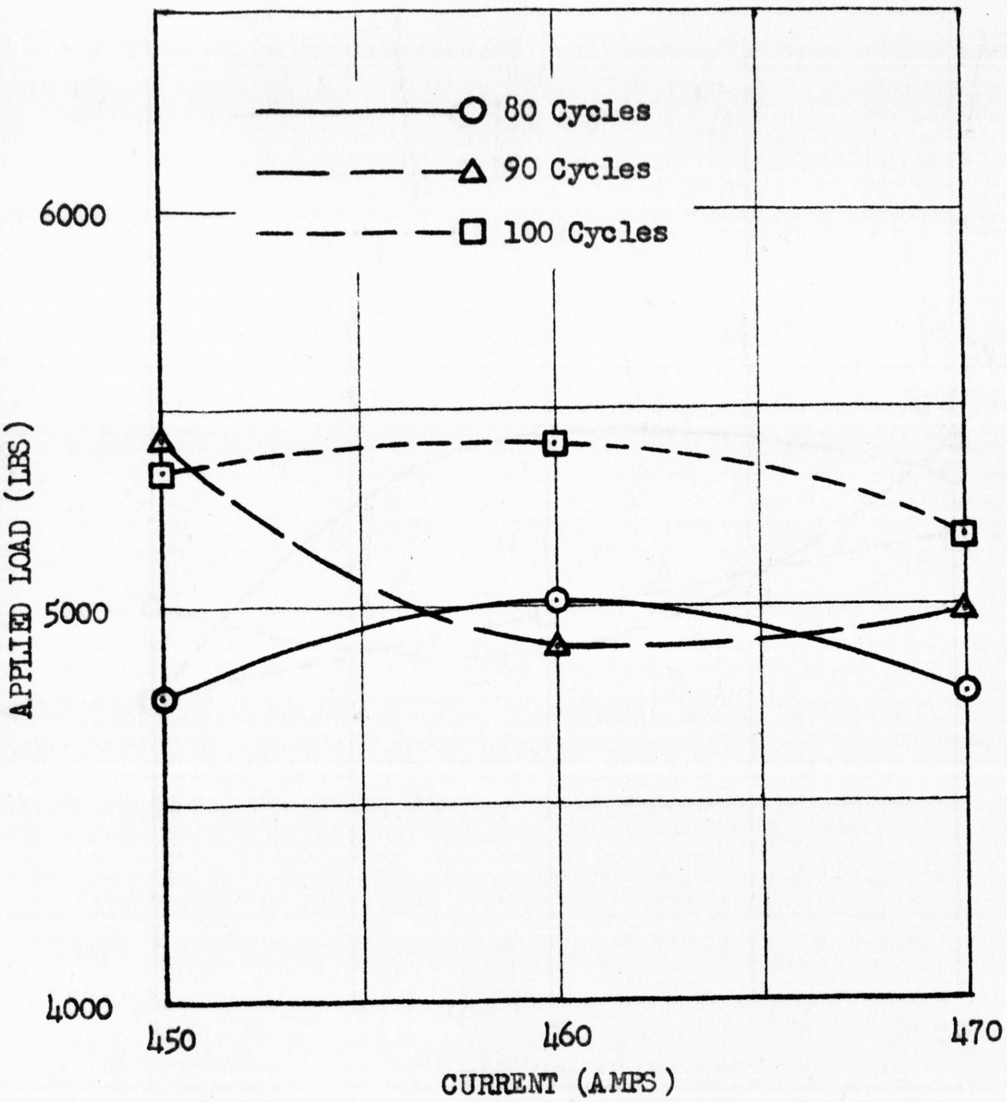


Figure 19. Effect of Time and Amperage on Load. Type J2 Specimen, 230 Volts Input, 42 Volts Output.

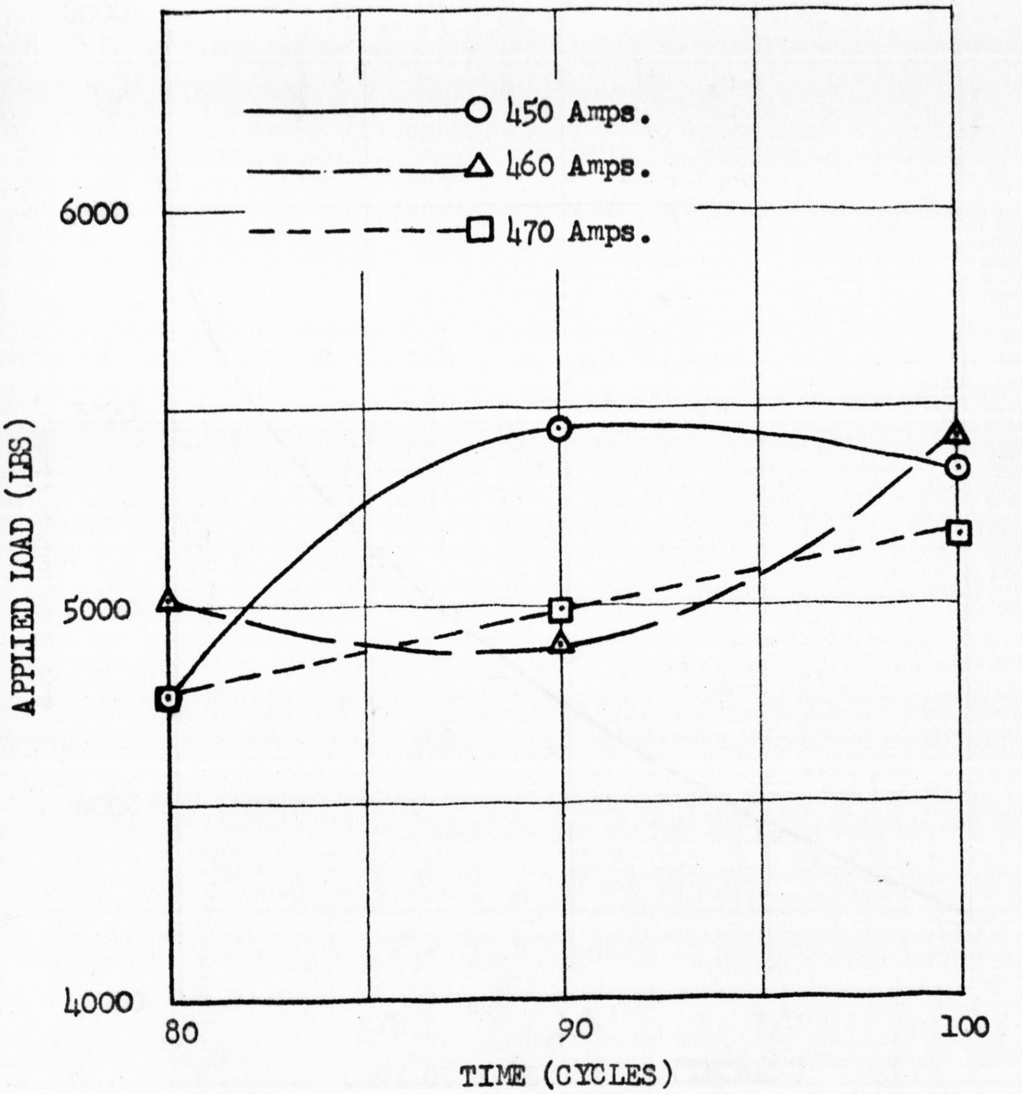


Figure 20. Effect of Time and Amperage on Load. Type J2 Specimen, 230 Volts Input, 42 Volts Output.

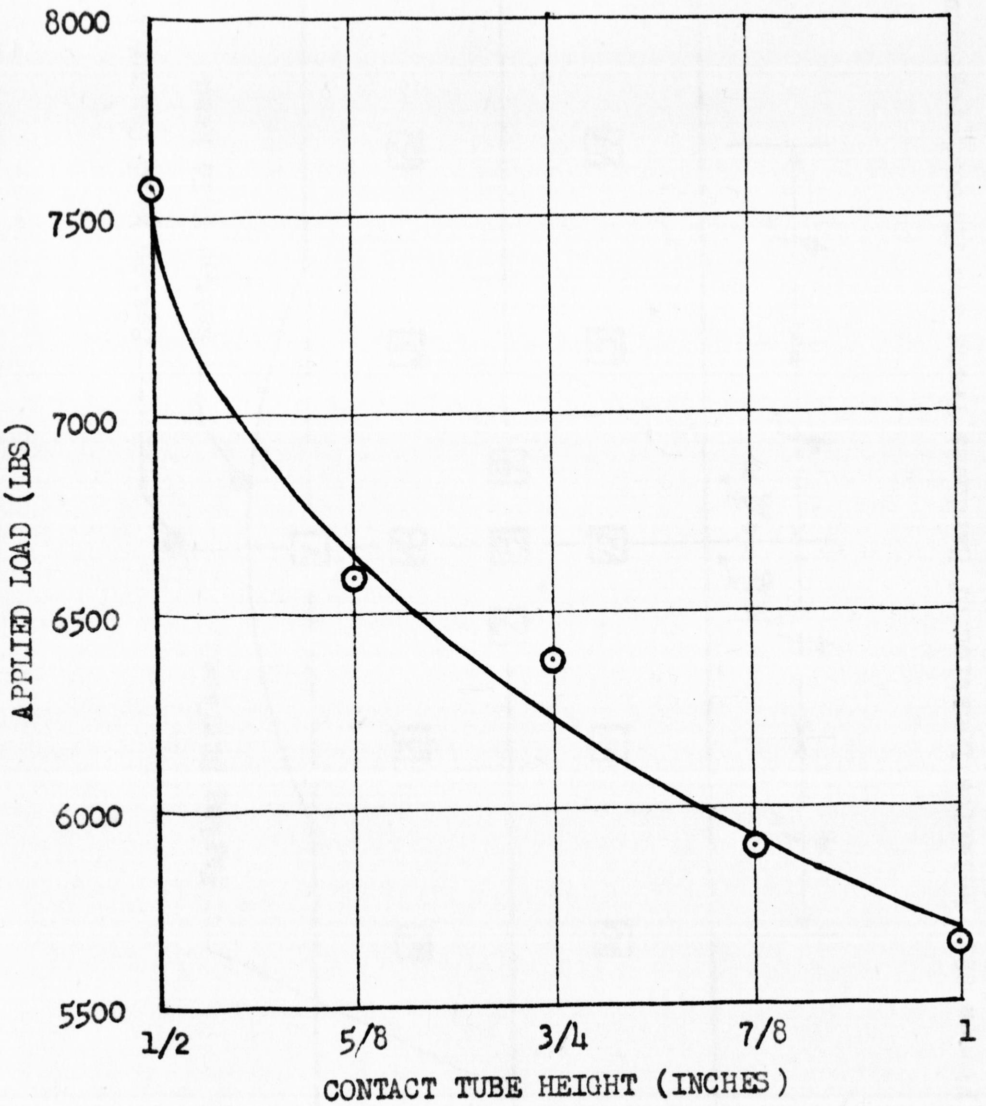


Figure 21. Effect of Contact Tube Height on Load. Type J1 Specimen, 230 Volts Input, 46 Volts Output, 400 Amperes, 180 Cycles Welding Time.

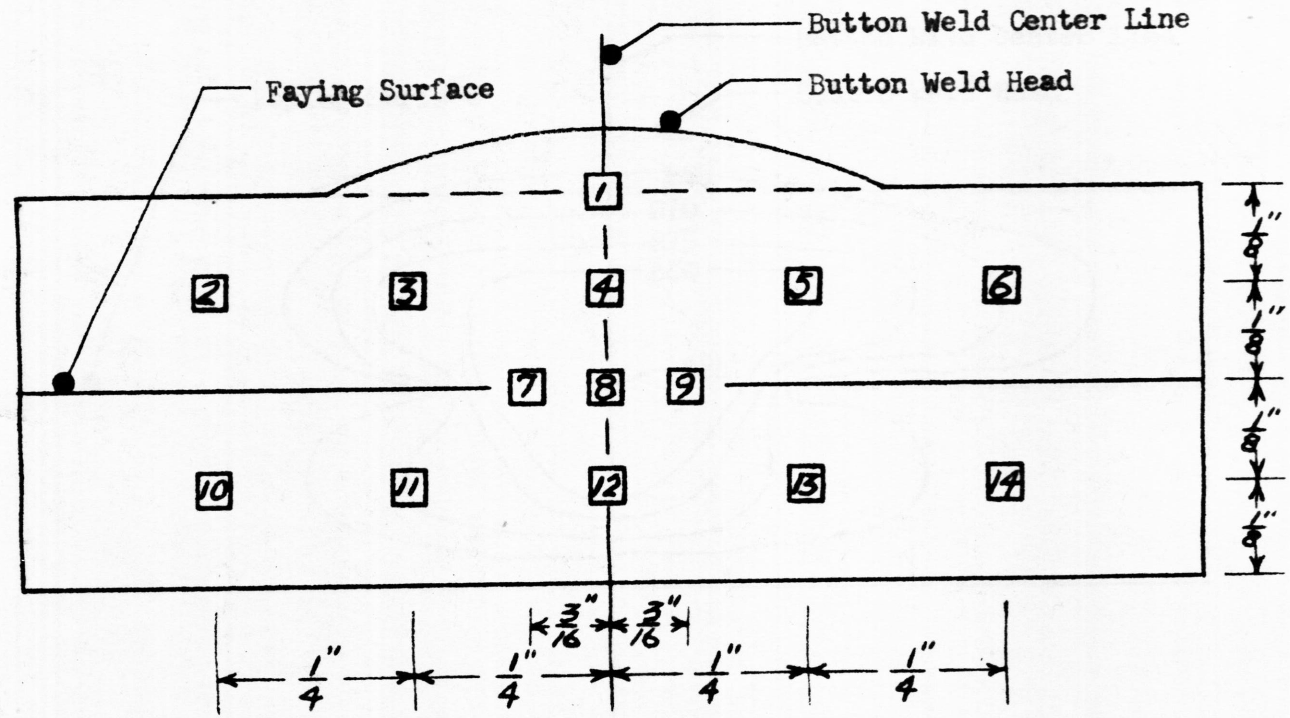


Figure 22. Relative Location of Hardness Tests and Photomicrographs.

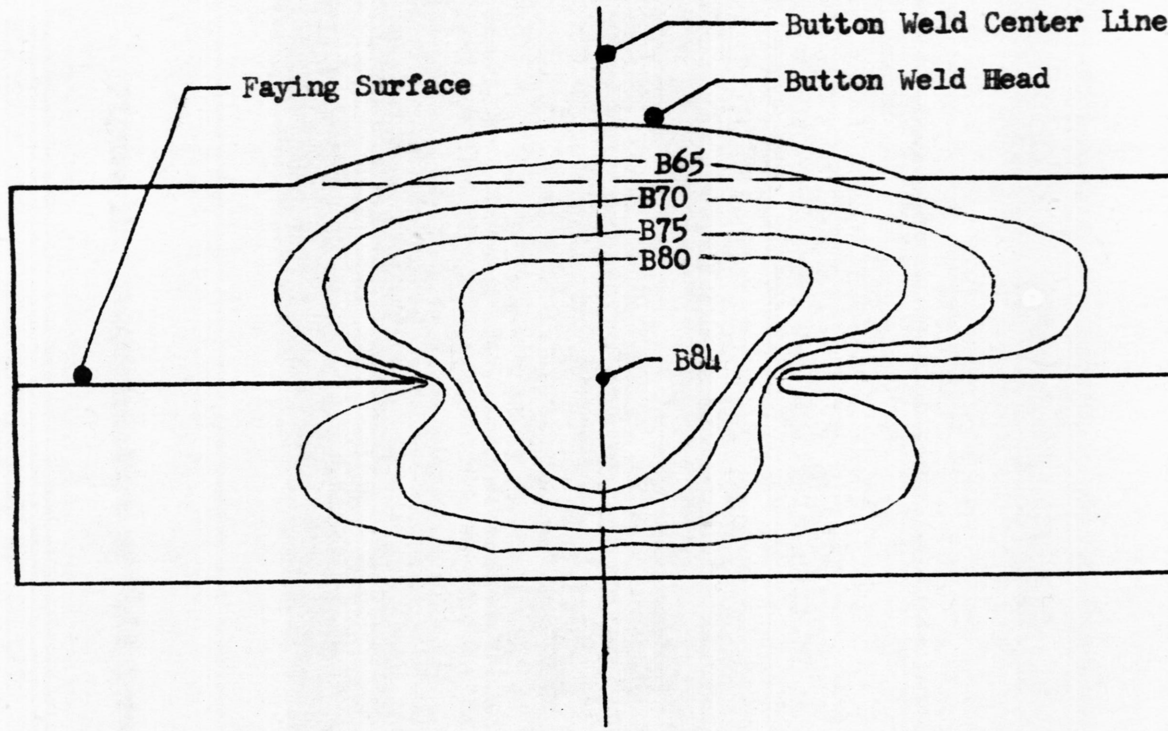


Figure 23. Hardness Cross-Section of Weld Area for Specimen No. 623.

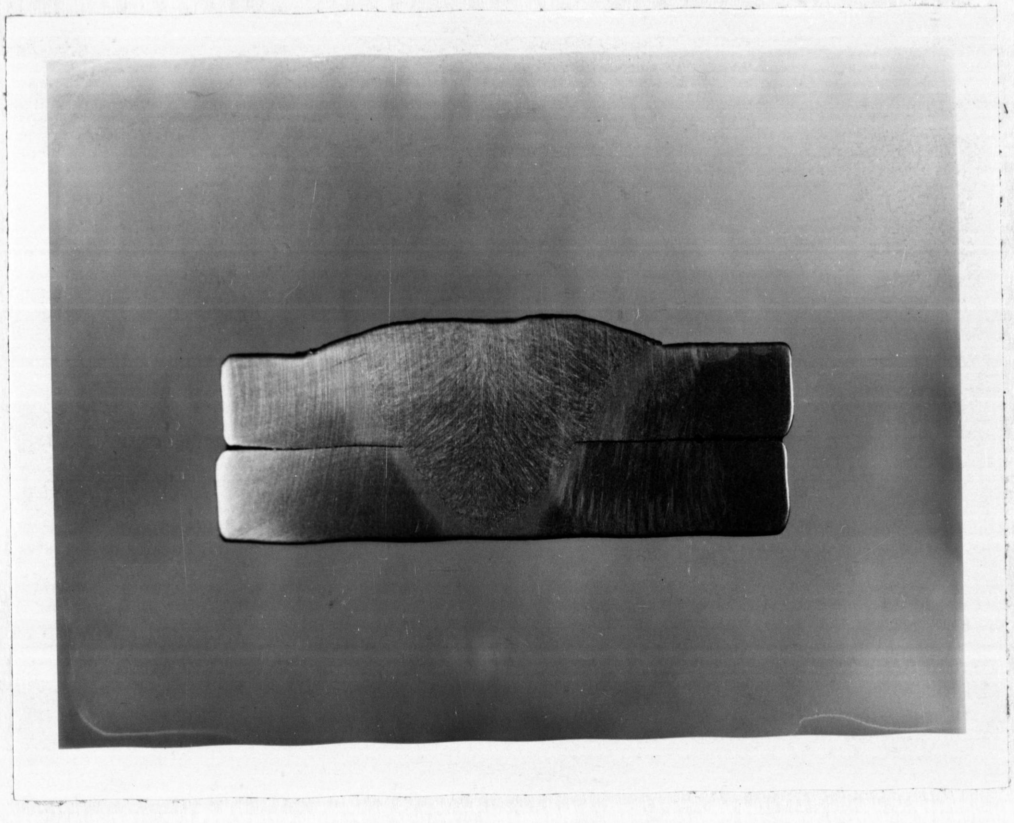


Figure 24. Macrostructure of Weld Area.

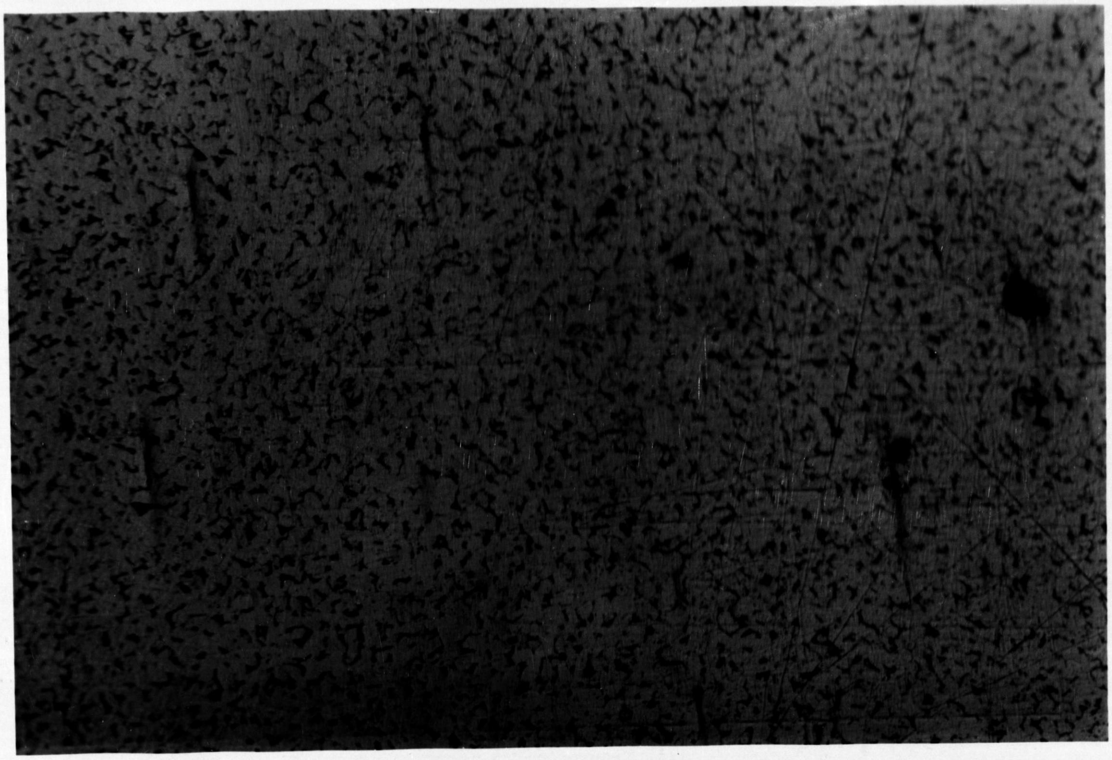


Figure 25. Microstructure of Work Pieces Prior to Welding.

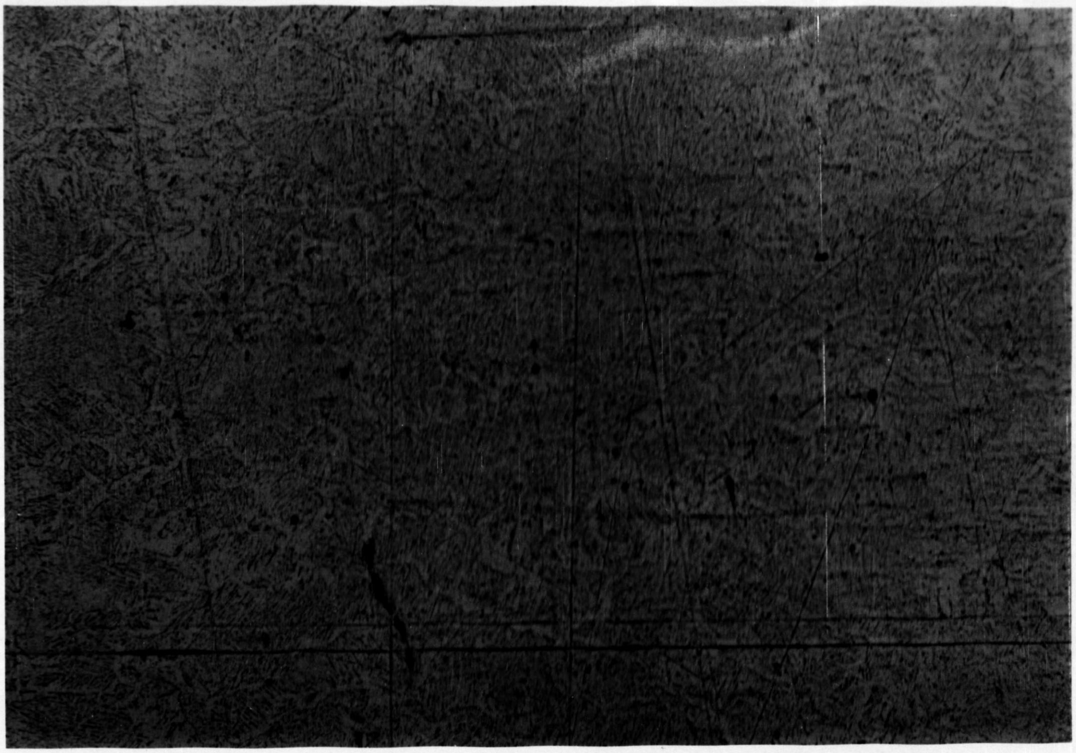


Figure 26. Microstructure of Weld Area.
(Location Number 1, Figure 22)

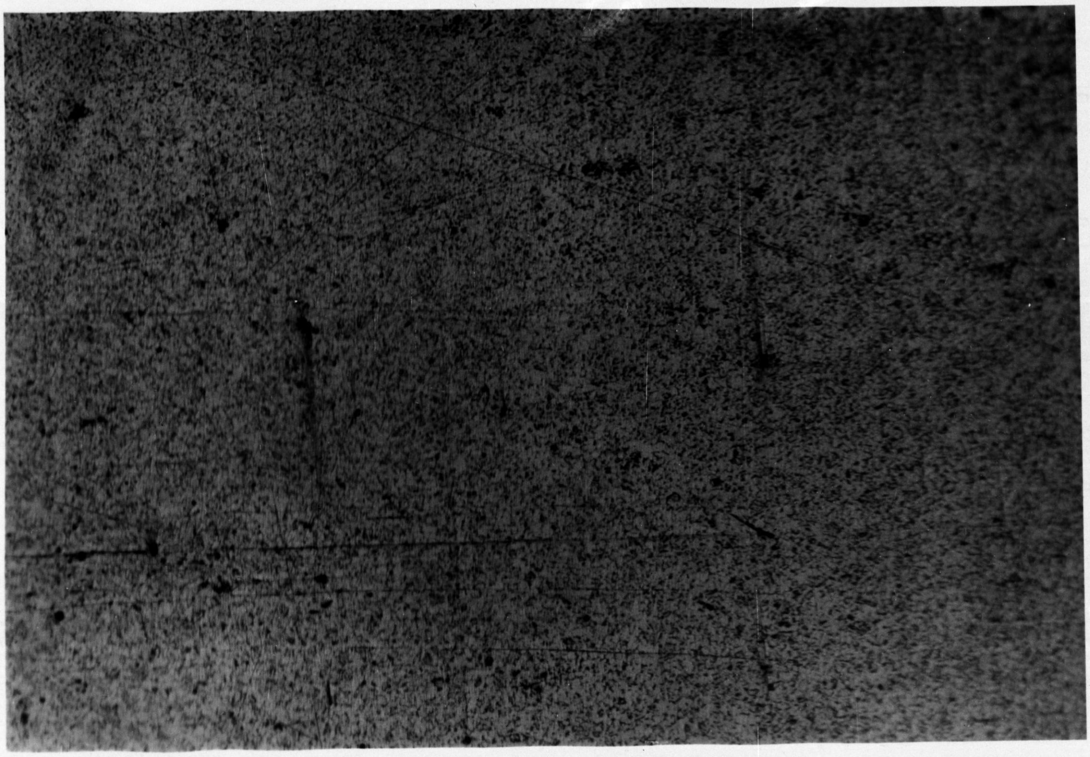


Figure 27. Microstructure of Weld Area.
(Location Number 2, Figure 22)

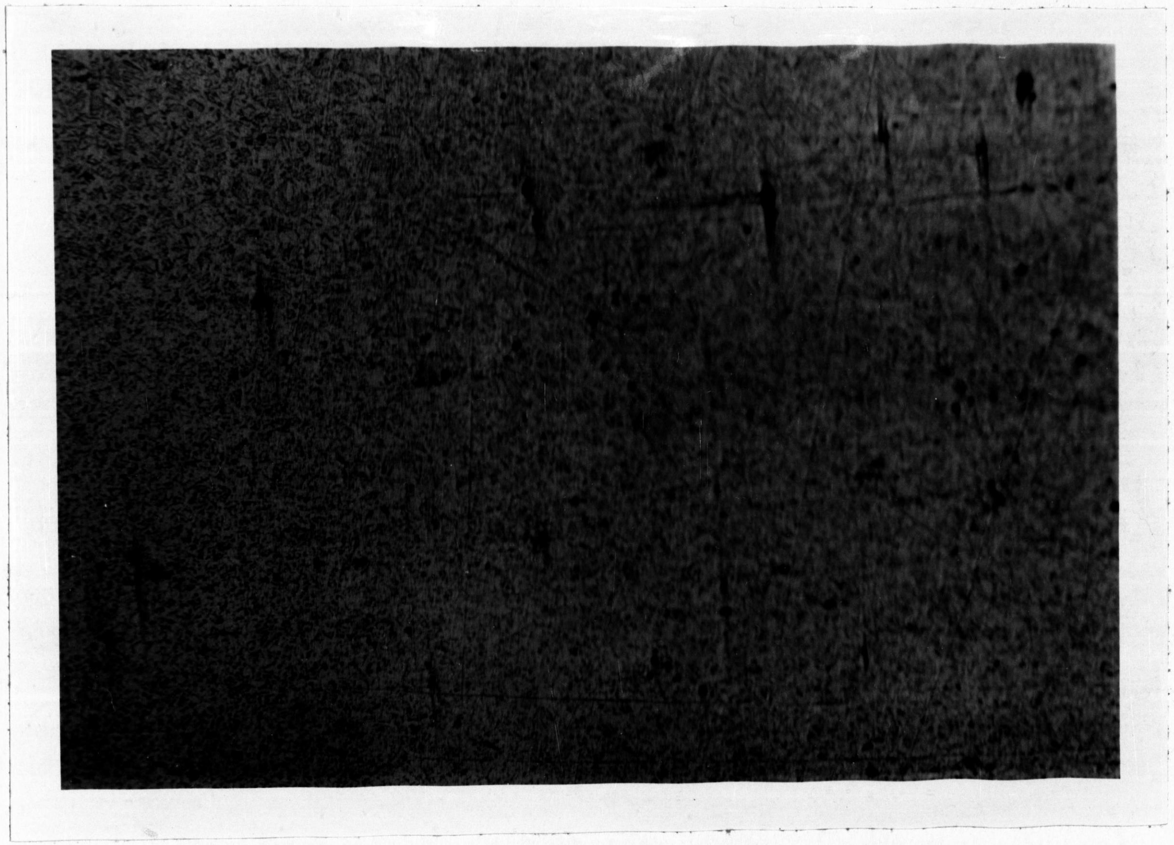


Figure 28. Microstructure of Weld Area.
(Location Number 3, Figure 22)

Figure 29. Microstructure of Weld Area.
(Location Number 4, Figure 22)

Figure 30. Microstructure of Weld Area.
(Location Number 5, Figure 22)

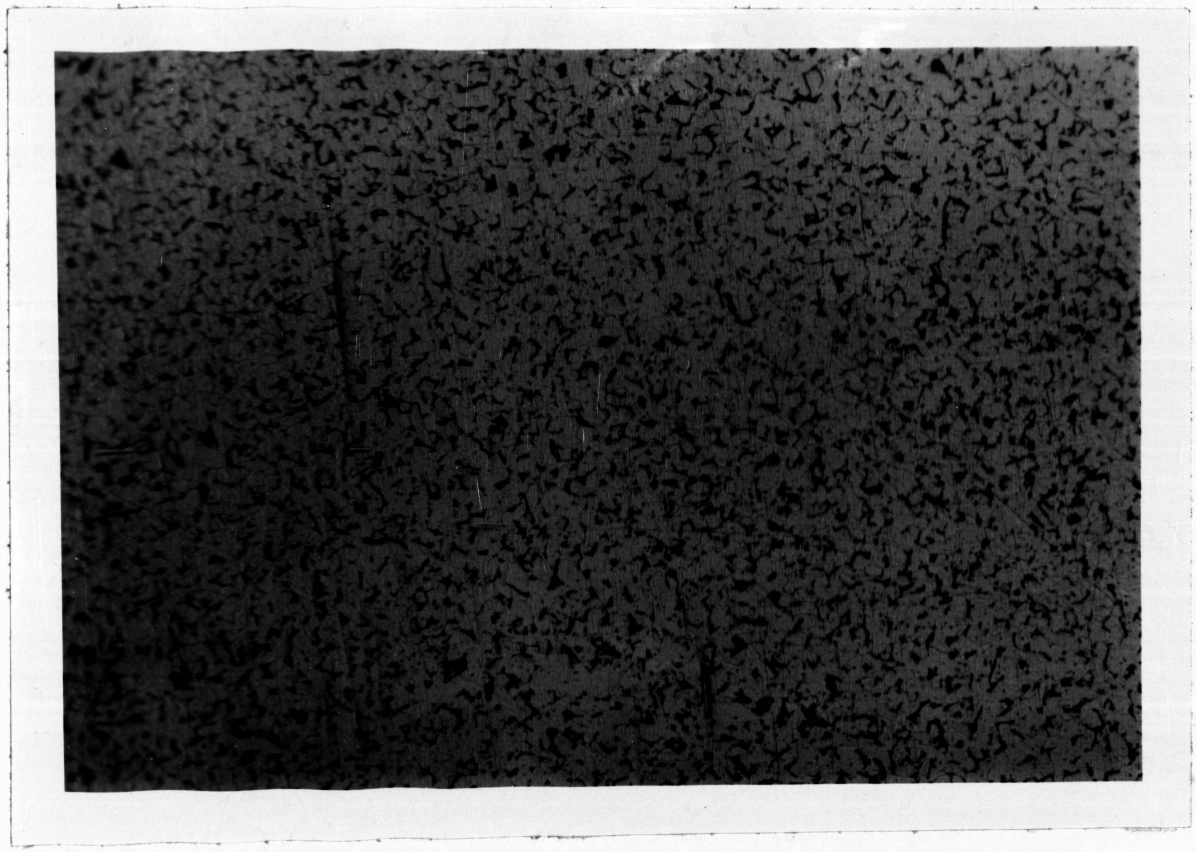


Figure 31. Microstructure of Weld Area.
(Location Number 6, Figure 22)

Figure 32. Microstructure of Weld Area.
(Location Number 7, Figure 22)

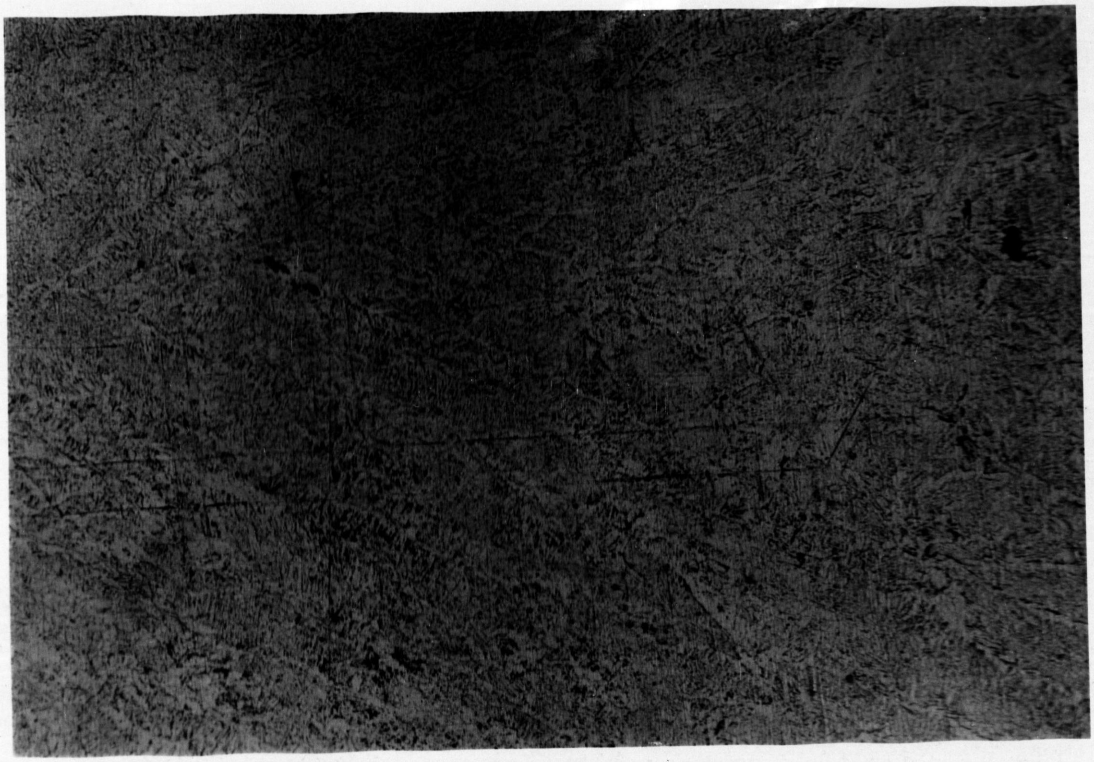


Figure 33. Microstructure of Weld Area.
(Location Number 8, Figure 22)

Figure 34. Microstructure of Weld Area.
(Location Number 9, Figure 22)

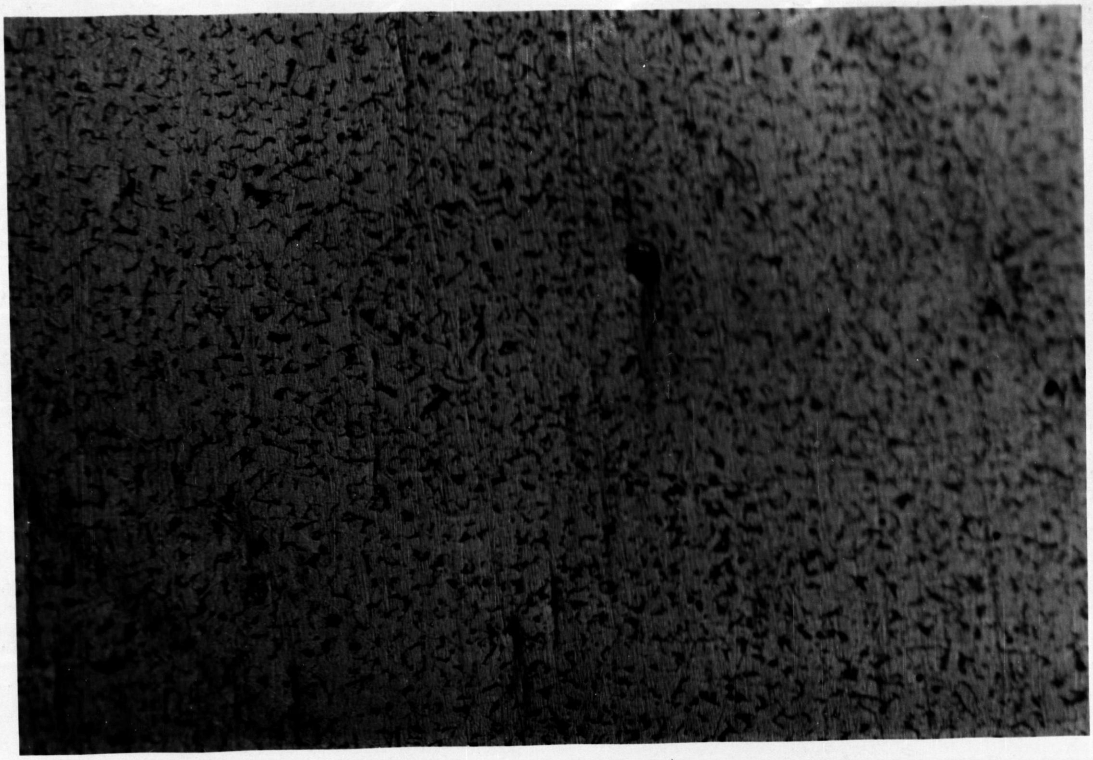


Figure 35. Microstructure of Weld Area.
(Location Number 10, Figure 22)

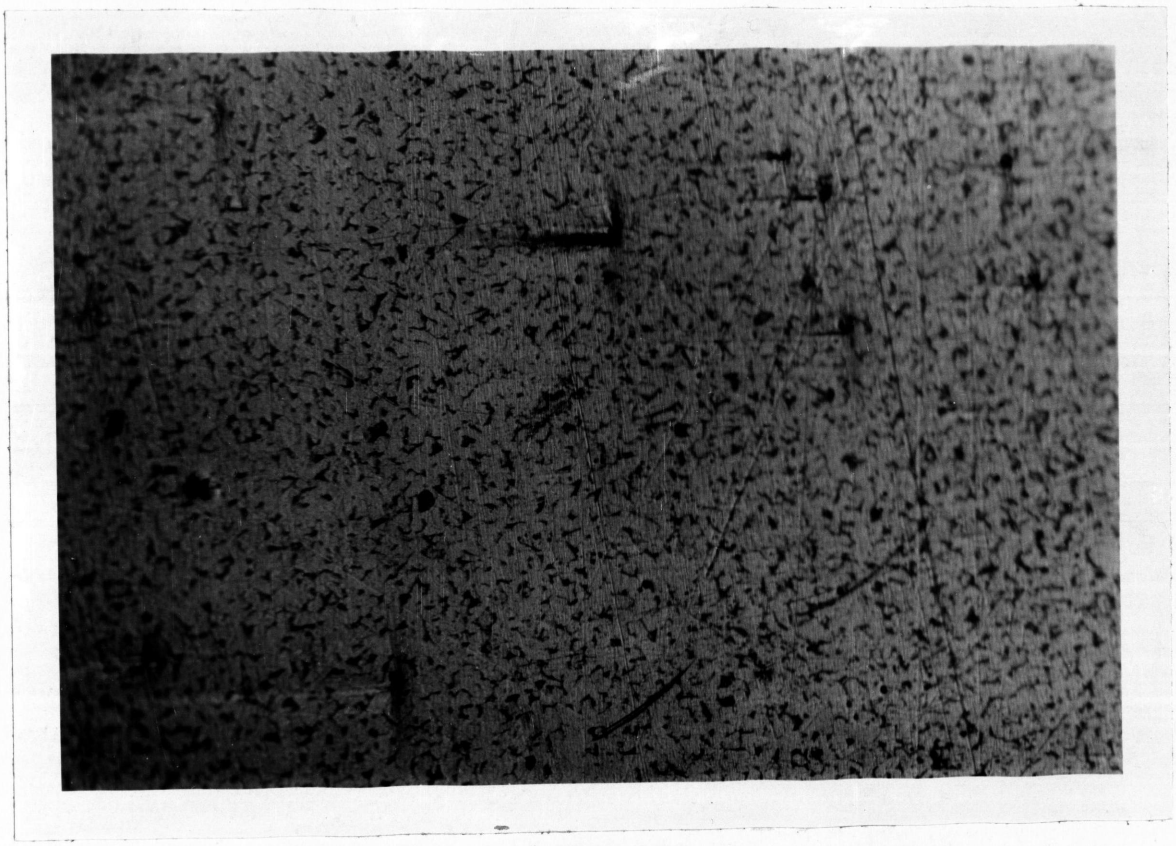


Figure 36. Microstructure of Weld Area.
(Location Number 11, Figure 22)

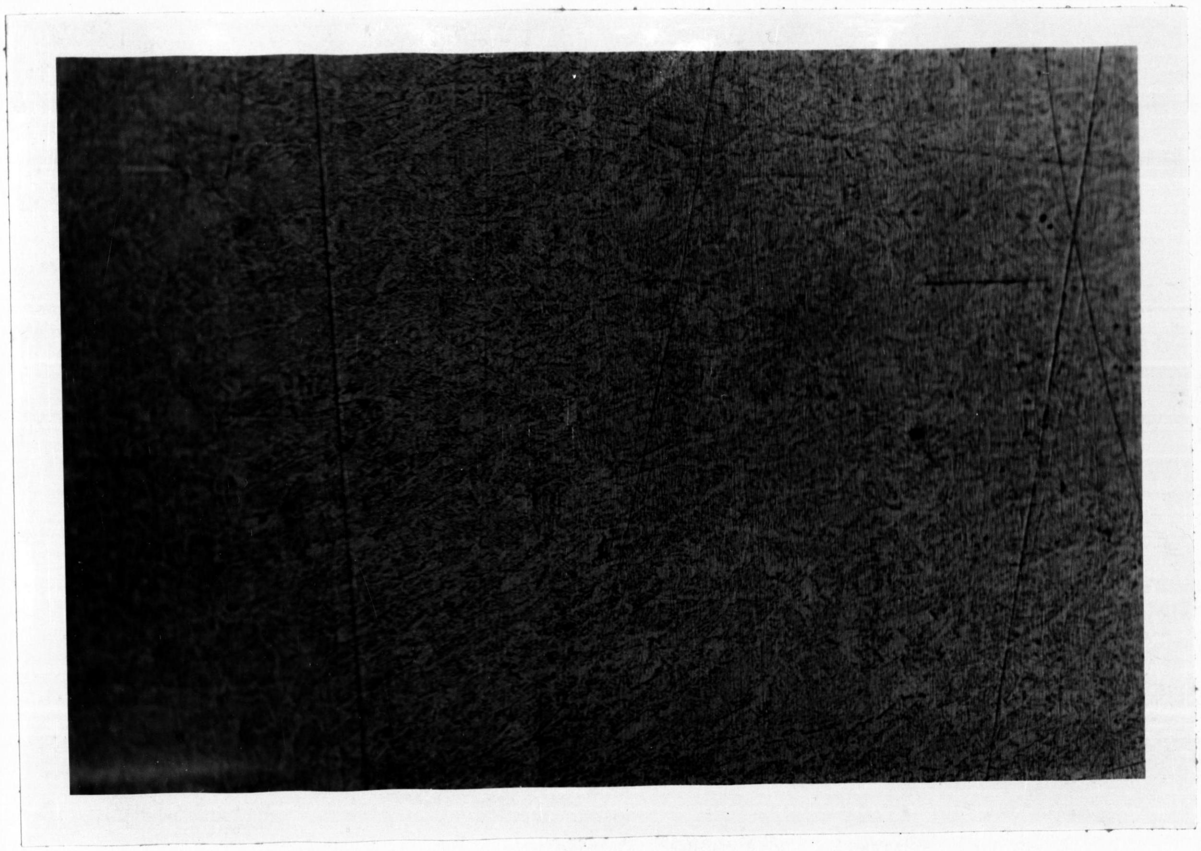


Figure 37. Microstructure of Weld Area.
(Location Number 12, Figure 22)

Figure 38. Microstructure of Weld Area.
(Location Number 13, Figure 22)

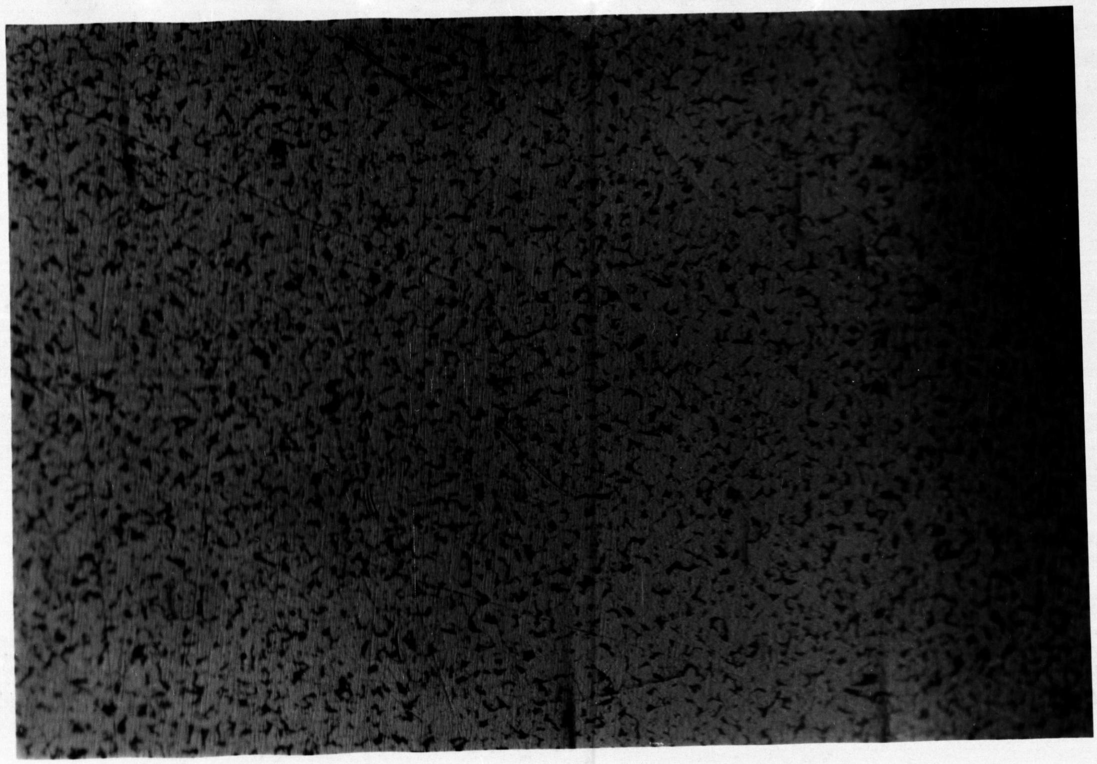


Figure 39. Microstructure of Weld Area.
(Location Number 14, Figure 22)