ELECTRIC WELDING OF HIGH PRESSURE VESSELS

by

Alfred Cave Richardson

A THESIS SUBMITTED FOR THE DEGREE OF

BACHELOR OF SCIENCE

MECHANICAL ENGINEERING COURSE

The University of Tennessee

1932

TABLE OF CONTENTS

I. GENERAL SURVEY OF THE FIELD.

1. Historical review.

2. Present state of the art of science.

3. Relation of proposed work to what has been done.

II. GENERAL THEORY.

III. DESCRIPTION OF METHOD USED FOR QUALIFICATION OF WELDERS.

1. Radiography.

2. Physical tests.

IV. APPARATUS USED.

1. Arc-welding machines.

2. Electrode coating.

3. Radiography equipment.

4. Annealing furnace.

V. DIFFICULTIES ENCOUNTERED AND METHODS OF OVERCOMING THEM.

VI. ECONOMICS OF WELDING.

1. Unit cost for different thickness plate.

2. relative cost of riveting and welding.

VII. BIBLIOGRAPHY.

VIII. APPROVAL SHEET.

GENERAL SURVEY OF THE FIELD

Far back into the ages of history comes fragments of history of the welding of ferrous metals. An outstanding example is the wrought iron column at Delhi, which is sixteen inches in diameter and extends twenty-two feet above the ground. This column is made up of welded sections, and is known to have been placed about the Fourth Century A. D. Many distinct types of welding come between this primitive type used and the so-called modern electric method used today. Among these are: forge welding, hammer welding, roll welding, resistance welding, and fusion welding.

Forge welding consists of three essential operations: (1) preparation of pieces to be joined, (2) heating and fluxing, (3) joining and hammering the juncture of the two pieces. In the preparation for this weld, the most common type of joint is the lap joint. The pieces after being heated by some heating element are fluxed to remove the oxide scale and to preserve clean surfaces. Having attained the proper temperature, the pieces are fitted together and rapidly hammered, working from the center of the juncture area, outward, so as to force out all slag and flux. The metals adjacent to the weld juncture are then hammered in order to break up any large grain structure caused by the high heat subjected.

Hammer welding is very similiar to the above described method of forge welding. It differs in that the joining of the two pieces is accomplished by rapid succession of blows by machinery, thus enabling larger sections to be welded.

Roll welding is used most extensively in the manufacture of pipe. The edges to be lapped are prepared similiar to that of forge welding. The plate is then heated and drawn thru a bell die which gives it the proper curvature and required lappage. It is then brought to a white heat and fed through the welding rolls which unite the two edges and reduce the juncture to the proper thickness. The complete process is carried out while the metal is at a white heat which prevents oxidation of the weld.

In resistance welding, the heating of the sections to be welded is accomplished by electricity. However, the joining of the sections is brought about by machinery. In this type of welding the units are first brought up to a white heat. Then the current is cut off and pressure is applied.

Fusion welding may be defined as the process of fusing and uniting metals with or without the introduction of additional materials. Oxy-acetylene and electric welding are the most important types used in the fusion

welding process. The oxy-acetylene type was the first to be introduced, since in this process two of the oldest combustible gases known are used.

The electric welding process is a more recent development. It has only been used for a short number of years, and is still in its infancy. It is with this latter process that the writer will endeavor to familiarize the reader. This process is used by the Hedges-Walsh-Weidner Company of Chattanooga, Tennessee.

GENERAL THEORY

Electric or arc welding is divided into two distinct types, metallic arc and carbon arc. The former is a process wherein the electrode used is a metal rod or wire, which, when melted by the arc, supplies the filler metal in the weld. Carbon arc welding is a process wherein a carbon electrode is used and filler metal supplied by a welding rod, which is melted by the heat resulting from the arc between the electrode and the base metal. Since the former process is preferable, the discussion will be limited to this type of welding.

The three primary requisites in this field are: (1) a well trained and experienced welder, (2) suitable equipment to give a constant flow of current and power, and (3) electrodes of proper chemical, physical, and electrical properties, together with proper coating.

As to the training of welders, the shop in question conducts its own instructional departments, thereby helping each man to become a qualified production welder. These men must be trained in order that they may become skilled in the art, being careful to note that they are consistent in turning out their work and doing their best at all times. The procedure used in qualifying new men to become welders will be discussed later.

The temperature of the electric arc is beyond the

scope of ordinary measuring instruments, but it is thought to be about 3600 degrees Centigrade. This, of course, is sufficiently high to cause the fusion of any metal to be welded. A large portion of the heat produced is generated in the positive electrode, thereby causing the heat to be most effective for melting the metal, which gives a chance for better fusion at the base.

Hand welders find that the welding current flowing to the electrode often sets up a magnetic field causing the arc to run wild. A remedy for this condition may be had by slanting the electrode forward or backward. Generally speaking the welder slants the electrode away from the ground connection.

Arc lengths do not alone govern welds. However, they constitute one of the most important factors. With a short arc, the heat is concentrated on the plate, while with a long arc a great deal of this heat is lost into the surrounding space. However, a short arc often causes a blowing effect with the electrode, and the base metal, thereby, allows atmospheric gases to enter the weld, making it very porous. On the other hand, a long arc is not as stable as a short arc, and tends to wander about over the plate. This action causes the hot metal to pool or crater and cool. This results in the impurities being

trapped along the sidewalls of the weld and forming what is known as slag.

It is almost impossible to give applicable figures covering current, speed, etc., for electric arc welding. This may be due to the condition under which the work is done and the skill of the workman. The same size electrode may be used with various thicknesses of plate, but the heavier plate will require the use of heavier current or higher heat.

A definite heat used for one size weld rod for a thin plate will often result in a very low heat for a heavier plate. A heavier plate conducts the heat more readily and cools off the weld, thereby causing the impurities to be trapped within the deposited metal.

From figure 1 for different size electrodes, a relation of pounds of metal deposited per hour to current in amperes may be of interest to the reader.

In the selection of metallic electrodes, it is very essential that the material used should have a composition as good, if not better, than the base metal. The chemical properties should be such that the material will be relatively free from impurities so as to mix thoroughly with the base metal, and forming as little slag as possible. For a sound weld, the chemical composition of the elec-

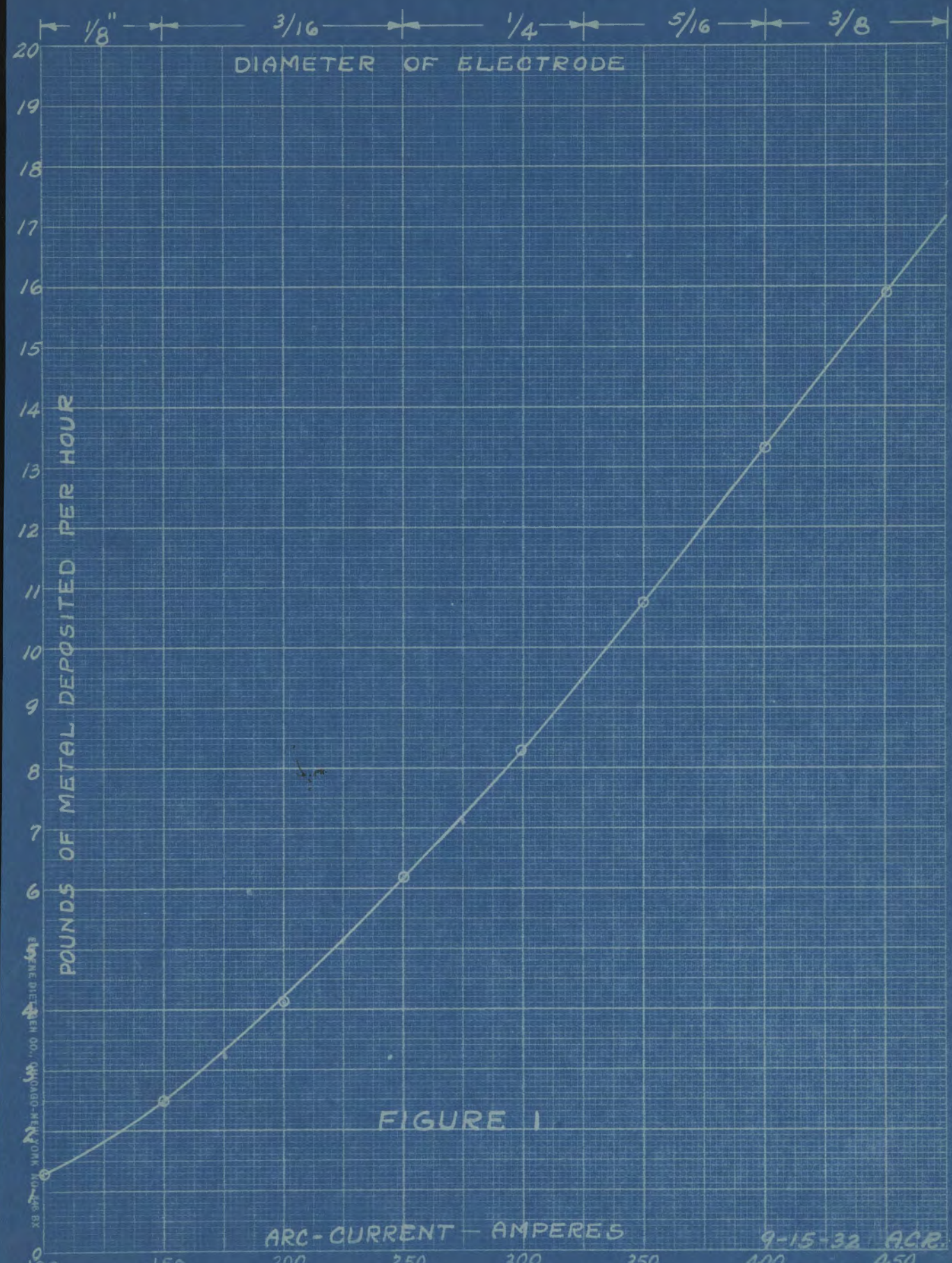

1/8"
3/16
1/4
5/16
3/8
DIAMETER OF ELECTRODE
POUNDS OF METAL DEPOSITED PER HOUR
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
100
150
200
250
300
350
400
450
ARC-CURRENT — AMPERES
9-15-32 A.C.R.
KEUFFEL & ESSER CO., CHICAGO-NEW YORK

FIGURE 1

trode should be within the following limits.

Carbon.....not over .06

Manganese.....not over .15

Phosphorous.....not over .04

Sulphur.....not over .04

Silicon.....not over .08

DESCRIPTION OF METHOD USED FOR QUALIFICATION OF WELDERS

The qualification of welders is a very serious problem with the manufacturer in that it requires considerable time and meney before these men are ready to do production welding. It has been found best to qualify several of these men at a time as the organization grows and the business requires their services. A school of twenty to thirty men working together has proved very satisfactory. That is, a class lecture may be conducted twice each week for the first two or three weeks by some member of the organization in order to familiarize the men with the fundamentals of welding. This is a great saving of time by getting the men started correctly.

After these lectures, the men are given their necessary apparatus, a location for all their work, and an instructor who at all times helps them to improve the quality of their work. When the instructor thinks that a man has successfully completed the welding of two test plates together, the plate is then carried to the X-ray department where it is inspected for defects. If the weld is found to have many defects, it is thrown into the scrap and two more plates given the man to start welding on again.

If, however, the weld is found to be sound, it is annealed and cut up for physical test. Among the tests for each plate are transverse tension, transverse bend, deposited metal tests, and specific gravity. After a number of these tests are made for different thickness plate in the physical laboratory, and found to come up to or above the ASME Code requirements, the welder is then qualified to do production welding.

Shown below are results taken from nearly eight hundred welded qualification plates. These results are taken from the welder's qualification records, and include only those welds made from the first attempt to the point at which they were allowed to do production welding.

TEST	CODE REQUIREMENTS	AVERAGE RESULTS	% FAILURE
Free Bend	30 % Elongation of outer fibers	50.7	2.6
Transverse Tension	55,000#/ "	58,330#/ "	9.1
Specific Gravity	7.80 Minimum	7.842	1.2
Yield Point Deposited Metal	27,500#/ "	38,300#/ "	0.0
Elongation in 2"	20%	29.45%	5.0
Tensile Strength	55,000#/ "	60,000#/ "	5.0

ARC-WELDING MACHINES

In the early stages of the art, little was known about arc-welding requirements and procedure. However, as this method has advanced, a number of different type machines have been introduced to the manufacturer of welder pressure vessels. Many of these machines were very good considering the fact that they varied somewhat in the principal operation and control.

Since the generator is the most important part of the arc-welding machine, it should be given very careful study of design by the purchaser. It must be capable of welding successfully over a wide range of current, and should have a rapid step-up of voltage in order to provide a stable and flexible arc.

The generator is differentially compound wound and self-excited. It has dual magnetic circuits; one carries the main flux and the other the cross flux. The current and voltage characteristics are produced by the combining effects of armature reactions, magnetic circuits, and the differential series field. In other words, with these characteristics the generator may be said to be self-regulating. A transformer is used in connections to limit excessive current surges, provide a very rapid voltage recovery, and thereby, maintain constant current during the welding operation.

Shown below are average results taken from more than fifty different welders as to the current and voltage used on coated electrodes of different diameters.

DIAMETER ROD	CURRENT	VOLTAGE
1/8"	120 Amps	50 Volts
3/16"	200 "	70 "
1/4"	275 "	70 "
5/16"	350 "	70 "
3/8"	425 "	70 "

These figures do not take into consideration the distance the welder may be from his machine. The size and length of lead constitutes to a great extent just how much additional heat must be generated. A lead of from fifty to seventy-five feet requires additional current of from seventy-five to one hundred amps.

ELECTRODE COATING

As an improvement over bare rod welding, there are several brands of flux coated rods on the market. Many of these have been used with better results than with bare rods. The functions of this flux coating in the writers opinion are three-fold.

First, it must be a material having the same rate of fusion as the electrode so that protection is afforded just previously to, and at the point of, the electrode's being converted into the vaporous state at the arc. It probably provides to some extent a cylinder of shielding vapor to the arc, preventing combination with atmospheric gases which burn out the carbon content, oxidizing the vapor, and allowing the harmful formation of nitrides.

Secondly, as the flux is deposited on the surface of the molten metal, it forms a protective coating during the solidification and cooling of the metal.

Thirdly, some of the molten flux is carried beneath the surface of the metal pool at the base of the arc, and there tends to unite with impurities and float them to the surface as slag.

It is with this shielded arc that manufacturers of welded pressure vessels have been able to produce a weld of any practical thickness plate so adapted to withstand the most rigid of physical test.

RADIOGRAPHY EQUIPMENT

Inspection of welded pressure vessels are of the most rigid nature. Vessels of riveted design can be determined by formulas, but by other than destructive tests there are no means of determining the quality of welded work. No matter how efficient the welding operation may be, there always remains the possibility of defects beneath the surface of the weld. X-ray examination has proved to be an extremely reliable means of determining the internal nature of welded joints.

With the X-ray machine used in the above mentioned plant, steel plates up to four inches in thickness have been successfully examined. The entire unit, with the exception of the controls, is housed within a heavily lined lead cab; lead, being practically immune to X-ray penetration, affords protection from the X-ray energy to the operator. This cab is mobile, being set upon tracks to make possible its being moved along the side of the vessel to be examined, or being racked toward or away from the vessel.

The X-ray tubes are mounted inside the cab and on the same framework as the adjustable openings on the side of the cab toward the vessel to be X-rayed. These openings or cones are 18" x 6", and can be raised or lowered any desired amount by controls near the operator. These cones

are brought up to touch the side of the vessel, and the X-rays generated by the tubes are projected through them on the film placed inside the vessel. Before the X-raying is started, the longitudinal seams are laid off in sections of sixteen inches, and these sections are numbered in order and stenciled on the center lines above the weld. The same procedure is followed for the girth seams, except that the numbers are stenciled on the centerlines of the sections along the side weld. Small lead numbers are stuck on top of the stenciled numbers. When the picture is taken, the rays do not penetrate through the lead numbers, thus leaving their image upon the film. This makes possible the exact location of any defects to be removed from the weld.

The use of radiography in examination of welded joints has been very satisfactory. However, a still more thorough examination of this joint in question may be made by the use of the stereoscope.

The stereoscope is an instrument so constructed that the operator may obtain a depth perspective as well as a length and breadth of the point or region under observation.

This instrument consists of two illuminating boxes that are arranged, facing one another, on a sliding track, in such a manner that they may be moved toward or from each other. At a central point between the two boxes is placed

a pair of mirrors with angular adjustment for the accommodation of the observer's eyes. The reflection in the mirrors of the two respective radiographs in the illuminating boxes brings out an optical effect, whereby the eyes view the radiograph as one image in stereoscopic relief. The illuminating boxes are constructed so that they may be shifted backward or forward in order that any slight errors in the focal film distance (focal film distance means, distance from target of X-ray tube to film) may be compensated for.

This instrument is equipped with a resistance unit, attached under the mirrors in the center. The purpose of this unit is to increase or decrease the intensity of the light, and to find the relation of the different densities of films, which must be viewed stereoscopically. The mirrors are so constructed that they may be lowered or raised, in order that they may be centered vertically with the film. They are arranged to be tilted sidewise to compensate for any error in the films, for they may not be exactly in the same position in relation to the part exposed. They, also, are so arranged that their angle in relation to the film may be altered. This is done in order that the images of the two films may be so superimposed, that in effect, only one image appears when looking into the mirrors.

Two films are necessary in doing stereoscopic work. One exposure must be made with the X-ray tube in one position, and another exposure made with the tube in another position, these positions corresponding to the average interpupillary distance of the eyes. The two films are then placed in the illuminating boxes in such a manner that one eye will see one film, and the other eye will see the other film through their respective reflections in the mirrors. The illuminating boxes and mirrors are then so adjusted that the two images become superimposed, thereby giving a stereoscopic image or the depth perspective, which is desired.

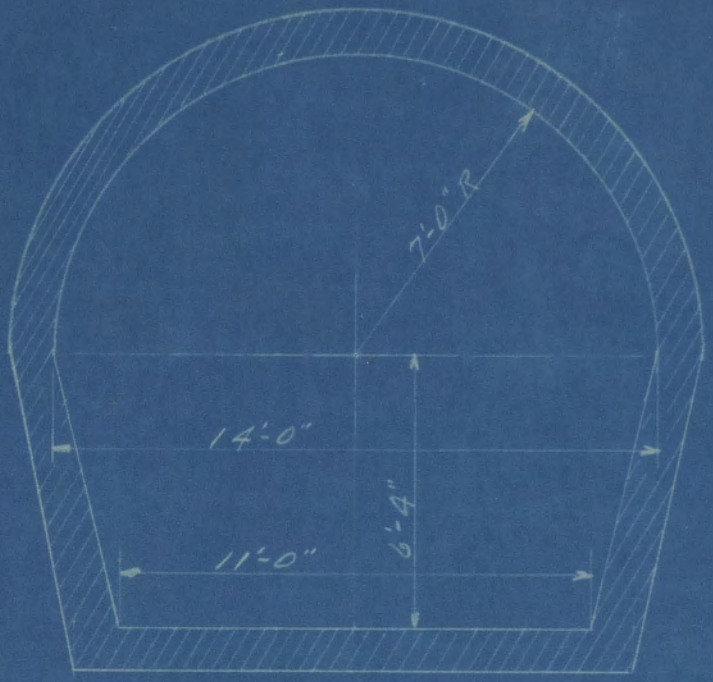
ANNEALING FURNACE

A very important step, and one of great necessity in the building of welded pressure vessels, is that of stress relieving. The furnace design is one for careful consideration, since it must be of a very large capacity with sensitive temperature control, uniformity of temperature, economical, and efficient operation.

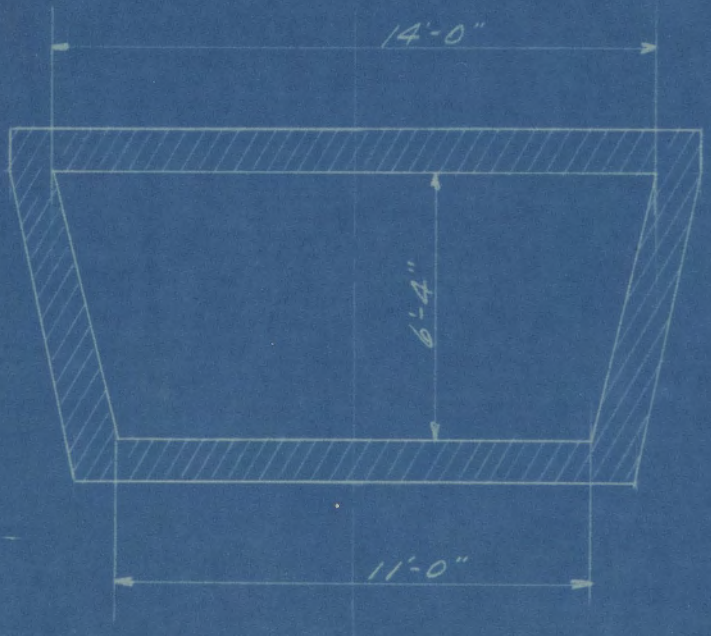
The outcome of several months of study of existing furnace designs has resulted in the furnace now in use at the plant under discussion. Figure 2 is a cross section of the furnace, built with its bottom section having sloping sides outward, and with elevated tracks at each end to accommodate the rolling off of the arch top and flat top. The arch top may be used with vessels up to eleven feet in diameter, while the flat top is used for vessels six feet and under in diameter.

Each of the covers is made up of sixteen-foot lengths, so that with the use of two end seals, which are handled by shop cranes, the furnace may be quickly changed from sixteen-foot to thirty-two, forty-eight, or sixty-four-foot lengths. So uniform are the temperature regulations that under normal operating conditions of 1250 degrees Fahrenheit, this temperature may be reached in three to four hours after "setting off", with maximum temperature difference at that point of 50 degrees.

ANNEALING FURNACE
HEDGES WALSH WEIDNER CO.
CHATTANOOGA



CROSS SECTION WITH ARCH TOP



CROSS SECTION WITH FLAT TOP

FIGURE 2

ANC 10-6-31

A vessel, the largest that can be shipped, may be stress-relieved in a furnace of this design.

DIFFICULTIES ENCOUNTERED AND METHODS OF OVERCOMING THEM

Some impurities affect the weld by weakening it, some by making it brittle, while others by making the deposited metal so hard that it cannot be machined. Gas pockets, slag, oxides, etc., will to a great extent weaken the weld, and can be best eliminated by using a short arc and by keeping the weld and electrode clean. The short arc increases the heat, thereby doing away with practically all slag inclusions, but encountering a greater possibility for gas pockets. In this case the flux coated rod is an essential factor, since it shields the arc from outside gas vapors.

Brittle and hard welds are often caused by a long arc which permits the hot metal to be exposed to the air, causing an absorption of nitrogen. This is especially true of welds on metal of high carbon content. During the fusion welding of plates of appreciable thickness, stresses are very often so great as to cause shrinkage cracks. In some instances, these cracks are confined to one thin layer or one bead of the metal, while again they may reopen through the next layer and continue through-out the depth of the weld. These cracks are most apt to occur in the weld at an angle normal to the surface, which can be easily detected on the X-ray photograph. Here again, the

experience and ability of the welder enter into the class of work produced.

ECONOMICS OF WELDING

To date, very little is known as to the economics of welding. Many factors enter into an estimate when one stops to compare the relative cost of riveting and welding. Manufacturers do know that at the present time the fabrication of thin plates, one inch and under, can be riveted at a less cost than can be welded. From figure 3, it can be very easily seen where the cost of riveting as compared to welding starts upward. This chart was prepared on a standard water tube boiler drum 48" in diameter by 20' long for different thickness plate.

In the fabrication of pressure vessels to be used in the oil refining industry, still another factor enters into the comparative cost of design. With these vessels where internal trays and supports are necessary, the cost of fabrication has in most every case proved to be less with welding, regardless of thickness plate. This may be accounted for by the fact that the joint efficiency for riveted vessels would be much less, since only outside buttstraps could be used. And, too, the cost of countersinking every rivet head from the inside of the shell is high.

Considering a case in which the weight of the vessel becomes an important factor, there can be no other design to compete with butt-welded seams. Here, it is possible

EUGENE DIETZGEN CO., CHICAGO-NEW YORK NO. 346 EX

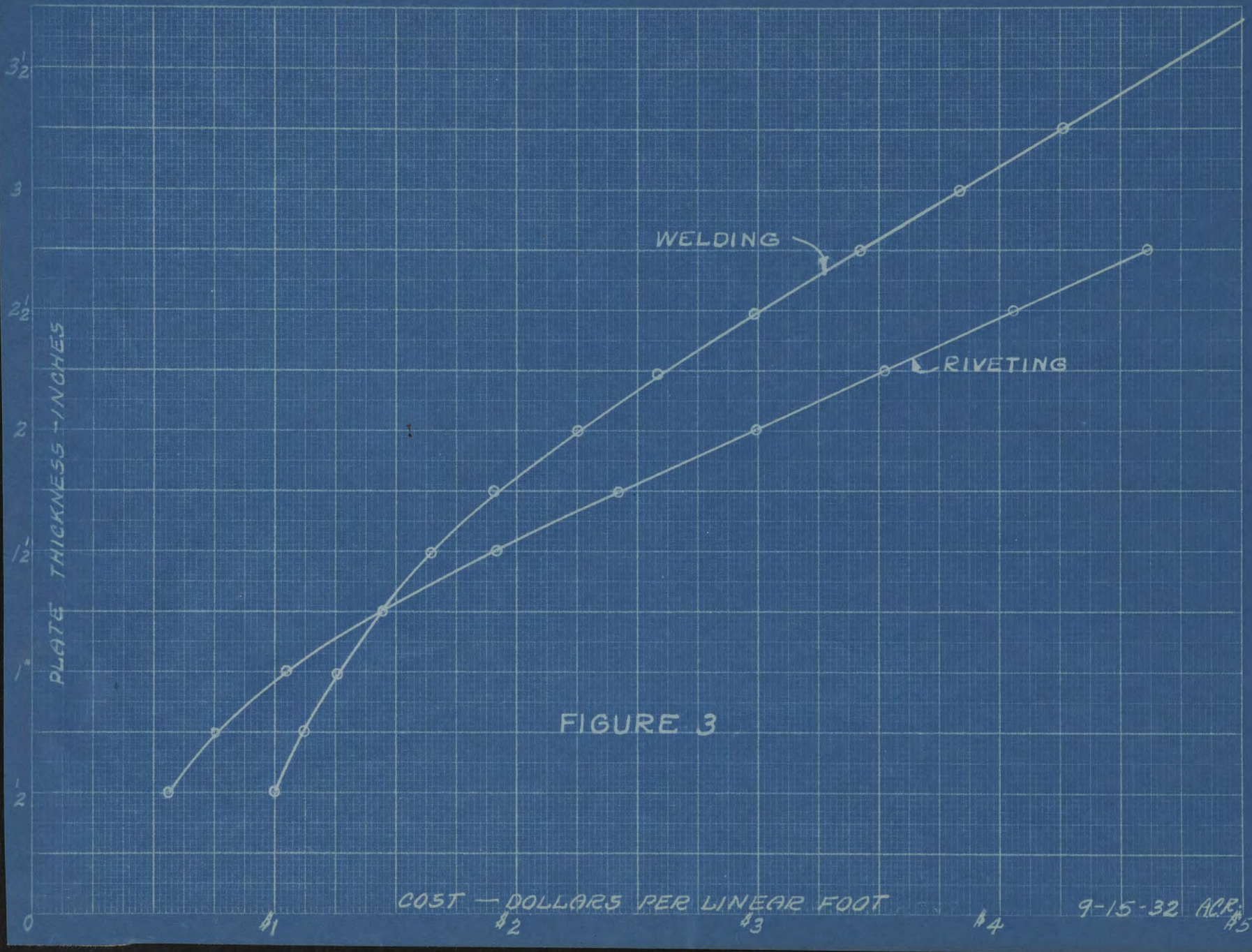


FIGURE 3

to do away with the weight of buttstraps, lapping of head seams, and excessive weights of rivets. From figure 4, weights of weld rod used per linear foot for different thickness plate may be studied. These weights vary but little with the weight of the solid plate itself.

Manufacturers, who are confronted with the problem of the hauling of liquors and strong acids, have learned that welded joints have a much greater resistance to corrosive tests than joints of riveted design. Results from a series of tests made by the writer on boiler plates welded together with standard rod, then boiled in new concentrated acid for five 48 hour runs, show that the deposited metal has a greater resistance to corrosion than the plate itself. Just recently, the Hedges-Walsh-Weidner Company finished the welded fabrication of several high chrome iron vessels for a well known concern with this point in mind.

EUGENE DIETZGEN CO., CHICAGO-NEW YORK NO. 246 8X

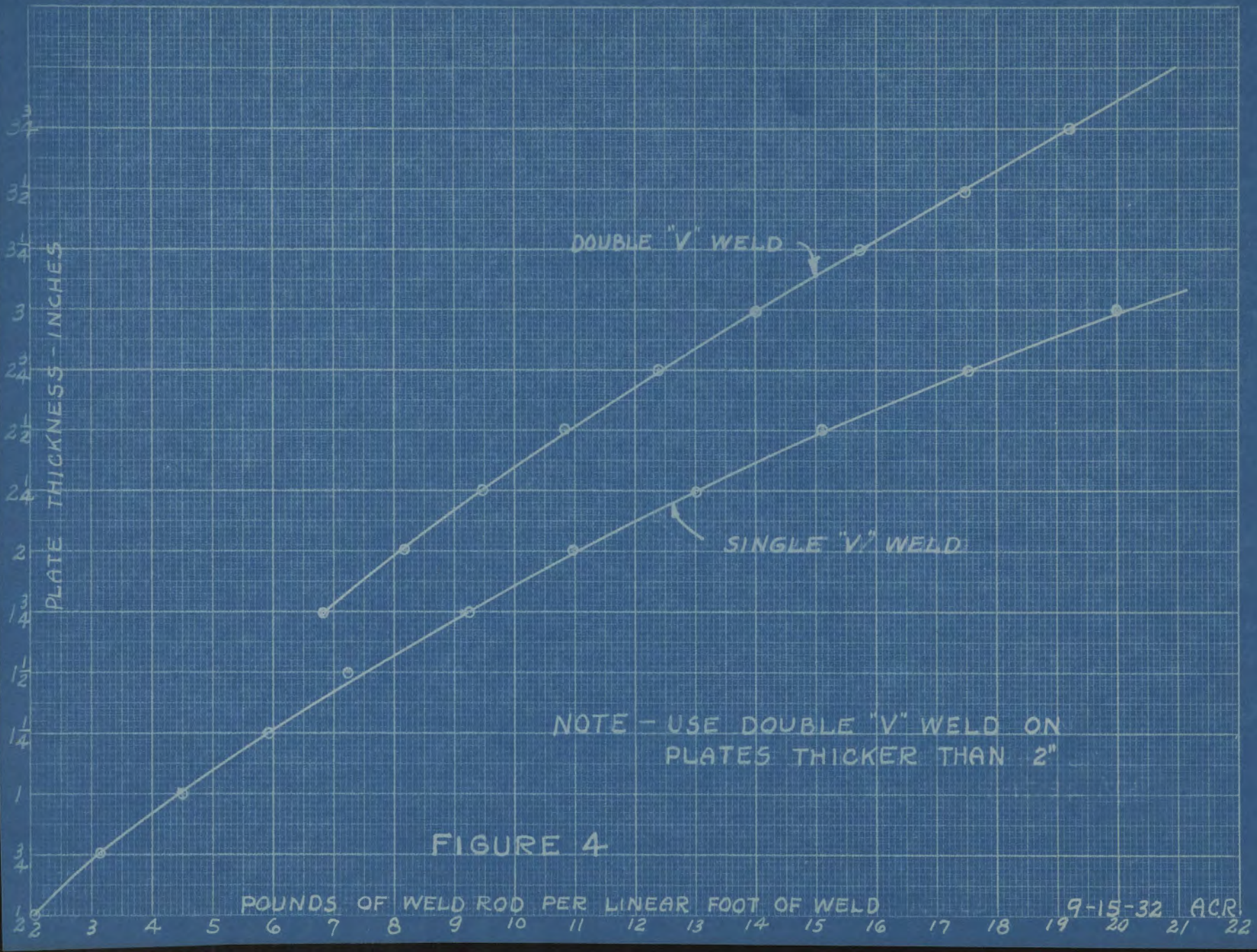


FIGURE 4

BIBLIOGRAPHY

1. Jerman's Modern X-ray Technic.

2. Wright, F. H., Research Engineer,
Hedges-Walsh-Weidner Company.

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

Name W. T. Woodbridge

Title Prof. Mech. Eng.