

A STUDY OF THE STRENGTH
OF
ARC WELDED JOINTS

by

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INTRODUCTION

In view of the rapidly increasing importance and widespread use of arc welding, it should be of interest to those in the engineering profession, or to those about to enter that profession, to become acquainted with the possibilities of this comparatively new art. With this idea in mind, this paper was written.

Contained herein will be found the treatment of three things: First, the ability of the average person to learn the art of arc welding; Second, actual tests of welded joints; Third, the importance of careful work by welders in commercial fields.

The respect in which this work differs from the mass of writing upon the subject is that this work was performed by one who undertook the learning of the art of arc welding. It was not done by a professional welder, nor was it carried on for commercial gain, but expressly for the purpose of this study.

GENERAL SURVEY OF THE FIELD

Arc welding seems to have had its beginning in 1881. At that time, De Meritens employed the process for uniting lead storage battery plates. The process was simple; an arc was drawn between the lead and a carbon electrode, the heat from which fused the work into the desired union. Later the process was applied to iron and steel by Bernardos, Olezewski, Coffin and others. It was found, however, that the combination of the carbon from the electrode with the steel to be welded tended to harden the steel and cause cracks. To remedy this difficulty, Slavienoff employed a metal electrode. The gradual melting away of the metallic electrode furnished metal for forming the joints and building up defective spots in the work.

Since the discovery of the process of arc welding, great progress has been made in its development. In the early stages of development, industry regarded it with suspicion and scepticism. In recent years, however, as a result of thousands upon thousands of tests and practical applications of arc welding, the industrial world has become reconciled to the fact that the process is one of the strongest, simplest, and most economical methods of joining metals both in construction, manufacture, and repair work.

The ferrous metals such as structural steel, wrought

iron, steel castings, cast iron, nickel and manganese steels, and a few of the other alloy steels may be welded with great success. Some of the non-ferrous metals such as brass, bronze, and monel metal may be welded by the metallic arc, but with difficulty.

The greatest portion of the arc welding work today is being done upon structural steel. The joining of steel members by metallic arc welding has become a recognized practice in the structural steel field. A large number of welded buildings and structures of various types have been erected and have proven entirely satisfactory. There is no longer any question as to the safety or desirability of this type of construction when properly applied by competent designers and fabricators. In manufacture, there are countless applications of arc welding. There is an ever growing tendency in manufacture for heavy and costly castings to be replaced by lighter and inexpensive arc-welded steel fabrications. As regards repair practice, repairmen consider arc welding indispensable in their line of work. Thousands of dollars are saved annually by the use of arc welding in repair work.

It is the general opinion of many authorities on arc welding that the process will almost entirely replace riveting in the structural field. Arc welding has the following

advantages over riveting:

1. Saving in steel, thru elimination of gusset plates in such members as trusses.
2. Saving in steel in tension members because the effective cross section is not reduced by rivet holes.
3. Elimination of a large amount of detailing necessary in the layout of riveted members.
4. Elimination of punching operations necessary in riveted construction.
5. Elimination of noise caused by riveting.

A very important possibility for development in arc welding is found in boiler manufacture. At present, numerous experiments are being carried on in the large boiler plants in order to develop satisfactory arc welding methods which will eventually replace the costly riveting in the boiler field.

There have been numerous books and papers written upon the strength of arc-welded joints. The work done for this paper was done by an inexperienced welder, and the results recorded herein greatly underestimate the true value of the process of arc welding.

STATEMENT OF PURPOSE

The purpose of the work described in this paper is two-fold:

1. To make a study of the ability of the average individual to learn to weld simple joints by the metallic-arc process.

2. To make a study of the strength of the joints so welded.

It is intended to be shown that arc welding, when properly done by expert workmen may be made stronger than the metal itself, and that joints of 100% efficiency are not only not uncommon, but easily made. Such is not the case with the riveted joint.

GENERAL THEORY

Welding by means of the electric arc utilizes heat liberated in the arc passing between the electrode and the work. The arc melts a small pool of metal on the work piece, and any additional metal required to complete the weld is furnished by the wire electrode. The electrode is melted by the arc and deposited in the pool in a molten state. The result is a perfectly fused and homogeneous mass, provided that proper care was used in performing the weld.

The arc is formed by current flowing across a gap in an electric circuit. A small amount of the material, forming the terminals of the arc gap, is heated to an incandescence vapor. This vapor provides a conducting medium in the arc stream by which the current is carried from one terminal to the other. The terminal from which the current passes to the arc is termed the positive electrode, or anode, and the terminal to which the current passes from the arc is called the negative electrode, or cathode. Altho the exact distribution of heat in the arc between the electrodes is still unknown, it is the generally accepted theory that approximately two-thirds of the heat is liberated at the positive terminal, while the remaining one-third is liberated at the negative terminal. Since the mass of the work to be welded is large in comparison to the

mass of the electrode, it is desirable to have more heat liberated at the work than at the electrode. Consequently, the work is connected to the positive side of the current source. In some cases involving the welding of certain alloy steels and a few other metals, it is sometimes desirable to reverse the polarity and make the electrode positive.

Direct current is by far more satisfactory than alternating current for arc welding. The direct current arc is more stable than the alternating current arc due to the fact that one terminal is continuously positive and the other is continuously negative, when direct current is used. The current is usually supplied by special low-voltage direct current generator built especially for the purpose.

The light given off by the arc is so intense that a colored glass must be used to protect the eyes. Unless the body is protected by suitable clothing, the rays from the arc will produce burns on the skin similar to sun-burn.

At the point where the arc strikes the work, assuming that current, polarity, and speed of travel are correct, the metal is melted and seems to be forced out of the pool by some sort of a blast from the arc. This results in the metal piling up around the edges of the small depression in which the metal is in the molten state. This depression

is referred to as the "arc crater", and its depth is an index to the depth of penetration of the weld. As the work progresses, the molten metal rapidly solidifies. Due to this rapid solidification, arc welding may be carried on overhead, or on vertical seams.

The various details of welding such as size of electrode to be used, value of current, rate of travel, welding position, and the like come to the operator thru practice. There are tables furnished that specify sizes of electrodes and current to be used for different jobs, but the operator learns these items best thru long experience at welding.

In attacking the problem of determining the strength of arc welded joints, there are several methods open to the experimenter. The joints might be tested by any of the following forces:

1. Bending.
2. Compression.
3. Tension.
4. Shear.
5. Shock or impact.
6. Repeated stress, or fatigue.

In this paper, the method used was that in which tension was applied to the joint until failure occurred. Altho tension was actually applied to the joint as a whole, the weld metal itself in some cases was subjected to tension and shear. In the case of the butt joint, the weld metal is entirely subjected to tension. In the case of the lap joints

welded at the ends, tension and shear both are present. In the case of the longitudinally welded lap joints, shear alone could be considered present.

It might be stated that the strength in tension bears no definite relation to the strength of the welded joint under bending stress, impact stress, or any other stress. Hence, if the all-around strength of the joint is to be studied, tests would have to be devised using the various other forces to determine the strength under all conditions.

DESCRIPTION OF METHOD AND APPARATUS USED

All steel used in the tests described herein was open-hearth structural steel obtained from the Knoxville Structural Steel Company. Standard 3" X 1/4" and 3" X 1/4" stock was sheared into short lengths to be welded.

A Westinghouse "Flex-arc" portable welding set was used to supply welding current. This machine is a compact unit of 200 amperes capacity. It is driven by a 220 volt, 3 phase motor. All auxiliaries are contained within the machine itself. Welding current is controlled by a single rheostat. The machine is the very latest development of Westinghouse.

The testing machines employed in the tests were as follows:

1. Olson 50,000 pound machine.
2. Riehle 100,000 pound machine.

Before starting upon this study, the writer of this paper had never attempted to make a weld with the electric arc. Consequently, it was necessary to learn the process before any work could be done.

An arc welding manual published by the General Electric Company provided the necessary instructions for the beginner. After much practice at welding various kinds of joints, some fairly uniform welds resulted. Continued practice brought the welder to a point where the real test work could be started.

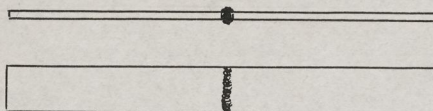
To successfully perform good arc welding, one must have

a very steady hand. The greatest difficulty to overcome is learning the welding is the unsteadiness which one is likely to have. Continued practice will overcome this difficulty.

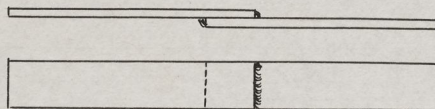
The writer made hundreds of welds of all descriptions previous to making those which were tested. Many of the experimental welds were broken and the defects noted. These defects were corrected, if possible, on later work. During all the experimental or practice work, notice was taken of size of electrode used, value of current, rate of travel of work, and the like in order to discover the combination of these things which produced good welds.

In the test work, three different kinds of joints were selected for test. These were as follows:

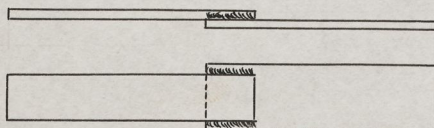
1. Butt joint.



2. Lap joint. End welded.



3. Lap joint. Side welded.



All welded specimens were placed between the jaws of

the testing machine and tension slowly applied until the unit failed.

The error which invariably crept into the results of the tests was due to improper fusion of the weld metal at the beginning of the weld. Such an error could be eliminated thru long practice at welding. Also, in inexperienced hand welding, there is difficulty in keeping uniform width of the fillet-weld. This lack of uniformity is another source of error and is also curable thru experience.

RESULTS OF TESTS

Tensile Strength of 2"x1/4" Test Pieces

Piece	:	Ultimate Strength
1	:	27770
2	:	27770
3	:	27420
4	:	27780

Average Strength of Test Pieces--27685 pounds.

Butt Joints

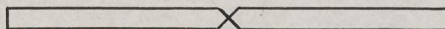
Test Piece	:	Ultimate Strength	:	Efficiency
1	:	22900	:	82.7
2	:	24100	:	87.0
3	:	23170	:	83.7
4	:	25860	:	93.4
5	:	24020	:	86.7
6	:	21740	:	78.4
7	:	22410	:	80.5
8	:	24600	:	88.8

Average Strength of Butt Joints 23586 pounds.

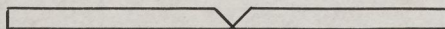
Average Efficiency of Butt Joints - 85.1%

Failure occurred at the weld in all of the above tests.

The first four test pieces were prepared for welding by "veeing" on both sides, thus:



The second four pieces were "veed" on one side only, thus:

Lap Joints
End Welded.

Test Piece	:	Ultimate Strength	:	Efficiency
1	:	27690	:	100.0
2	:	26770	:	96.4
3	:	26490	:	95.7
4	:	27020	:	97.6
5	:	24480	:	83.5

Average Strength of Lap Joints---26490 pounds.
 Average Efficiency of Lap Joints---94.6%
 Failure occurred at the weld in all of these joints.
 Weld laid on as standard 1/4" fillet weld.

End Welded Lap Joint



Lap Joints

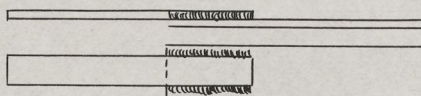
End welded, but heavily reinforced.

Test Piece	:	Ultimate Strength	:	Efficiency
1	:	27770	:	100.0
2	:	27410	:	100.0
3	:	27590	:	100.0
4	:	27230	:	99.0

Average Strength of Lap Joints---27500 pounds.
 Average Efficiency of Lap Joints--99.7%
 Only No. 4 joint failed at the weld. Nos. 1, 2, and 3 failed in the 2"x1/4" stock.

Lap Joints Side Welded.

All side welded lap joints were made by laying a 2"x1/4" upon a 3"x1/4" piece and making a standard 1/4" fillet weld along the lapped sides, thus:



Four different lengths of lap were tested, the length of lap ranging from 1" to 4".

One Inch Laps

Test Piece	:	Ultimate Strength	:	Efficiency
1	:	13910	:	50.2
2	:	13760	:	46.1
3	:	12320	:	44.1
4	:	9770	:	35.2
5	:	10920	:	39.4

Average Strength of Lap Joints---11916 pounds
 Average Efficiency of Lap Joints--43.0%
 Failure at weld in all of above cases.

Two Inch Laps.

Test Piece	:	Ultimate Strength	:	Efficiency
1	:	22820	:	82.4
2	:	20580	:	74.4
3	:	21500	:	77.6
4	:	23270	:	84.1
5	:	19650	:	71.0

Average Strength of Lap Joints---21564 pounds.
 Average Efficiency of Lap Joints--77.9%
 Failure at weld in all of above cases.

Three Inch Laps

Test Piece	:	Ultimate Strength	:	Efficiency
1	:	24800	:	89.6
2	:	26480	:	95.7
3	:	25610	:	92.5
4	:	25030	:	90.3
5	:	27470	:	99.4

Average Strength of Lap Joints--25878 pounds.
 Average Efficiency of Lap Joints--93.5%
 Failure at weld in all of above cases.

Four Inch Laps.

Test Piece	:	Ultimate Strength	:	Efficiency
1	:	28080	:	100.0
2	:	27220	:	100.0
3	:	25960	:	93.8
4	:	28170	:	100.0
5	:	28410	:	100.0

Average Strength of Lap Joints--27568 pounds.
 Average Efficiency of Lap Joints--98.7%
 Only Joint No. 3 failed at the weld in this group.
 Nos. 1, 2, 4, and 5 failed in the 2"x1/4" stock.

In all of these tests joints that did not fail at the weld were assumed to be 100% efficient.

CONCLUSIONS

As a result of this study these conclusions may be drawn:

1. That the strength of side or longitudinally welded lap joints decreases slightly as the length of lap increases.
2. That the appearance of a weld is no indication of its strength.
3. That 100% efficient joints may easily be made by experienced welders.
4. That the arc welded joint is the simplest, strongest, and most economical joint known.
5. That welding operators may learn the trade easily in a reasonable time.

There is no doubt that in the near future arc welding will replace riveting in structural, manufacturing and ship-building work. For example, the maximum efficiency that the United States Navy Department calls for in double riveted joints in tension is 89%. But arc welds may be made 100% efficient with ease. Already, many welded ships have been launched. These ships are much lighter than similar riveted ones, and, all other things being equal, can carry more cargo than riveted ones.

There will be more and more welding operators trained in the future to replace riveters. Any good workman can learn arc welding with ease. The noisy clatter of riveting

hammers will be a thing of the past in building construction. Structures will be strongly and noiselessly knit together with this efficient tool, arc-welding.

As a brief summary of the most important conclusion, it may be stated that arc welded joints are no longer looked upon as being experimental, but may be considered the best type of joint known for strength, economy, and convenience. Arc welding will soon be looked upon not as a tiresome and difficult process, but one which is simple and easy to learn by the average workmen.

BIBLIOGRAPHY

- Arc Welding In The Building Industry....Westinghouse
Electric Company.
- Arc Welding In Industry.....General Electric Co.
- Welding Steel Structures.....General Electric Co.
- Arc Welding Data..... Westinghouse Electric
Company.

The above referances are in the form of small
booklets published by the companies indicated.

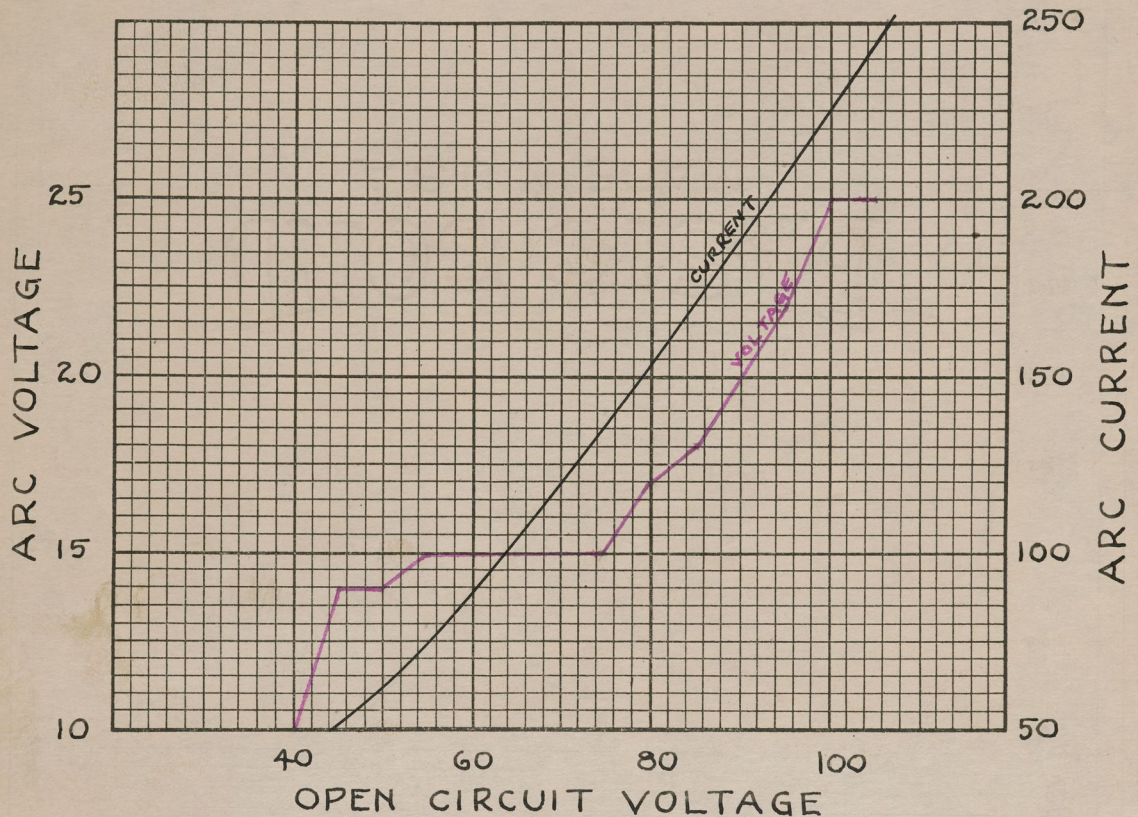
- Electric Welding and Welding Appliances... Herbert Carpmael.
- Arc Welding Manual.....General Electric Co.
- Arc Welding- The New Age of Iron and Steel.... Lincoln
Electric Company.
- Arc Welding-Lincoln Prize Papers..... Lincoln
Electric Company.
- Encyclopaedia Britannica.

APPENDIX

Following will be found two curves and a number of small illustrations pertaining to Arc Welding.

LABORATORY

DATE

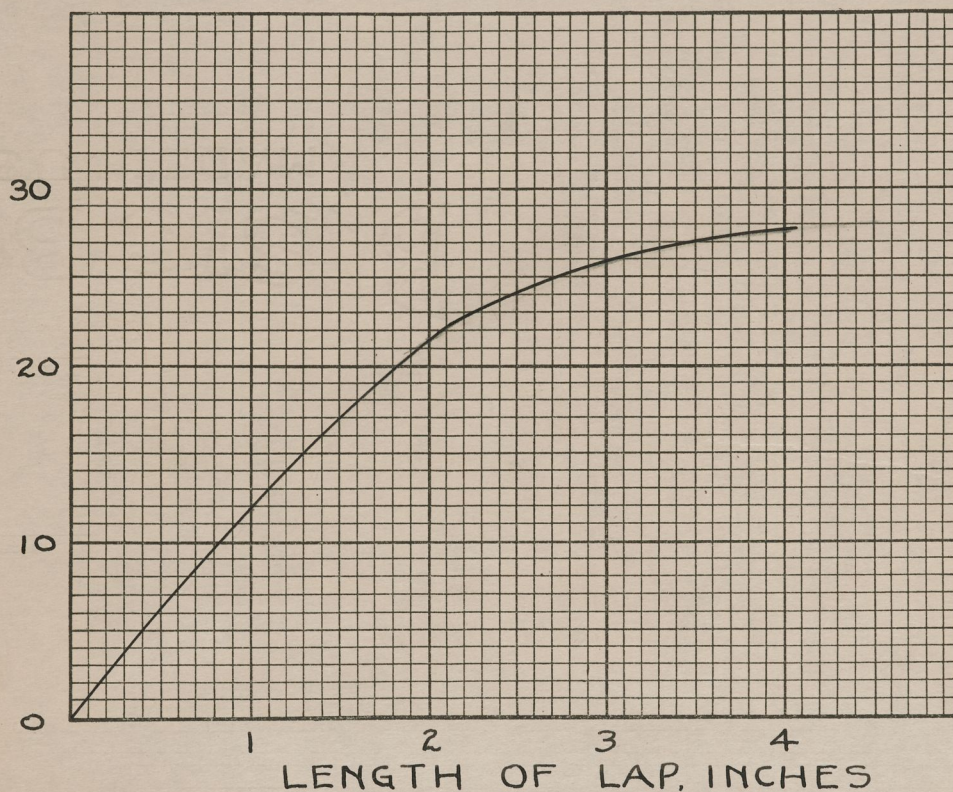
FIG. NO. 2

TITLE:- WESTINGHOUSE "FLEX-ARC" WELDER
 RELATION BETWEEN OPEN CIRCUIT
 VOLTAGE, ARC VOLTAGE, AND ARC CURRENT
 INTERPRETATION OF CURVES

LABORATORY

DATE

STRENGTH, THOUSAND LBS.

FIG. NO. 1

TITLE:-

RELATION BETWEEN STRENGTH AND
LENGTH OF LAP, LONGITUDINALLY
WELDED LAP JOINTS, $2" \times \frac{1}{4}"$ STOCK.

INTERPRETATION OF CURVES

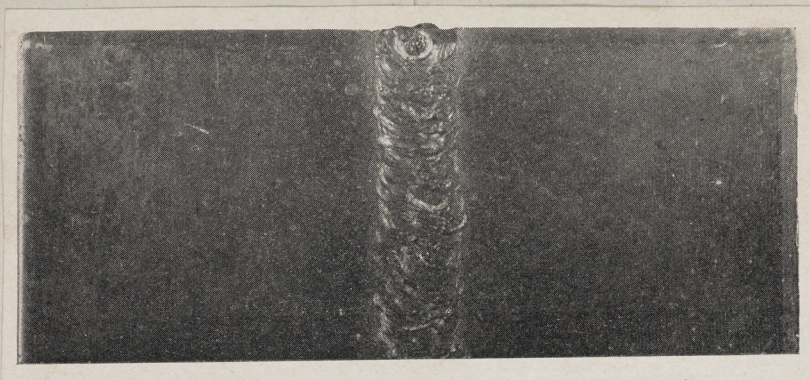


Fig. 3

Typical Arc Welded Butt Joint

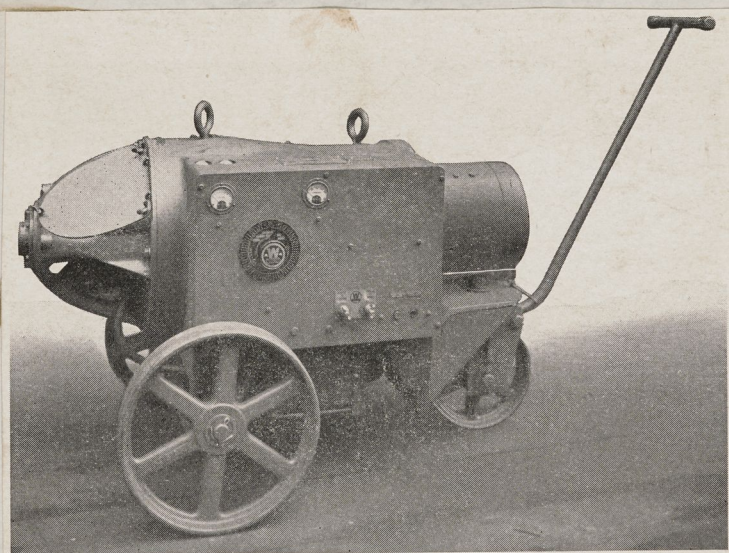


Fig. 4

Westinghouse "flex-Arc" 200 Ampere Portable Welder. A machine identical to this one was used in the welding work for this study.

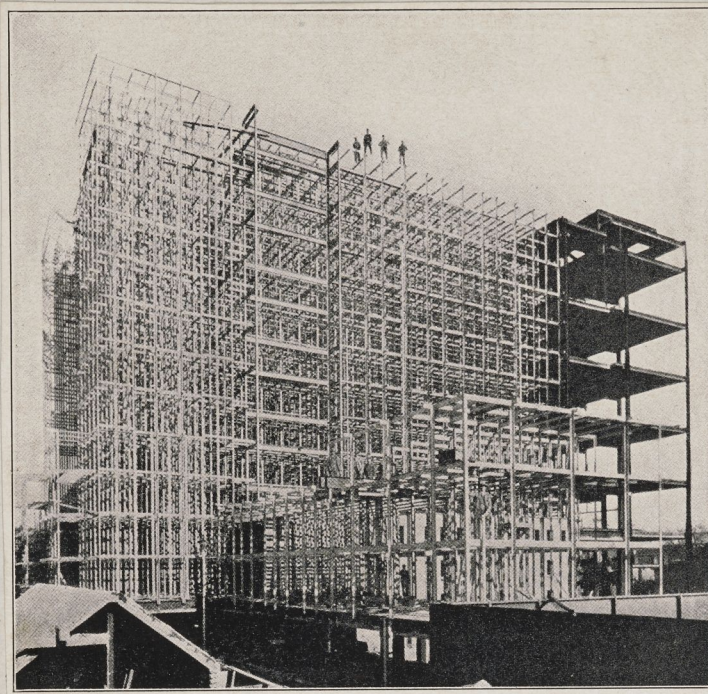


Fig. 5

An All Arc Welded Building

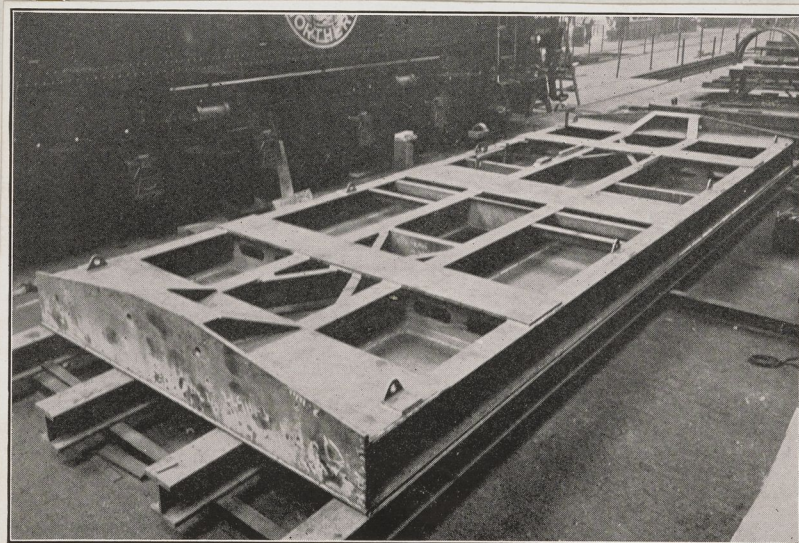


Fig. 6

An Arc Welded Electric Locomotive Frame

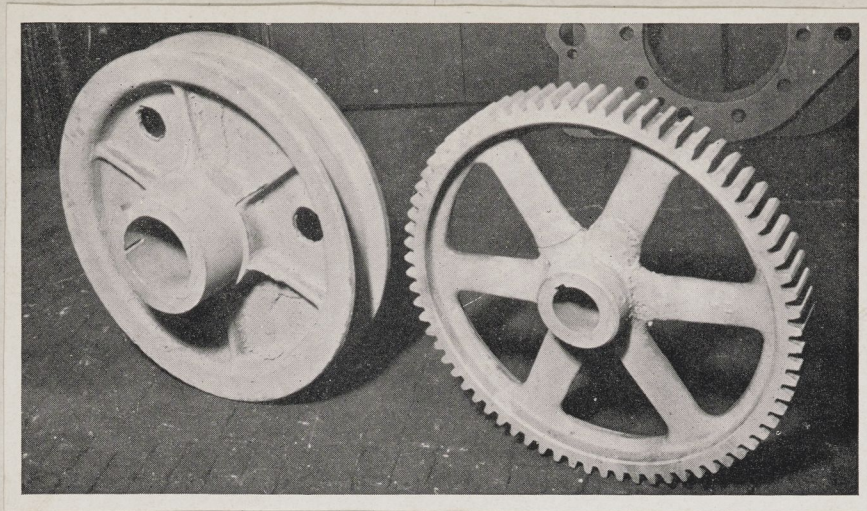


Fig. 7

Typical Arc Welded Repairs on Cast Iron

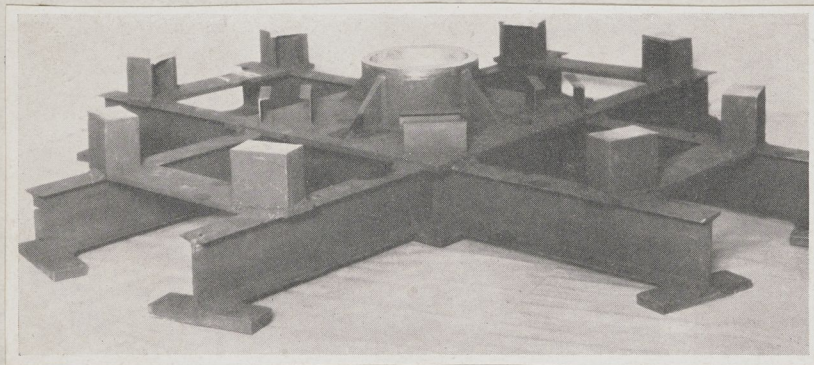


Fig. 8

Arc Welded Lower Bearing Support for a Large
Hydraulic Turbine

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 by this approval that 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 was written.

Name

W. R. Woolrich.

Title

Prof. M.E.