PHYSICAL AND METALLOGRAPHICAL PROPERTIES
OF WELDED CAST IRON

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By

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PREFACE

One of the most common repair jobs encountered in the average commercial welding shop consists in the repair of fractured grey iron castings. Numerous methods of welding are employed in welding cast iron, and the technique used in each shop may vary widely in solving a given problem.

Where welders congregate, the old controversial issue regarding the best method to use in welding a given casting is discussed. This problem is never settled for no proof exists concerning the actual physical properties obtained by different welding methods other than an expression of individual opinion based upon the past experience of the operator. It would be impossible to estimate the time and material that might be saved if specific information were available to the welding industry concerning the true physical characteristics of the various welding techniques.

It is the purpose of this thesis to undertake a scientific approach to the solution of the above problem, which is quite extensive and will require much time and effort before final conclusions are reached and the results are in form for publication in welding periodicals.

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TABLE OF CONTENTS

CHAPTER		PAGE
I.	THE PROBLEM AND DEFINITIONS OF TERMS USED	1
	The problem	1
	Statement of the problem	1
	The importance of the problem	2
	Definitions	3
	Delimitations	5
II.	METHOD OF PROCEDURE USED IN STUDY	7
	Method of testing	7
	Preparing specimens for welding	11
	Welding	11
	Metallographical examination	14
III.	ANALYSIS OR RESULTS OF STUDY.	19
	Physical results of the welds	19
	Metallographical results of the welds	19
	Hardness tests	36
IV.	CONCLUSIONS AND RECOMMENDATIONS	42
	Conclusions	42
	Recommendations	43

LIST OF FIGURES

NUMBER PAGE

1. Original Cast Iron T Beam. 8
2. Universal Hydraulic Testing Machine 10
3. Beam, Fractured and Beveled for Welding 12
4. Beam Prepared for Welding 13
5. Beam as Welded 15
6. Beam, Fractured After Being Welded. 16
7. Bosch and Lomb Photomicrographic Equipment 18
8. Photomicrograph of Brazed Joint,Taken of Deposited Metal . 23
9. Photomicrograph of Brazed Joint, Taken Between Weld Zone and Parent Metal 24
10. Photomicrograph of Brazed Joint, Taken of Parent Metal . . 25
11. Photomicrograph of Oxy-acetylene Fusion Weld, Taken of Deposited Metal 26
12. Photomicrograph of Oxy-acetylene Fusion Weld, Taken of Fusion Zone 27
13. Photomicrograph of Oxy-acetylene Fusion Weld, Taken of Parent Metal 28
14. Photomicrograph of Non-preheated Arc Weld, Taken of Deposited Metal 29
15. Photomicrograph of Non-preheated Arc Weld, T ken of the Fusion Zone. 30

NUMBER PAGE

16. Photomicrograph of Non-preheated Arc Weld, Taken of the Parent Metal 31

17. Photomicrograph of Preheated Arc Weld, Taken of the Deposited Metal 32

18. Photomicrograph of Preheated Arc Weld, Taken of the Fusion Zone 33

19. Photomicrograph of Preheated Arc Weld, Ta ken of the Parent Metal 34

20. Photomicrograph of Preheated Arc Weld, Ta ken of the Parent Metal 35

21. Hardness Test on Oxy-acetylene Fusion Weld Specimen . . 38

22. Hardness Test on Oxy-acetylene Brazed Joint Specimen . . 39

23. Hardness Test on Preheated Arc Weld Specimen 40

24. Hardness Test on Non-preheated Arc Weld Specimen . . . 41

LIST OF TABLES

TABLE PAGE

I. Methods and Conditions Used in Study 1

II. Results of Four Methods for Welding Cast Iron as Tried Using Different Operators and Various Conditions 20

III. Results of Hardness Tests Made on the Four Specimens . . . 37

CHAPTER I

THE PROBLEM AND DEFINITIONS OF TERMS USED

For many years a difference of opinion has existed among authorities on the resulting relative physical properties of cast iron welds, when certain methods are used in the welding processes. There are also many different opinions and views as to which methods of welding are most satisfactory and what techniques should be used to obtain desirable results.

A. THE PROBLEM

Statement of the problem. It was the purpose of this study (1) to collect pertinent data for a comparison of four of the most commonly used methods for welding cast iron by observing and studying physical and metallographical properties of welded samples, and of the original castings; (2) to determine which one of several welding methods is best for welding cast iron under specific conditions. The following four methods and conditions were used in this study:

TABLE I

METHODS AND CONDITIONS USED IN STUDY

	Method	Electrode	Preheat - F°
1	Gas Fusion Weld	Cast Iron	1050
2	Bronze Weld	Bronze Rod	500
3	Arc Weld	Mild Steel	1050
4	Arc Weld	Mild Steel	None

It will be observed from Table I that the following comparisons were made: (1) gas fusion welds with bronze welds; (2) gas fusion welds with preheated arc welds; (3) gas fusion welds with non-preheated arc welds; (4) bronze welds with preheated arc welds; (5) bronze welds with non-preheated arc welds; (6) preheated arc welds with non-preheated arc welds. The term "preheated weld" refers to the entire casting and not the weld only.

The importance of the problem. Which is stronger, a cast iron weld made with the oxy-acetylene process or one made with the electric arc process? What method is best to use? Just what procedure should be used? These, and many other questions regarding cast iron are frequently asked in the school shop where welding is taught or in the repair shops where welding is being done. Because of the fact that little research work has been done in the field of cast iron welding it is difficult to answer such questions with any degree of assurance that the answer is correct. There are several reasons why more work has not been done in this large field; the first and foremost being that cast iron welding is used in repair and not in production work. However, the extensive use of cast iron and the amount of repair work done each year on castings justify a careful study of the most effective means of welding. Hundreds of thousands of tons of iron are cast, and there are thousands of men who weld cast iron each year. The many welding operators who repair castings use many techniques, ways, or methods. In many cases the welds are not successful. This develops the idea on the part of many people that cast iron cannot be welded successfully. As indicated above, little or no research work has been done to determine whether cast iron can be welded successfully and if so which method is the most effective to use. One thing that many do not stop to consider is that the casting may have been too small for the load originally and will still be too small after it is welded. In other cases the part may have been badly worn before the breaking occurred and had probably served its purpose for many years. Other failures are caused by sudden impacts which are not ordinarily encountered in the normal life of the machines on which the castings were a part. Often a casting breaks due to poor design of the machine itself. The part of the machine may be out of line, or some other irregular condition may exist, which caused the casting to break. B reaking will continue until corrections are made.

B. DEFINITIONS OF TERMS USED

Metallography. Metallography may be defined as the study of the structure of metals. Most people who work with metal know that it has a grain, but perhaps some do not realize to what extent this grain structure influences its properties. That the structure of a piece of metal is not as readily apparent as the structure of, say a piece of wood, probably accounts for this fact. For centuries men have judged the character of wood by its grain, and have classified it as close grain, coarse grain, clear or free from blemishes, etc. It has been only recently that the importance of the structure of metal in influencing its physical properties has been realized. Metallography is the science which studies these grain structures, and seeks to determine how the different properties of the steel are affected by its structure. (1, page 298.)

Photomicrograph. A photograph of microscope enlargement of welded test pieces. The welded specimens are sawed, or tested to destruction, and filed, polished and etched, after which photographs on an enlarged scale may be made. (1, page 360.)

Arc welding. Non-pressure (fusion) welding process wherein the welding heat is obtained from an electric arc formed either between the base metal and an electrode or between two electrodes. (2, page 22.)

Bevel. Angle that one surface or line makes with another when not at right angles. (2, page 24.)

Brass. Alloy consisting essentially of copper and zinc in variable proportions. (2, page 24.)

Brazing. Group of welding processes wherein the filler metal is a non-ferrous metal or alloy whose melting point is higher than 1000° F. but lower than that of the metals or alloys to be joined. (2, page 24.)

Bronze. Alloy consisting chiefly of copper and tin. (2, page 24.)

Cast iron. Iron produced in a blast furnace and cast into molds. It contains so much carbon or its equivalent that it is not malleable at any temperature. (2, page 25.)

Eutectic. Of maximum fusibility. Said of an alloy or solution having the lowest melting point possible with the given components. (1, page 235)

Elasticity. Power possessed by a body to resume its original form after removal of the force that has produced a change in that form. (2, page 29.)

Etching. Process of preparing the polished surface of a metal for examination and test by treating it with some acid . (2, page 30.)

Flexure. The act of bending. The part bent. (3, page 369.)

Flux. Fusible material or gas used to dissolve and/or prevent the formation of oxides, nitrides, or other undesirable inclusions formed in welding. (2, page 31.)

Fusion welding. Group of processes in which metals are welded together by bringing them to the molten state at the surfaces to be joined, with or without the addition of filler metal and without the application of mechanical pressure or blows. (2, page 32.)

Fusion zone. That section of area of the weld-metal zone which borders on the unmelted base, or parent metal. (2, page 32.)

Nital. A solution of nitric acid and alcohol. (4, page 394.)

Porosity. Presence of gas pockets or inclusions. (2, page 38.)

Slag inclusion. Nonmetallic substance entrapped in a weld. (2, page 42.)

Welding operator. Operator of welding equipment, or an operator who makes the weld. (2, page 46.)

Welding procedure. Detailed methods and practices used in welding a structure. (2, page 46.)

Gas welding. By gas welding is meant the joining of cast iron by means of a gas flame, almost always oxy-acetylene, using a cast iron filler rod. The welding may be done with or without preheating. (5, page 2.)

Preheating. The main purpose of preheating in gas welding cast iron--for that matter in all methods--is to prevent the shrinkage stresses and attendant cracks which otherwise concentrate at the junction zone between hot and cold metal outside the weld. Another important consideration is the avoidance of the hard zone near to the weld. Most authorities recommend a preheating temperature of 700° C. Preheating also saves gasses. (5, page 2.)

Tinning. The act of coating another metal with tin. The term is also applied in bronze-welding where the spread out of a thin layer of fluxed weld metal ahead of the main deposit to form a "tinning" coating provides a strong bond between base metal and bronze. (1, page 580.)

C. DELIMITATIONS

Delimitations. This study is limited to the methods and conditions shown in Table I. It is not expected to cover the field of cast iron welding in its entirety in this study, nor to imply that the experimental work is completed. On the contrary it is barely a beginning: the surface is but scratched. To complete a study of this nature would take years and much more experimenting. Four operators were used in the welding experiment. Each operator welded four specimens, one for each of the four methods used in the experiment. It is realized that four specimens are not enough from which to draw complete and accurate conclusions; however, valuable data for immediate use and procedure for further research should result from this study.

CHAPTER II

METHOD OF PROCEDURE USED IN THE STUDY

This study, which was conducted in several of the laboratories at Oklahoma Agricultural and Mechanical College, was of an experimental nature. The following procedure was used:

1. The cast iron T beams (Figure 1) were selected for the experiment. Beams free from physical defects, as far as could be determined by sight, were used.
2. The beams were tested for flexure strength and the results were recorded.
3. Fractured edges of the tested beams were beveled and prepared for welding.
4. Four operators welded the prepared samples by pre-determined methods.
5. Welded beams were tested for flexure and results recorded.
6. A specimen was then cut through the weld and heat affected zone for a metallographic study.
7. The specimens were polished, etched, and photomicrographs taken for the metallographic study.
8. Hardness tests were taken of the specimens after the photomicrotraphs were taken and the results plotted on graphs.

A. METHOD OF TESTING

Method of testing. The beams were tested on a 60,000 pound universal

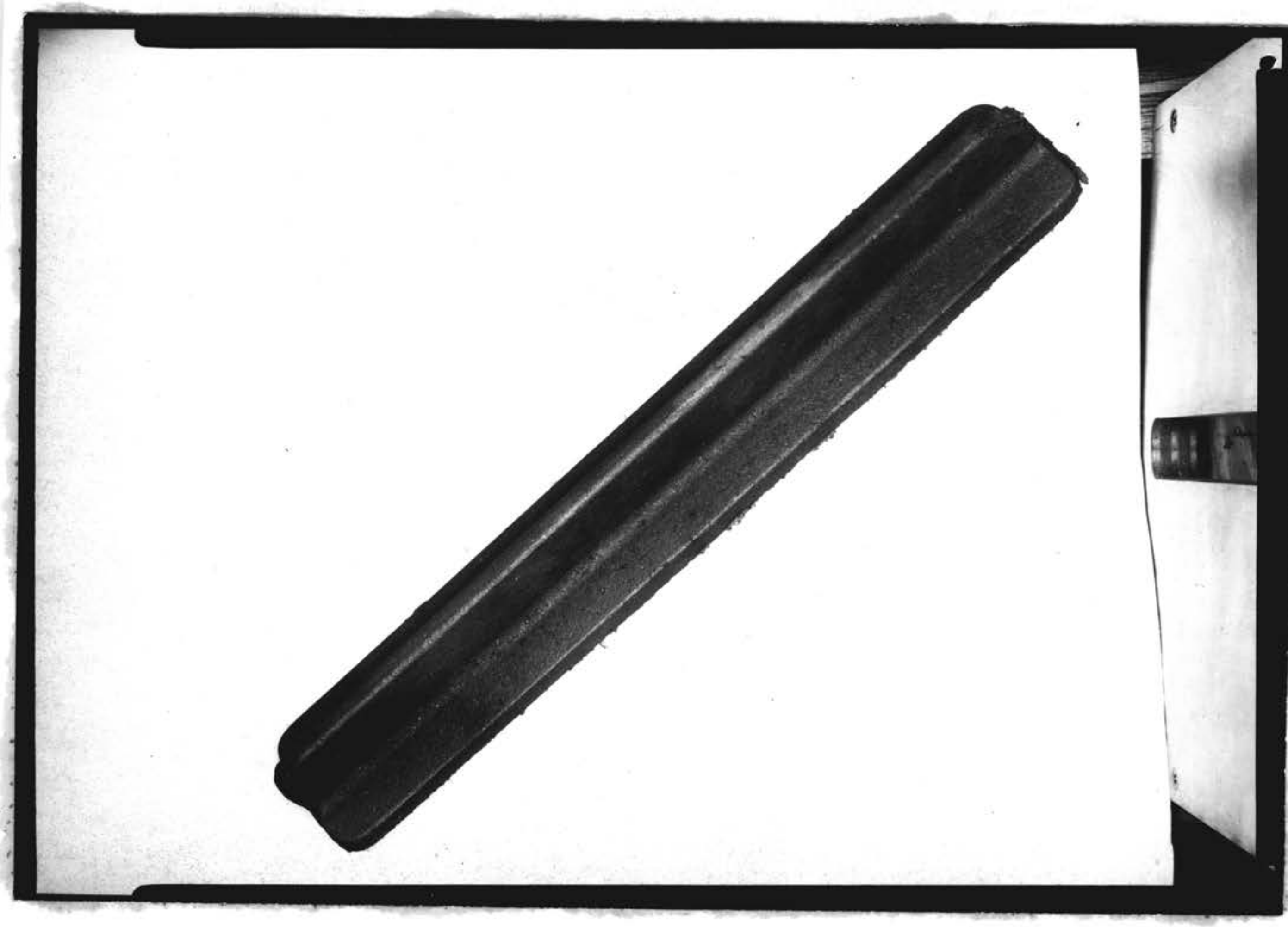


Figure 1. Original beam as cast at the Oklahoma Agricultural and Mechanical College foundry.

hydraulic testing machine (Figure 2) each beam being supported on knife edges with a concentrated load applied at the center. The load was applied very slowly, at the rate of .05 of an inch per minute, which conforms to the American Society for Testing Materials specifications for such spans. Since the overall length of the beam was sixteen inches, a span of fourteen inches was used. The beams were placed in the machine with the flange down, as shown in Figure 2, which also shows the loading knife edge in place.

Calculation of stress was accomplished by using the flexure formula. (6, page 127.)

$$S = \frac{Mc}{I}$$

where:

S is the value of the maximum bending stress expressed in pounds per square inch:

M is the moment for the cross section in inch pounds:

c is the distance to the extreme fiber in inches:

I is the moment of inertia of the cross section about the centroidal axis expressed in inches to the fourth power:

M for a simple loaded span, however, is:

$$\frac{Pl}{4}$$

therefore

$$S = \frac{Plc}{4I}$$

A sample calculation for beam number one was made where P equals

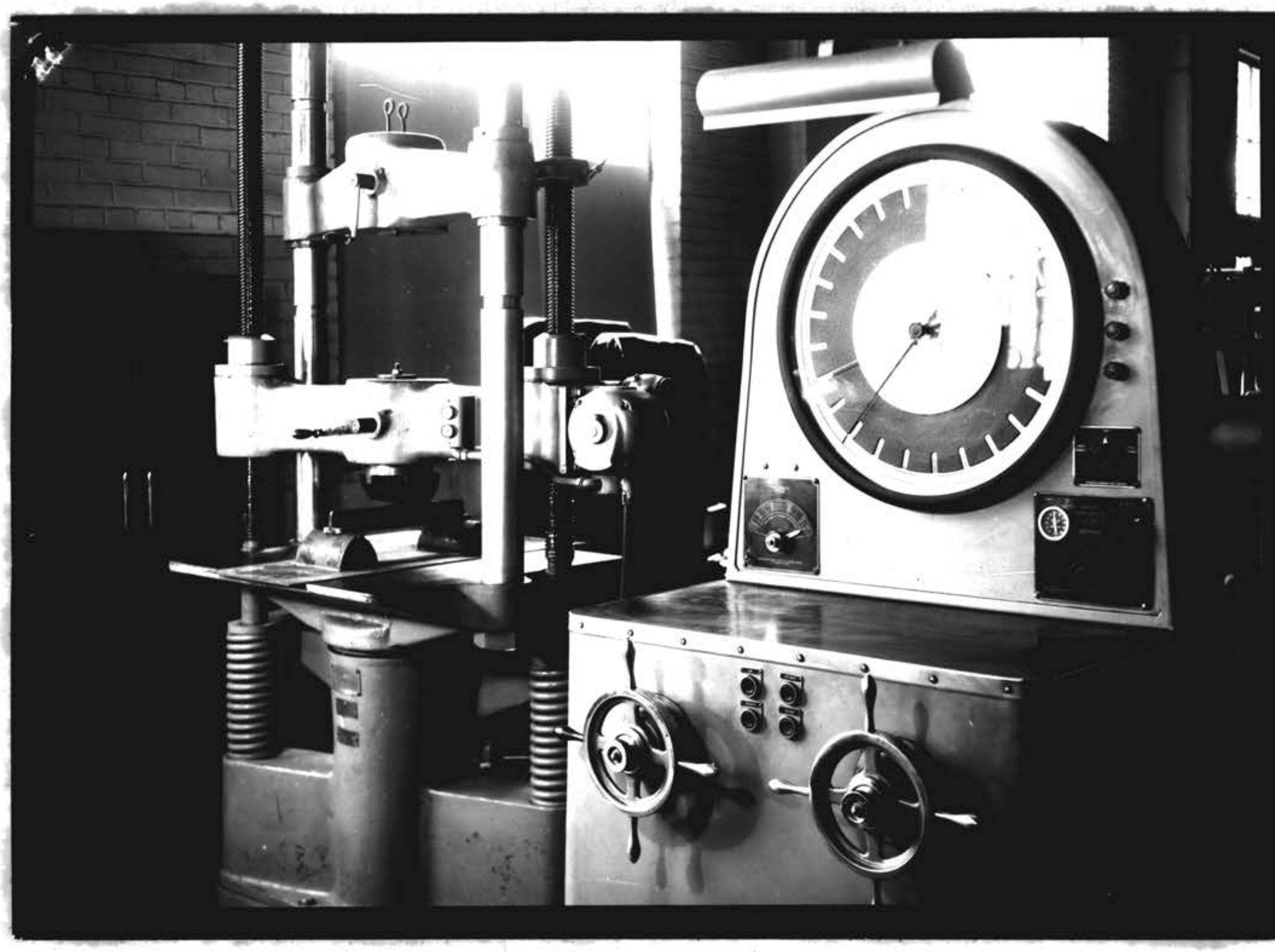


Figure 2. 60,000 pound universal hydraulic testing machine with beam on knife edges and loading knife edge in position.

9,900 pounds. c for these beams = .538 inches and I = .445 inches to the fourth power. Thus,

$$S = \frac{9,900\ (14)\ (.538)}{4\ (.445)} = 41,890 \text{ pounds}$$

per square inch.

Since all beams were cast from the same pattern, the dimensions were taken for all beams and averaged.

B. PREPARING SPECIMENS FOR WELDING

After the specimens were broken (Figure 3B) the two fractured edges were beveled, by means of an abrasive disc mounted on a portable grinder, as shown in Figures 3A and 4. The included angle on the beams to be fusion welded was ninety degrees and on the ones to be brazed was 120 degrees. The edges of the beams to be brazed were filed to remove surface graphite. Presence of graphite would prevent proper tinning.

When the edges were ground to the correct angle (Figures 3A and 4), the beams were placed on a carbon block and aligned with a straight edge. Mild steel electrodes were used to tack the pieces together.

The three sets of beams to be preheated were placed in a furnace and natural gas was used as the fuel. Temple sticks, temperature indicators, were used to determine when the temperature was correct. The beams to be gas fusion welded and the ones to be preheated for arc welding were heated to 1050 degrees Fahrenheit. The ones to be brazed were heated to 500 degrees Fahrenheit.

C. WELDING

The welding was done by four operators, each being an instructor in

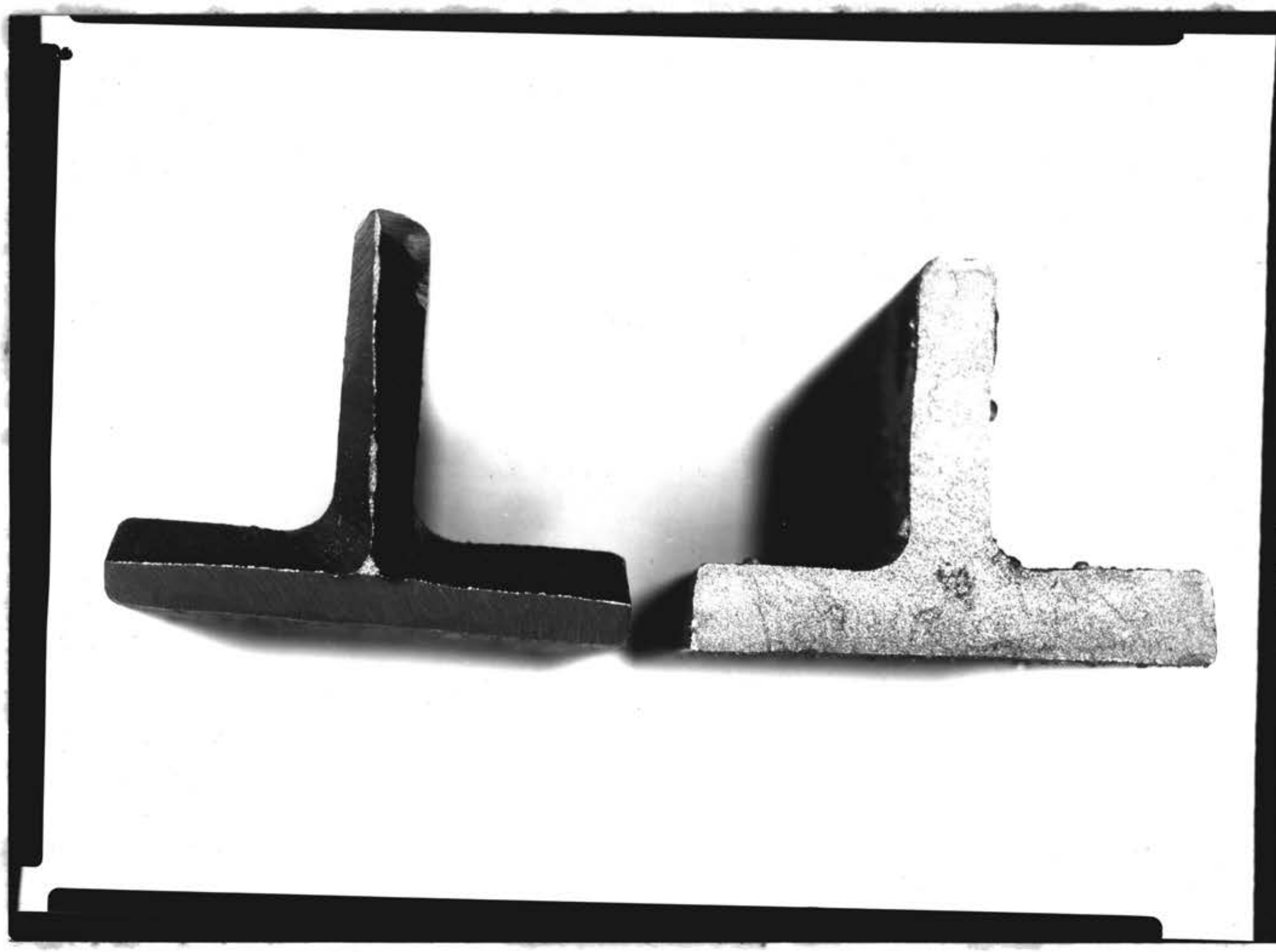


Figure 3. Figure 3A shows the beam as beveled for welding with the correct angle of 90° ground on the fractured edge. Figure 3B shows the cross section of the beam as fractured.

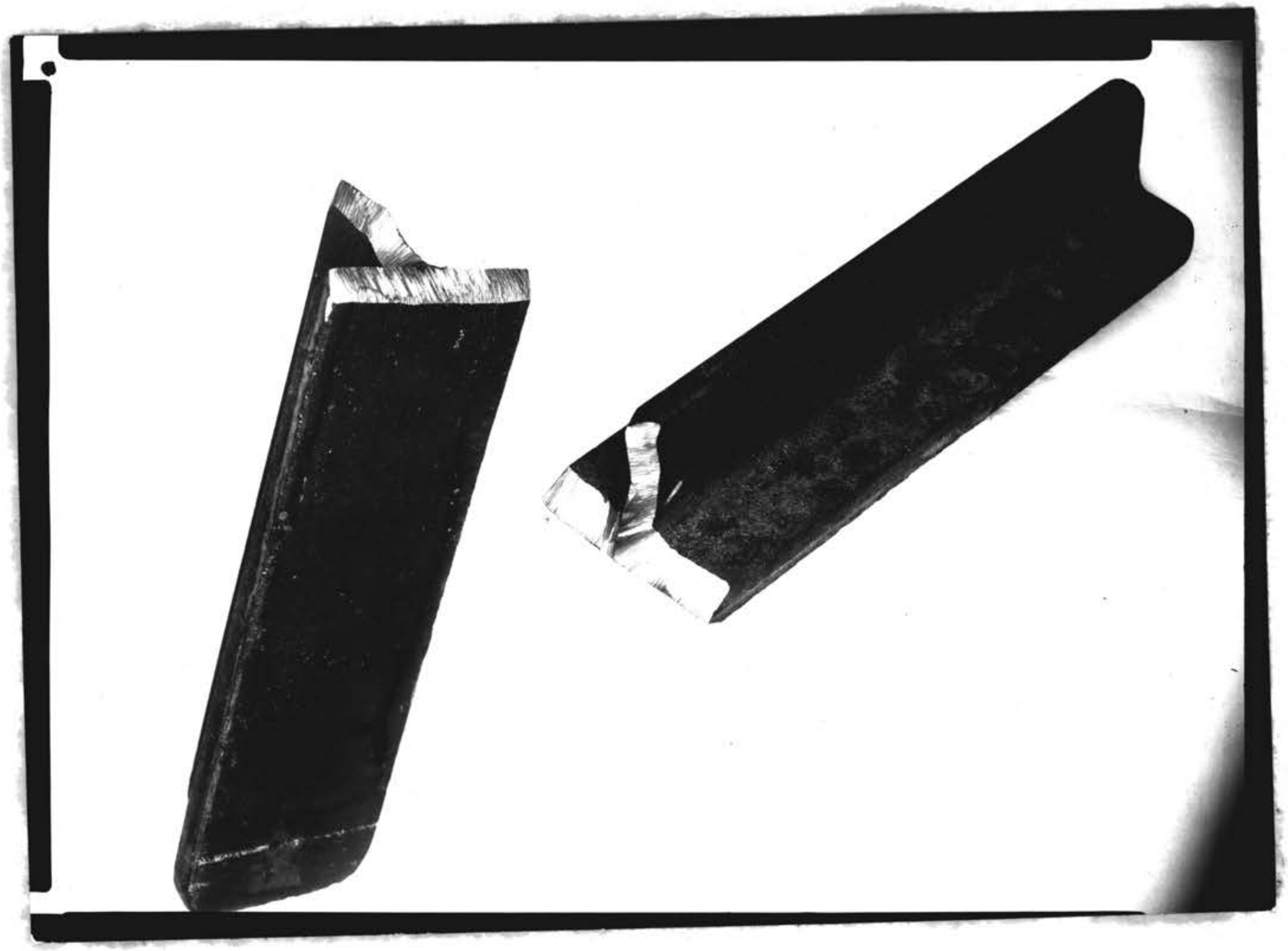


Figure 4. One of the beams as prepared for welding. The correct angle of 120° can be seen on each fractured end of the broken beam.

welding at Oklahoma Agricultural and Mechanical College. The beams in each set were welded under the same conditions. A standard one-fourth inch diameter cast iron welding rod and welding flux were used on the gas fusion weld, (Figure 5). On the gas brazed weld, York flux was used for tinning. Standard bronze three-sixteenth diameter rods and Brazo flux were used for the brazing process. All arc welds were made with mild steel electrodes.

The sets that were preheated were furnace cooled. They were then retested, Figure 6, and the values of the welded beams compared with those of the beams as originally tested. In the majority of cases the fracture occured completely out of the weld. In no cases did it break in the center of the weld and in very few cases did it break partially in the weld.

D. METALLOGRAPHICAL EXAMINATION

After the welded beams had been fractured a cross sectional cut was made through the weld, heat affected zone, and parent metal of one beam from each set for the purpose of obtaining specimens for metallographic examination. The specimens were then machined, polished, and etched for the metallographic examination. Dry polishing was done on Buehler perpendicular dry wheels with grits from 0 to 0000 size. The final polish consisted of two steps, the first of which was on canvas covered horizontal wheels with 600 alundum and the second on horizontal broadcloth wheels with levigated alumina as a polishing medium. Etching, to reveal grain structure, ranged from four seconds to twelve seconds in five per cent nital solution as required, with exception of the bronze deposit, which was etched nine

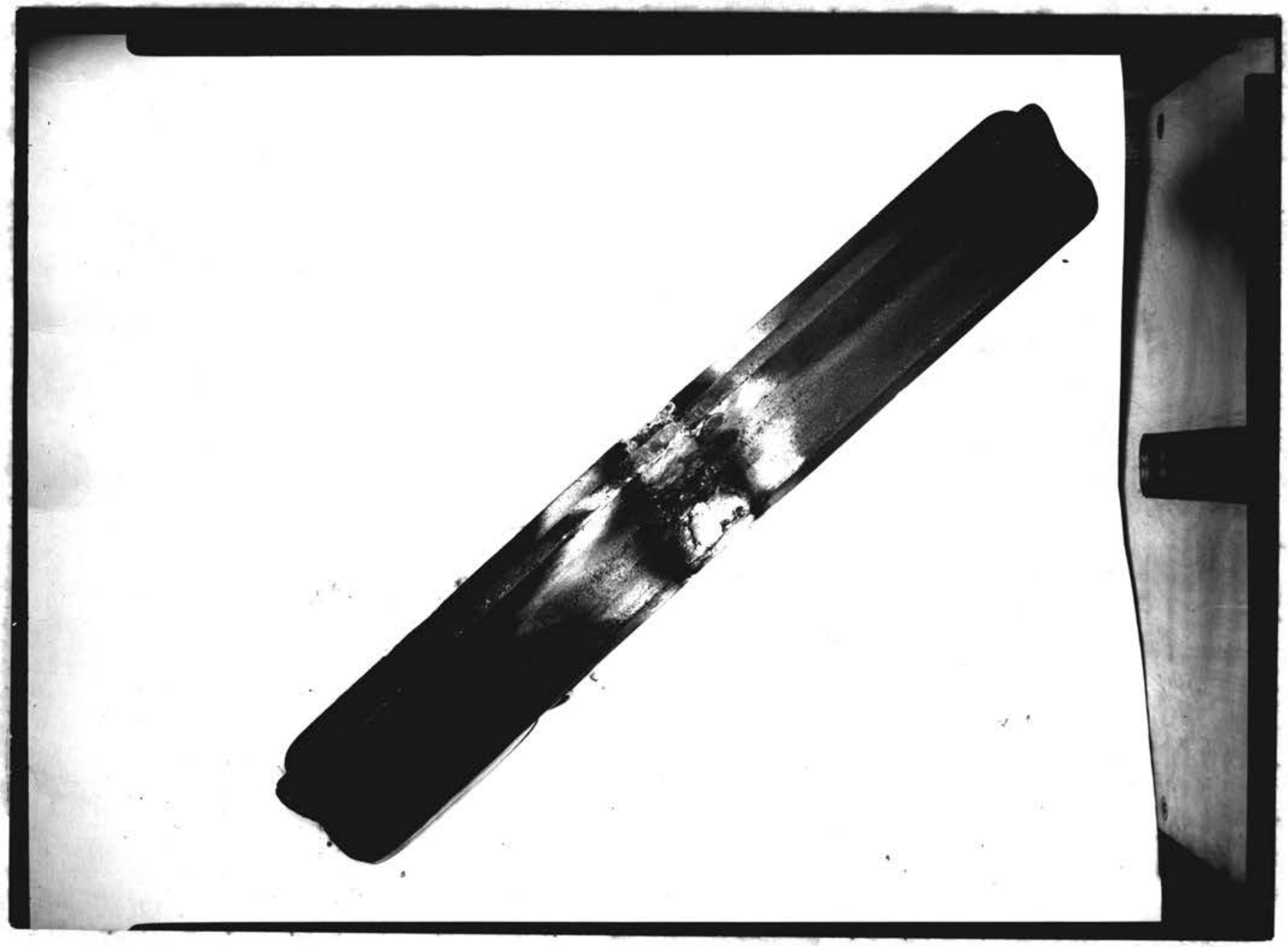


Figure 5. The beam as welded, ready for retesting.

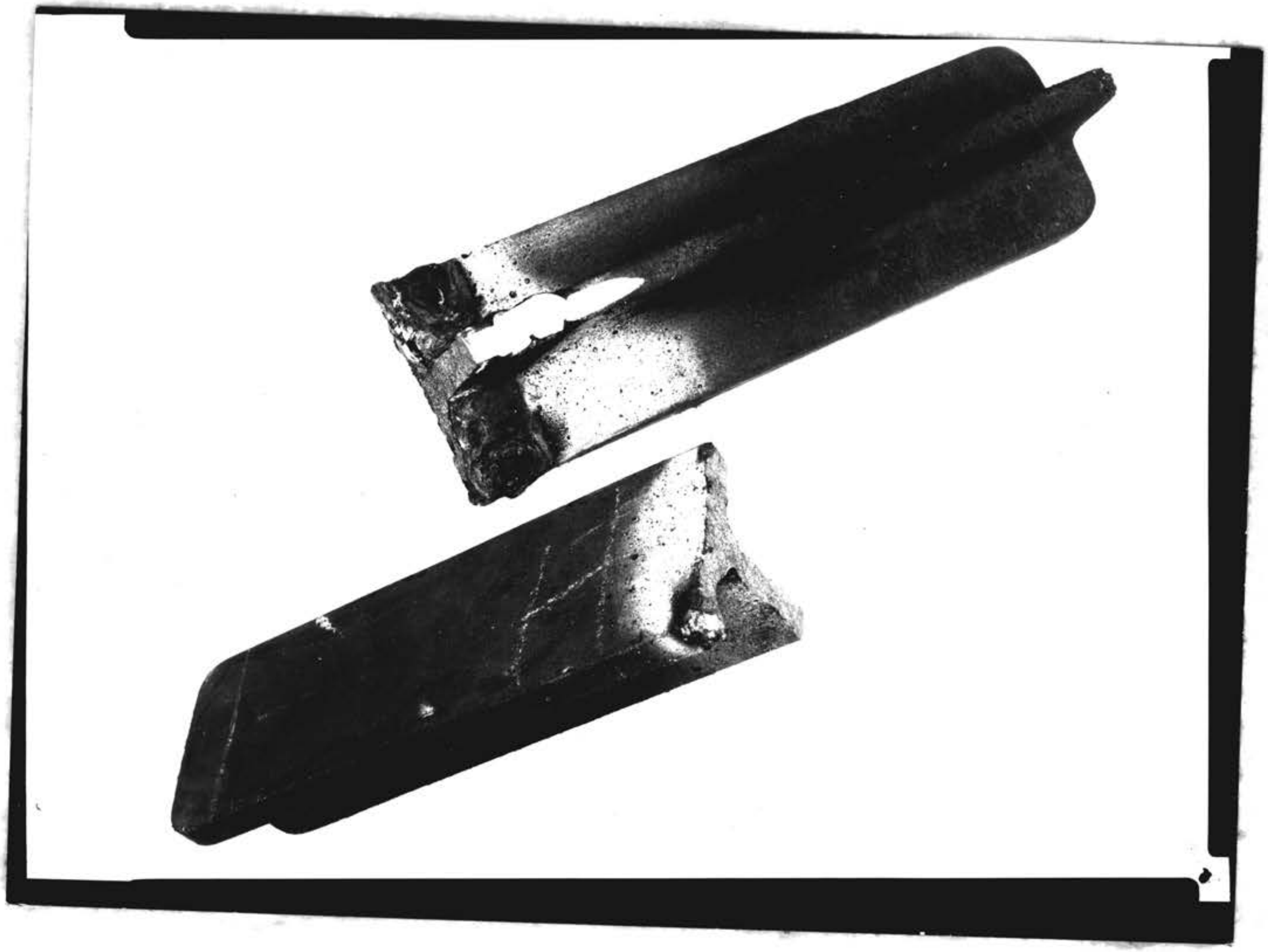


Figure 6. Preheated arc welded beam, fractured after welding, shows that the break occured completely out of the weld.

minutes in twenty per cent nital solution. The specimens were placed under a microscope for visual examination. Photomicrographs were then taken at magnifications of two hundred diameters on Bosch and Lomb Bench photomicrographic equipment (Figure 7) using Wratten M metallographic plates.

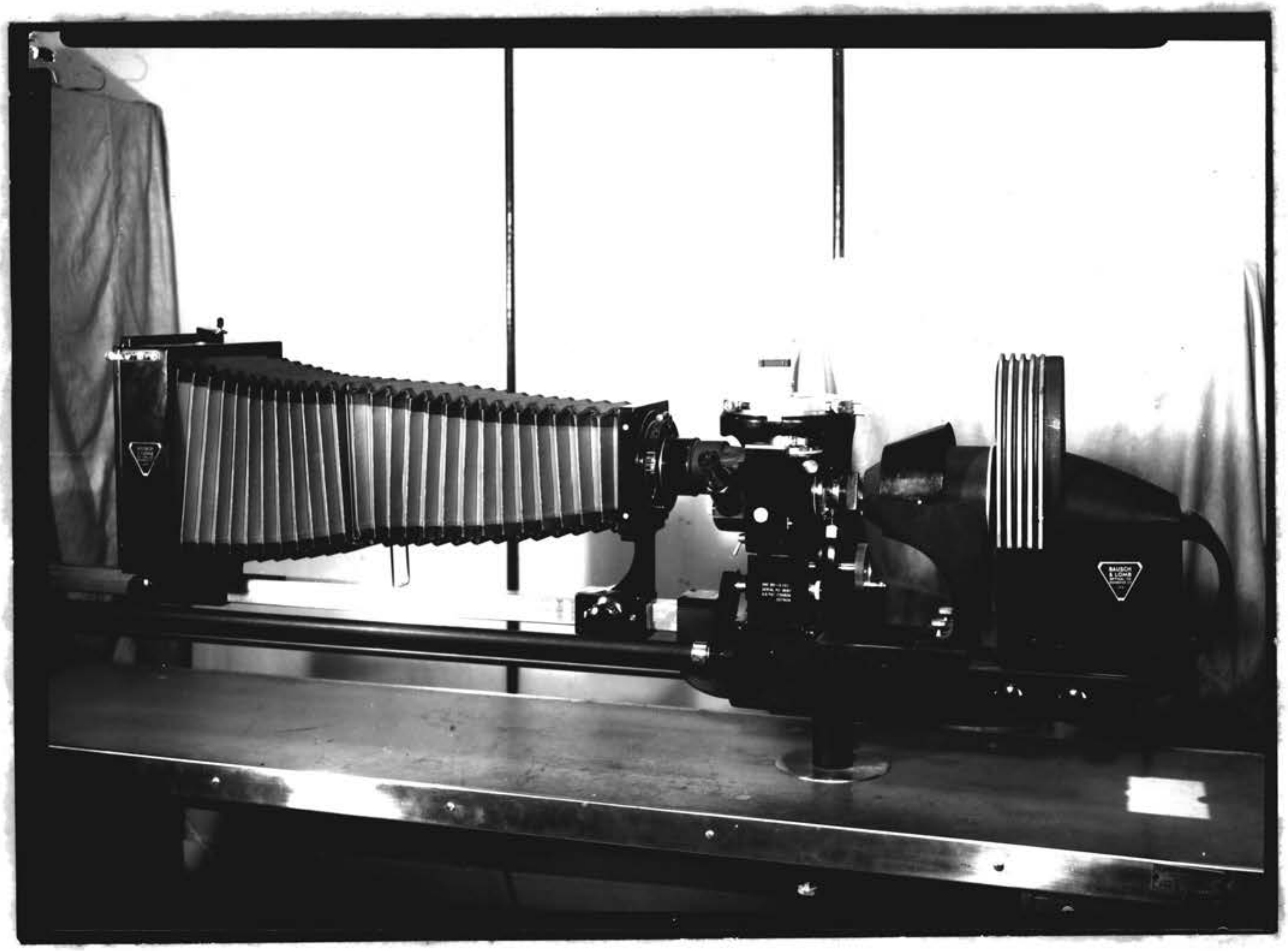


Figure 7. Bosch and Lomb Bench photomicrographic equipment.

CHAPTER III

ANALYSIS OF THE RESULTS OF THE STUDY

The data obtained as a result of the experimental welds as detailed in Chapter II is far from sufficient evidence to make final predictions of what will happen each time cast iron is welded; however, the results do indicate the effectiveness of the various welds.

Physical results of the welds. Table II shows the data of the physical properties of the welded joints. It will be noted from this table that in the set of four brazed joints there developed from 72.3 per cent to 83.1 per cent of strength or 10.8 per cent difference was encountered. These values are of the welded beam as compared to the beam as originally cast. The lowest variation was in the gas fusion weld which ranged from 77.1 per cent to 85.7 per cent of the original strength or a difference of 8.6 per cent. The averages of the sets of brazed joints and gas fusion welds were 75.7 per cent and 80.3 per cent, respectively. The set of preheated arc welds ranged from 65 per cent to 77.7 per cent or a difference of 12.7 per cent. The non-preheated ones ranged from 64 per cent to 75.5 per cent or 11.5 per cent difference. The averages of the two sets of arc welds were 71.5 per cent and 69.6 per cent for the preheated and non-preheated welds, respectively. Thus it may be seen that the highest variation encountered in the four welding methods was in the arc preheated welds.

Metallographic results of the welds. Figures 8 to 20 show the metallographic results of the welds to some extent. Had time permitted the

TABLE II

RESULTS OF FOUR METHODS FOR WELDING CAST IRON
AS TRIED USING DIFFERENT OPERATORS AND VARIOUS CONDITIONS

Sample number	Load of original in pounds	Method of welding	Welding operator	Preheat	Load on welded beam in pounds	P.s.i. of original beam	P.s.i. of welded beam	Percent welded beam is of original
1	9,900	Bronze weld	Christensen	500	7,150	41,800	30,210	72.3
2	9,950	Bronze weld	Bainum	500	7,250	42,200	30,610	73.0
3	10,100	Bronze weld	Rice	500	7,600	42,700	32,100	75.2
4	8,900	Bronze weld	McGregor	500	7,400	37,620	31,250	83.1
1	11,600	Gas fusion	Christensen	1050	9,000	49,000	38,000	77.7
2	10,200	Gas fusion	Bainum	1050	8,750	43,200	37,000	85.7
3	10,300	Gas fusion	Rice	1050	8,300	43,600	35,100	80.7
4	10,500	Gas fusion	McGregor	1050	8,100	44,400	34,200	77.1
1	10,100	Arc preheat	Christensen	1050	7,000	42,700	29,900	69.4
2	10,000	Arc preheat	Bainum	1050	6,500	42,300	27,500	65.0
3	10,000	Arc preheat	Rice	1050	7,700	42,300	32,600	77.7
4	8,900	Arc preheat	McGregor	1050	6,600	37,620	27,900	74.3
1	9,950	Arc non-preheat	Christensen	none	7,500	42,200	31,700	75.5
2	9,700	Arc non-preheat	Bainum	none	6,200	41,100	26,200	64.0
3	9,300	Arc non-preheat	Rice	none	6,900	39,400	29,200	74.3
4	10,500	Arc non-preheat	McGregor	none	6,800	37,600	28,800	64.7

Average of bronze welded set + 75.65% Individual differences 10.8%
Average of gas fusion welded set = 80.25% Individual differences 8.6%
Average of preheated arc welded set = 71.5% Individual differences 12.7%
Average of non-preheated arc welded set = 69.6% Individual differences 11.5%

retaking of several of the photomicrographs, more metallographic results could have been determined from the study. The photomicrographs shown in Figures 10, 13, 16, and 19 are all of the parent metal beyond the heat affected zone. Of these four Figures 10 and 19 are very similar, and a third, Figure 16 closely resembles the same pattern. Had a deeper etch been made on the fourth, Figure 13, the photomicrograph would have probably more closely resembled those shown in Figures 10, 19, and 16.

In all cases grain coarsening occurred near the weld metal in the heat affected zone, which partially accounts for the welded beam fracturing at this point. The grain structure was very fine in the welds compared to that in the parent metal, which gave the weld more strength than the parent metal in the grain coarsened or heat affected area. The grain coarsening also accounts for the welded beams fracturing at a lower value than that of the original.

Due to internal stresses caused by the welding process on the arc welded beams some small cracks could be seen when observed through the microscope. This accounts, in part, for the lower fracturing value. Had photomicrographs been taken of these cracks more could have been determined.

In Figure 13 the graphite flakes are large and coarse which indicates the photomicrograph may not have been taken of the parent metal or perhaps the specimen was not cut deep enough into the parent metal to get beyond the heat affected zone. In the other parent metal photomicrographs the graphite is fine and more of it is in the combined form. When enough carbon is in the combined form, white cast iron is the result. The mild steel electrode, which later becomes the deposited metal, has a much lower carbon content than the cast iron. In the process of welding, during the period the molten pool is present, a transfer of carbon from the parent metal to the deposited metal takes place. The carbon combines with the iron leaving the appearance white.

The photomicrograph shown in Figure 8 was taken in the bronze, or deposited metal, of the bronze welded series. The specimen was etched nine minutes in twenty percent nital solution, and the picture was taken with an exposure time of two seconds at f 7. A copper rich solid solution (white areas) is surrounded by a eutectic mixture (dark area). Small blow holes or gas inclusions can be seen as dark spots in the white areas.

Figure 8. Oxy-acetylene bronze welded (brazed) joint on cast iron. Photomicrograph at 200 diameters in deposited metal.

The photomicrograph shown in Figure 9 was taken of the brazed joint in the weld zone. The specimen was etched for twelve seconds in five per cent nital solution and an exposure time of four seconds at f 7 was used for making the photomicrograph. There is evidence of bronze penetrating into the parent metal via small openings. Coarse flakes of graphite are indicated by the elongated black areas along with the pearlite (gray areas) in the parent metal. The etching time was not sufficient for the bronze (Figure 8) which is the white area of the photograph.

Figure 9. Oxy-acetylene bronze welded (brazed) joint on cast iron. Photomicrograph at 200 diameters between the weld zone and the parent metal.

The photomicrograph shown in Figure 10 was taken in the parent metal of the brazed series. The specimen was etched for twelve seconds in five per cent nital solution and an exposure time of four seconds at f 7 was used for making the photomicrograph. Large amounts of pearlite, mottled gray areas, exist with small amounts of ferrite which are the white areas. In the pearlite areas there are a few inclusions noticable and in certain areas some excess iron phosphide eutectic is seen. The elongated black strips are flake graphite.

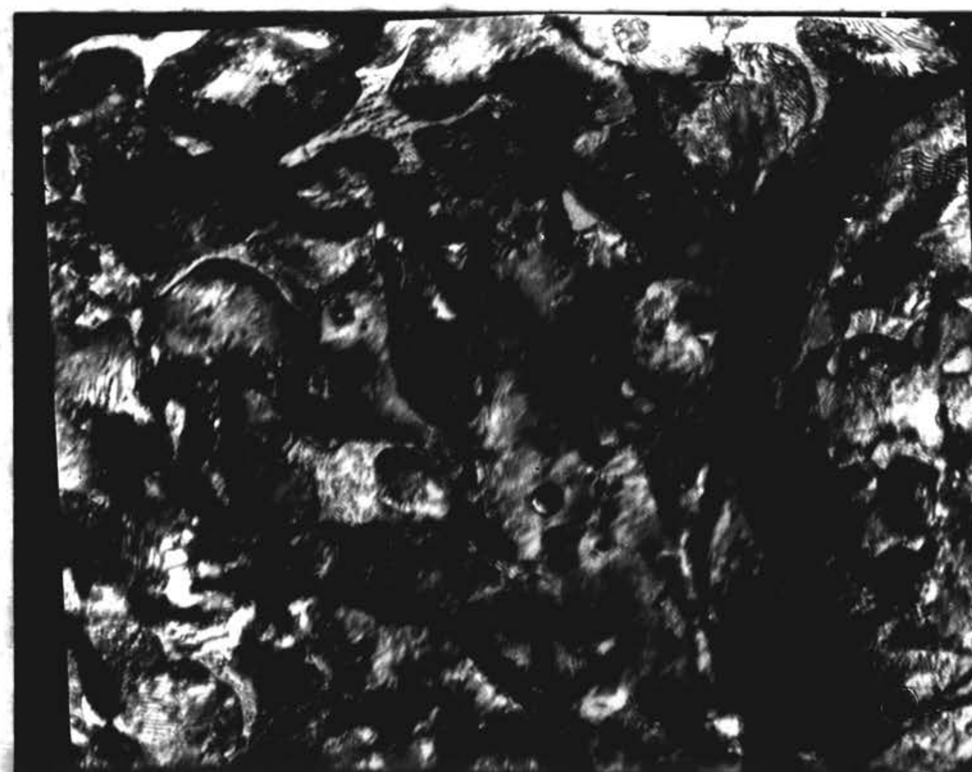


Figure 10. Oxy-acetylene bronze welded (brazed) joint on cast iron. Photomicrograph at 200 diameters in parent metal beyond the heat affected zone.

The photomicrograph shown in Figure 11 was taken in the weld metal of the gas fusion weld. The specimen was etched for twelve seconds and an exposure time of three seconds at f 7 was used for making the photomicrograph. It shows flake graphite, elongated dark areas, which are much finer in this picture than the others and indicates greater strength. Some pearlite, the gray areas, and iron phosphide, definite elongated white areas, are present. An eutectice mixture, large dark areas, is also present.

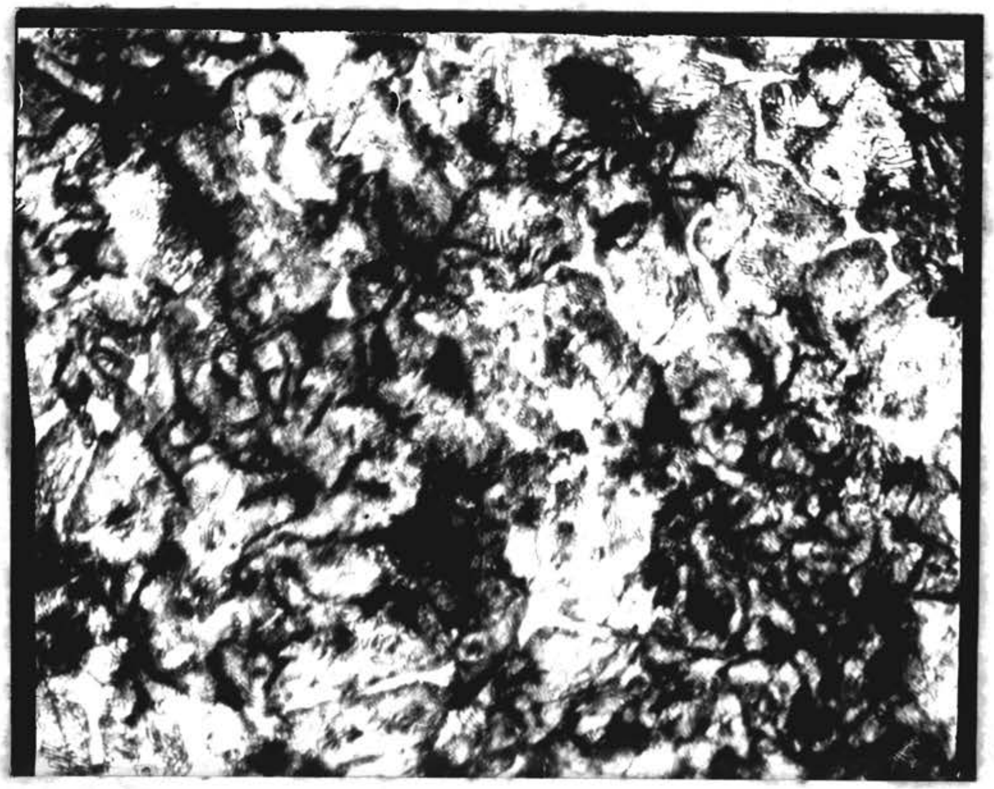


Figure 11. Oxy-acetylene fusion weld on cast iron. Photomicrograph at 200 diameters in weld or deposited metal.

The photomicrograph shown in Figure 12 was taken in the fusion zone of an oxy-acetylene fusion weld on cast iron. The specimen was etched for twelve seconds in five per cent nital solution and the photomicrograph was taken with an exposure time of three seconds at f 7. Some of the flake carbon, due to the heat, has been converted into a nodular form of carbon, the dark areas, as can be seen. Some scratches are visible in this picture and for best results better polishing and etching should be done.

Figure 12. Oxy-acetylene fusion weld on cast iron. Photomicrograph at 200 diameters in the fusion zone.

Figure 13 shows a photomicrograph that was taken in the parent metal of a gas fusion weld. The specimen was etched twelve seconds in five per cent nital solution and a four seconds exposure time at f 7 was used in making the photomicrograph. Coarse flakes of graphite, black areas, are readily noticable. The white areas are ferrite and pearlite which the etching was not sufficient to show. Had another picture been taken with a deeper etch, more could be seen about this area.

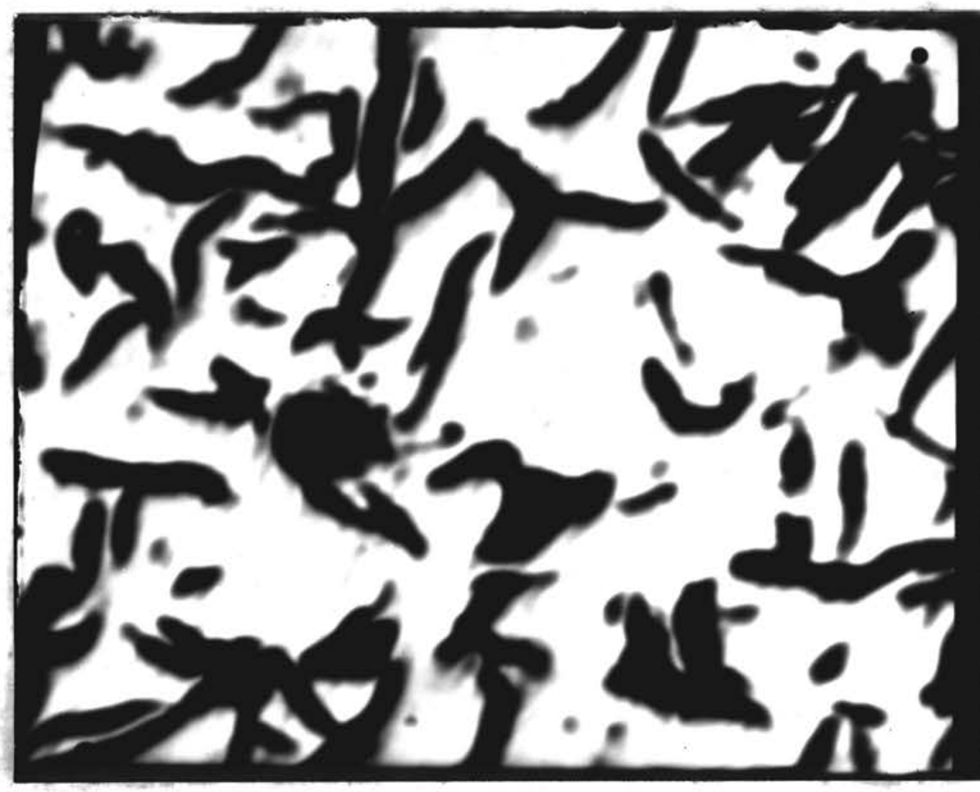


Figure 13. Oxy-acetylene fusion weld on cast iron. Photomicrograph at 200 diameters taken in the parent metal.

The photomicrograph shown in Figure 14 was taken in the weld or deposited metal of a non-preheated arc weld. The specimen was etched twelve seconds in five per cent nital solution and the photomicrograph was taken with an exposure time of four seconds at f 7. The gray area is pearlite, the white area is ferrite, while the black spots are inclusions. Although the picture is slightly out of focus, a very fine grain structure may be observed.

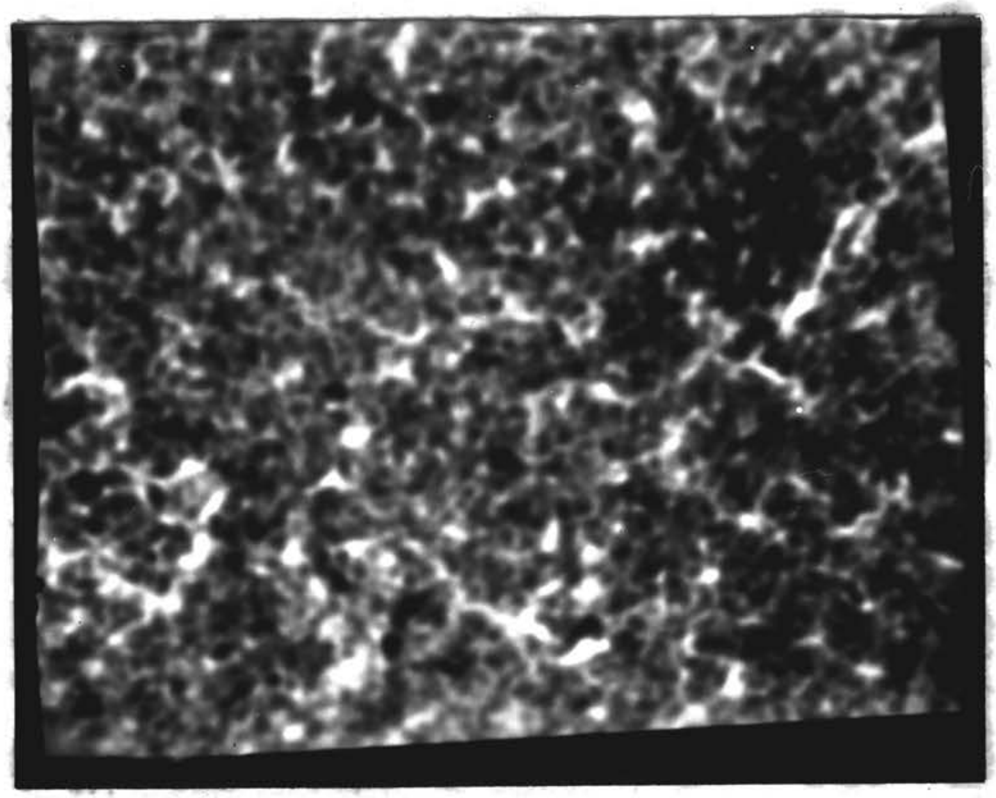


Figure 14. Non-preheated arc weld on cast iron using a mild steel electrode. Photomicrograph at 200 diameters in weld or deposited metal.

Figure 15 shows a photomicrograph that was taken in the fusion zone of a non-preheated arc weld. The specimen was etched twelve seconds in five per cent nital solution and an exposure time of four seconds at f 7 was used for making the photomicrograph. Cementite, the light areas, was caused by the carbon pick up of the mild steel electrode from the cast iron during the welding process. Pearlite, the dark areas, can be detected. Graphite, the dark areas, was evidently picked up from the cast iron. A better etch would have given more desirable results.

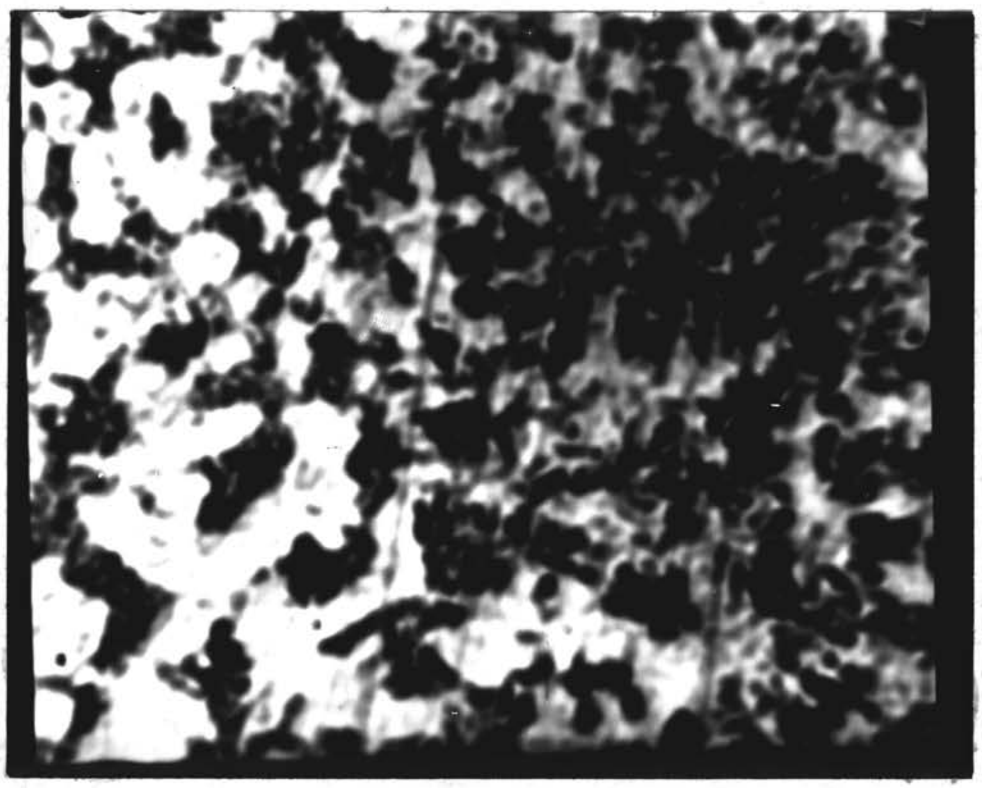


Figure 15. Non-preheated arc weld on cast iron using a mild steel electrode. Photomicrographs at 200 diameters in the fusion zone.

The photomicrograph shown in Figure 16 was taken in the parent metal of a non-preheated arc weld. The specimen was etched twelve seconds in a five per cent nital solution, and an exposure time of four seconds at f 7 was used for making the photomicrograph. Presence of the flake carbon, partly changed to nodular carbon, has caused a change in appearance from the other picture taken of the parent metal. It is present but is partly changed to nodular carbon. Iron phosphide is definitely present and although the pearlite is not readily seen there are indications that it is present and probably a deeper etch would have brought it out more clearly. Ferrite, which is the white areas, is easily seen.

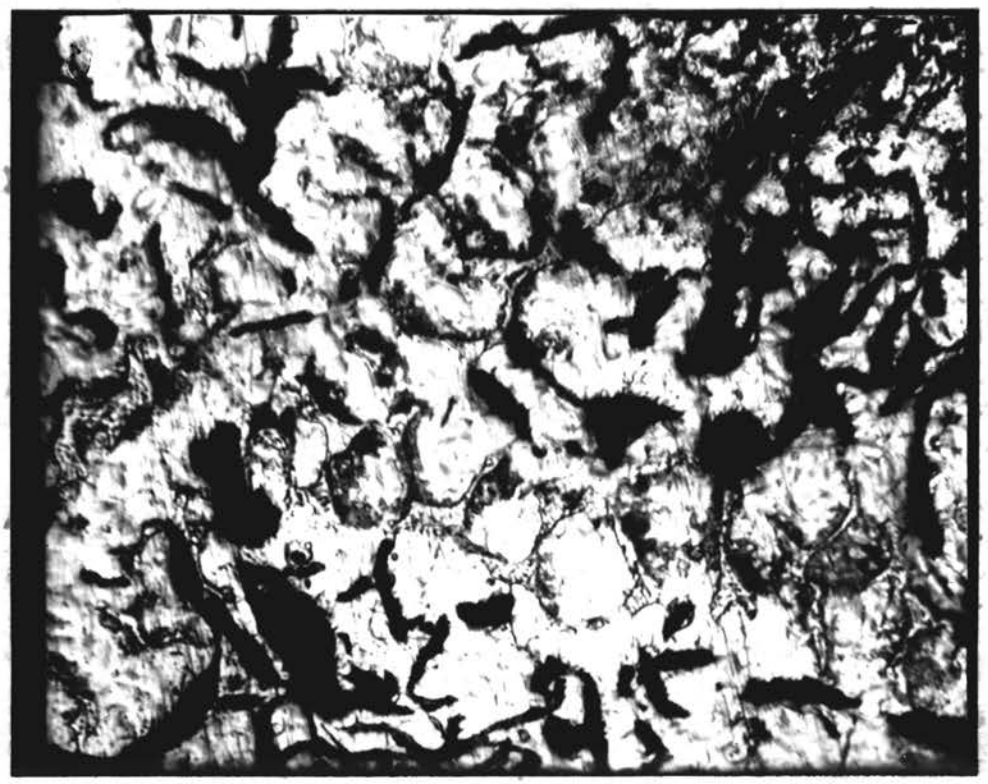


Figure 16. Non-preheated arc weld on cast iron using a mild steel electrode. Photomicrograph at 200 diameters in the parent metal.

Figure 17 shows a photomicrograph that was taken in the weld metal of an arc preheated weld. The specimen was etched for twelve seconds in a five per cent nital solution, and an exposure time of two seconds at f 7 was used. Ferrite, light areas, and pearlite, dark areas, are readily noticeable. Some oxide inclusions, scattered dark specks in ferrite areas, can be seen also. It is evident from an analysis of this photomicrograph that some carbon was picked up from the cast iron.

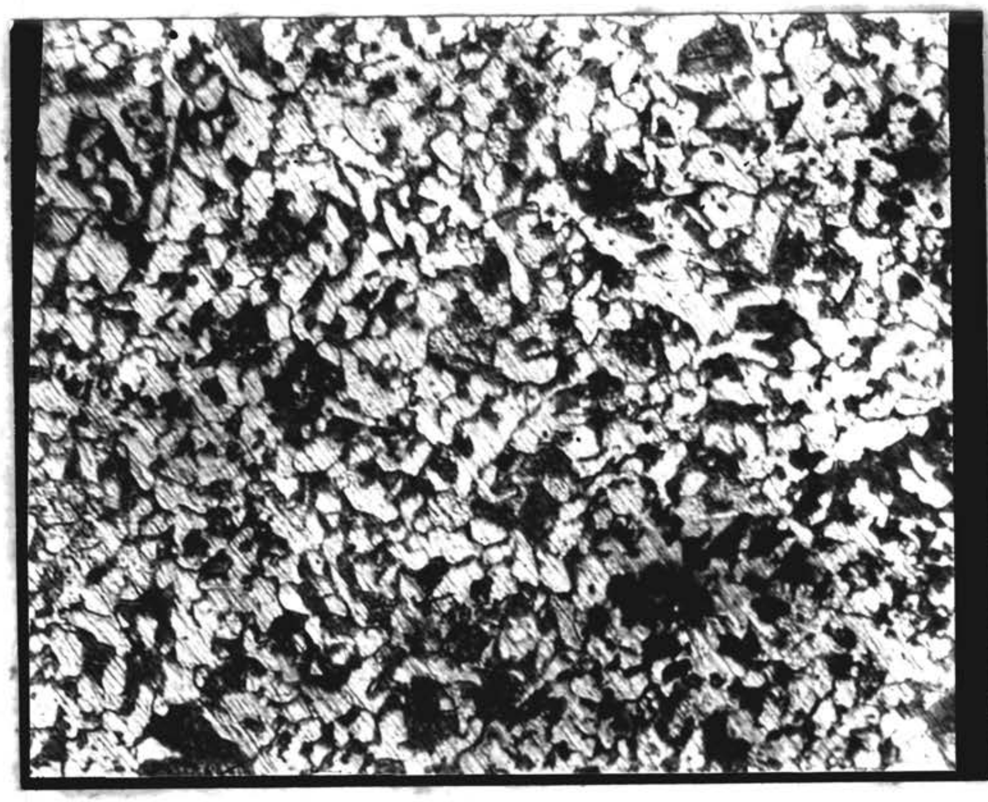


Figure 17. Preheated arc weld on cast iron using a mild steel electrode. Photomicrograph at 200 diameters in the weld or deposited metal.

The photomicrograph shown in Figure 18 was taken in the fusion zone of a preheated arc weld. The specimen was etched for twelve seconds in five per cent nital solution, and an exposure time of two seconds at f 7 was used for making the photomicrograph. Ferrite, the white areas, shows up very nicely in the weld metal compared to the cast iron parent metal. A very definite line can be seen between the parent metal and the deposited metal. Due to the difference of their respective carbon content, a definite color exists. The light area at the right is the metal deposited by the mild steel electrode and the dark in the parent metal at the left is high in carbon content. Pearlite, the gray areas, is also noticeable.

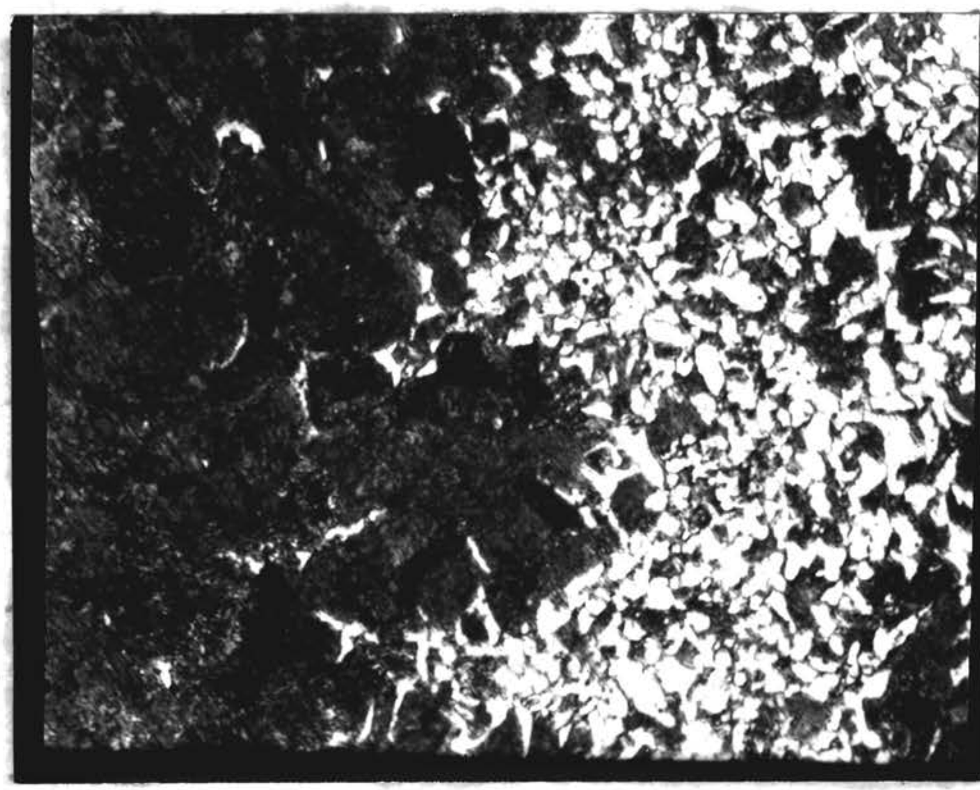


Figure 18. Preheated arc weld on cast iron using mild steel electrode. Photomicrograph at 200 diameters in fusion zone or zone between weld metal and parent metal.

Figure 19 shows a photomicrograph that was taken in the parent metal near a preheated arc weld. The specimen was etched for twelve seconds in a five per cent nital solution, and an exposure time of two seconds at f 7 was used. Flake carbon, elongated dark strips, and nodular carbon, round dark areas, are present in the picture. Ferrite, the white areas, and pearlite, the gray mottled areas, are easily seen.

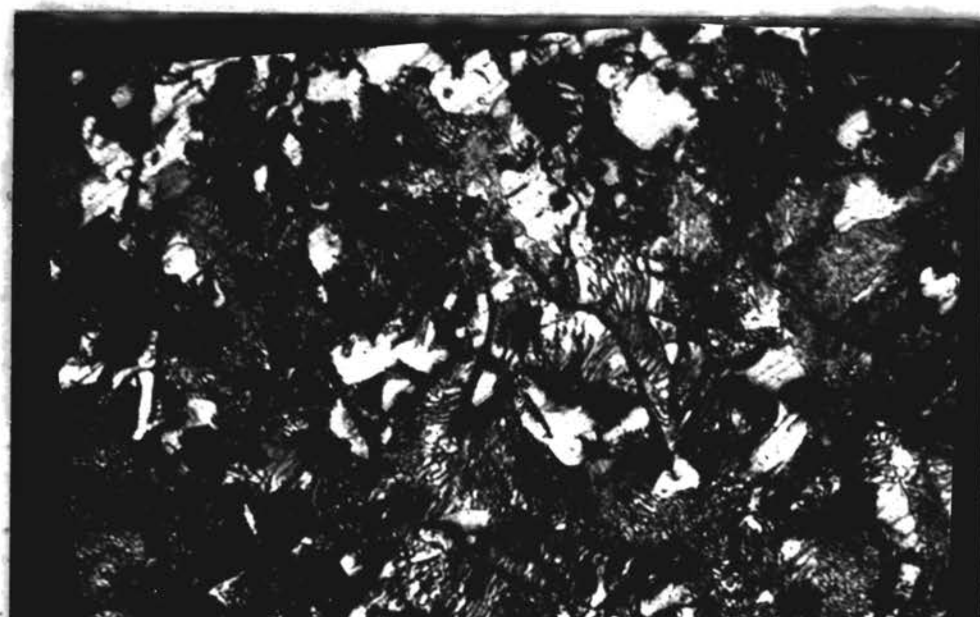


Figure 19. Preheated arc weld on cast iron using mild steel electrode. Photomicrograph at 200 diameters in parent metal near the center of the specimen.

Figure 20 shows a photomicrograph that was taken in the fusion zone or area between parent metal and deposited metal of a preheated arc weld. The specimen was etched for twelve seconds in five per cent nital solution and an exposure time of two seconds at f 7 was used in making the photomicrograph. A coarse grain structure compared with Figure 19 can be seen which shows that the outer beads anneal ones which have been previously deposited, refining their grain structure. For a more detailed study of the dark areas this photomicrograph should be taken at a higher magnification.

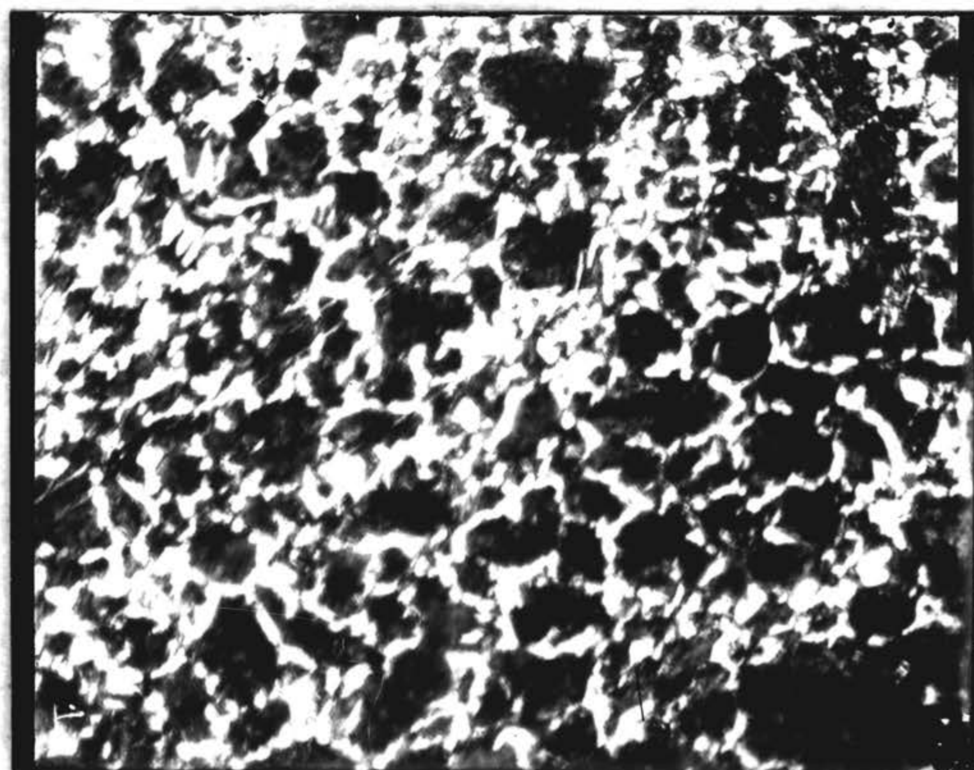


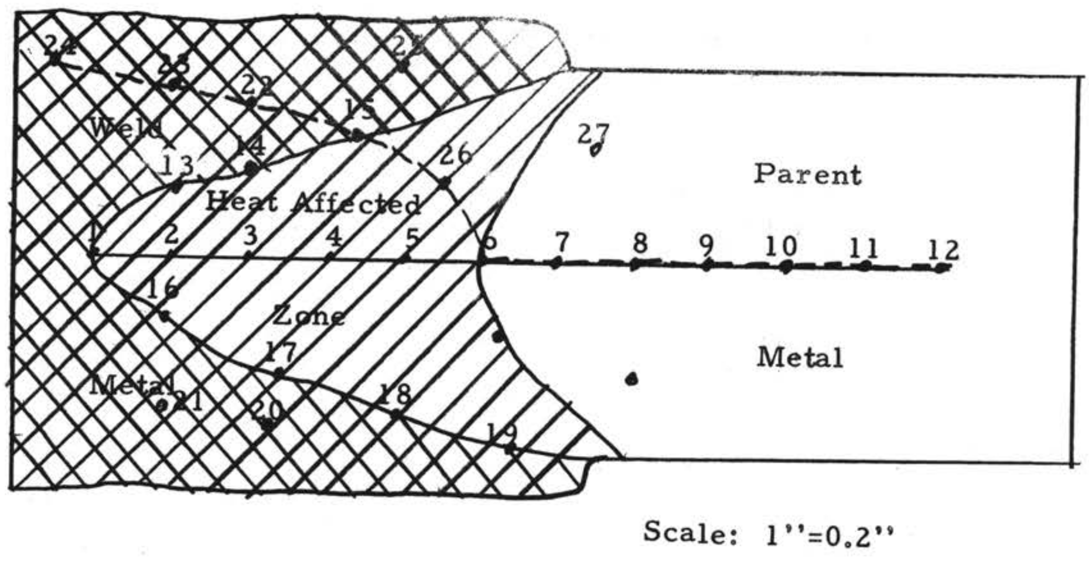
Figure 20. Preheated arc weld on cast iron using mild steel electrodes. Photomicrograph at 200 diameters in fusion zone or area between parent metal and deposited metal, near edge of specimen.

<u>Hardness tests.</u> After the photomicrographs were taken, hardness tests were made on the specimens, in the weld, the heat affected zone, and the parent metal. The results are plotted (Figures 21 through 24) from the weld through the heat affected zone and into the parent metal. These figures also show where each test was made with respect to the weld, the heat affected zone, and the parent metal. It will be noticed that the greatest hardness is in the weld and heat affected zone, whereas, the parent metal is softer. The brazed joint is an exception as the deposited metal is much softer than the parent metal, or other deposited metals.

TABLE III

RESULTS OF HARDNESS TESTS MADE ON THE FOUR SPECIMENS

Test number	Hardness number Rockwell B scale arc non-preheated weld	Hardness number Rockwell B scale arc preheated weld	Hardness number Rockwell B scale gas fusion weld	Hardness number Rockwell B scale brazed joint	Test number	Hardness number Rockwell B scale arc non-preheated weld	Hardness number Rockwell B scale arc preheated weld	Hardness number Rockwell B scale gas fusion weld	Hardness number Rockwell B scale brazed joint
1	77	98	100	86	17	95	103	103	86
2	81	115	99	67	18	90	100	97	80
3	78	106	102	85	19	89	101	90	61
4	83	97	102	90	20	90	102	102	56
5	80	102	101	85	21	89	106	101	57
6	81	111	88	88	22	85	115	99	62
7	81	109	83	91	23	104	115	100	63
8	80	109	79	93	24	97	113	90	60
9	74	103	76	93	25	110	114	96	88
10	65	108	76	94	26	107	109	101	88
11	62	101	77	93	27	109	97	82	89
12	73	98	76	94	28	44	98	87	89
13	79	98	101	66	29	108	100	79	91
14	80	98	101	85	30	110	104		93
15	82	97	101	79	31	110			
16	101	98	102	83	32	107			



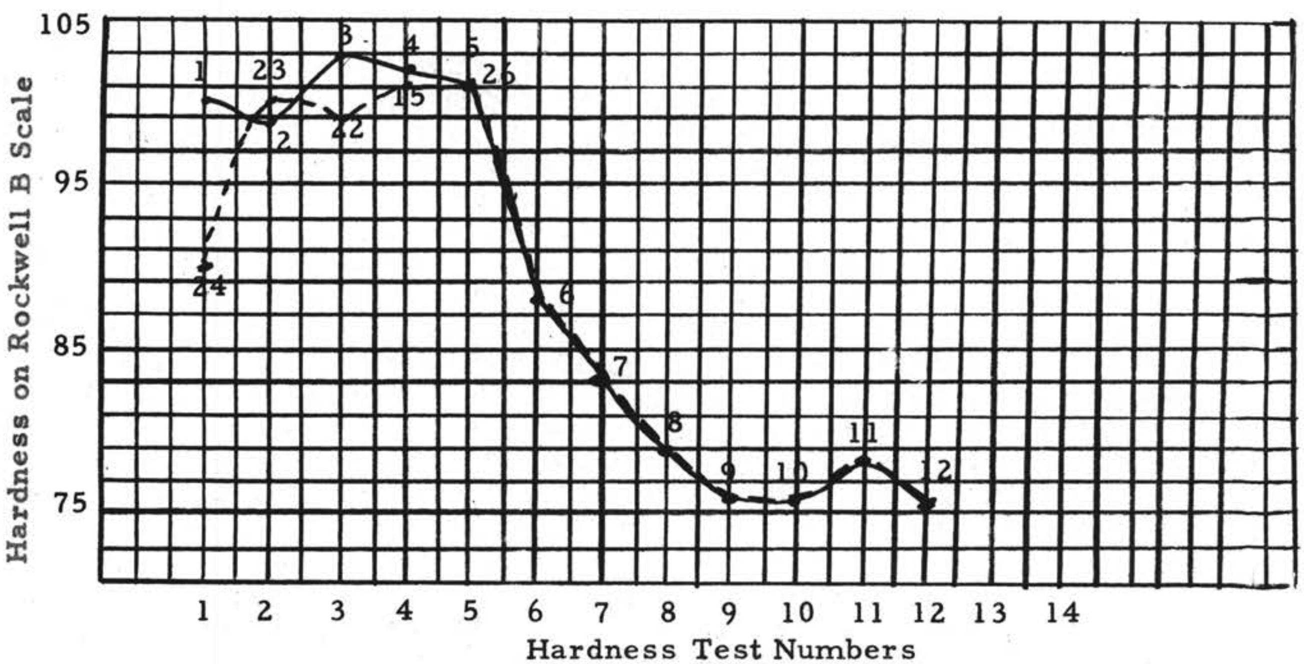


Figure 21. Hardness tests on an oxy-acetylene fusion weld specimen.

Figure 21 represents a specimen from an oxy-acetylene fusion weld enlarged five times, as cut through the weld or deposited metal, the heat affected zone and into the parent metal. This figure shows where each hardness test was made and the graph shows the relative hardness, on Rockwell B scale, plotted against hardness tests in different areas.

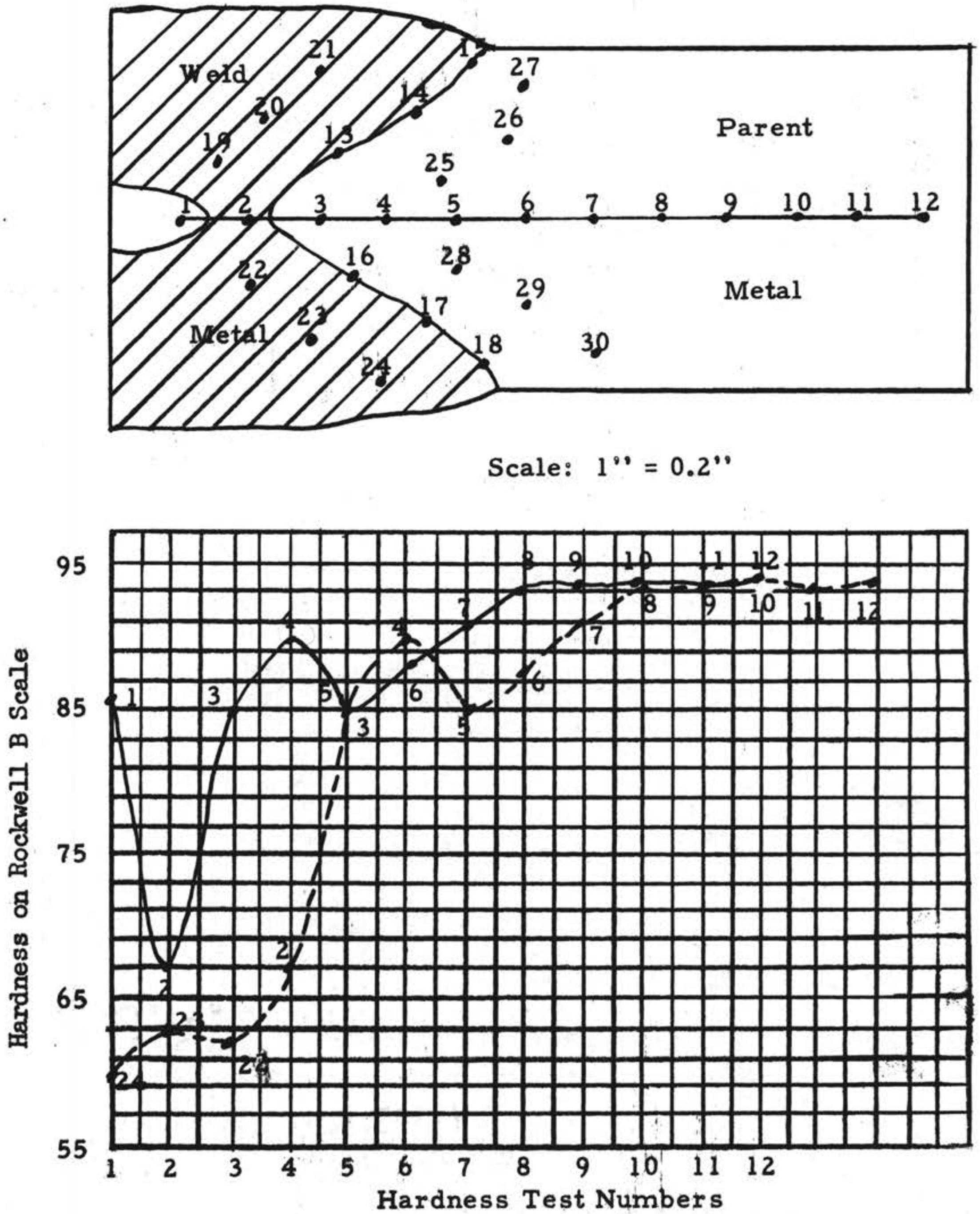
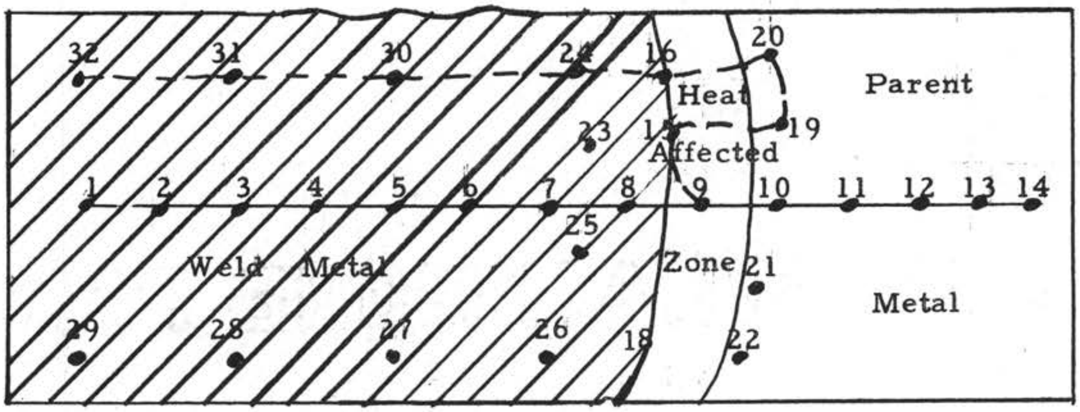


Figure 22. Hardness tests on an oxy-acetylene bronze weld specimen.

Figure 22 represents a specimen from an oxy-acetylene bronze weld enlarged five times as cut through the weld or deposited metal, The heat affected zone, and into the parent metal. This Figure shows where each hardness test was made and the results are on the graph. The deposited or weld metal is softer than the parent metal or heat affected zone, in this case.



Scale: 1" = 0.2"

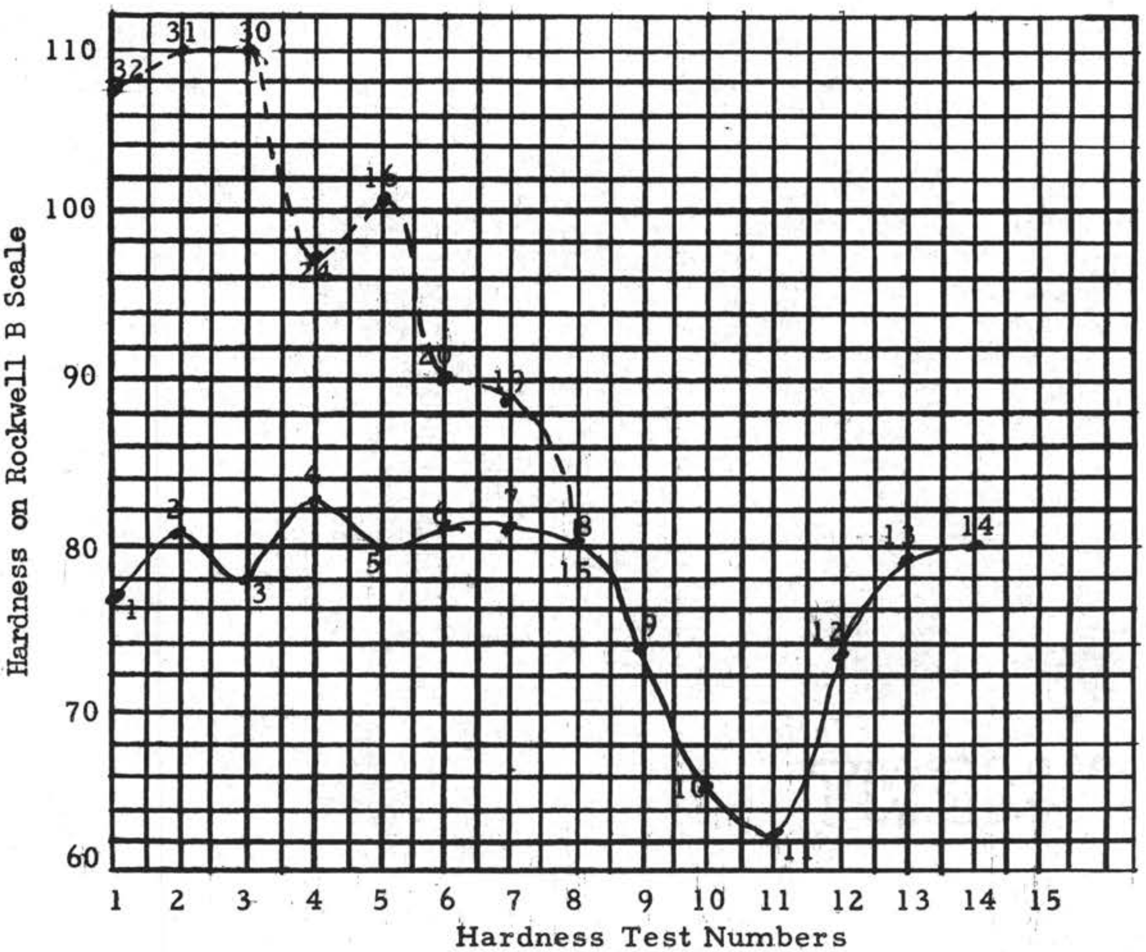


Figure 23. Hardness test on a non-preheated arc weld specimen.

Figure 23 represents a specimen from a non-preheated arc weld enlarged five times as cut through the weld, the heat affected zone, and into the parent metal. This figure shows where each hardness test was made and the graph shows the relative hardness, on Rockwell B scale, plotted against the hardness tests in different areas.

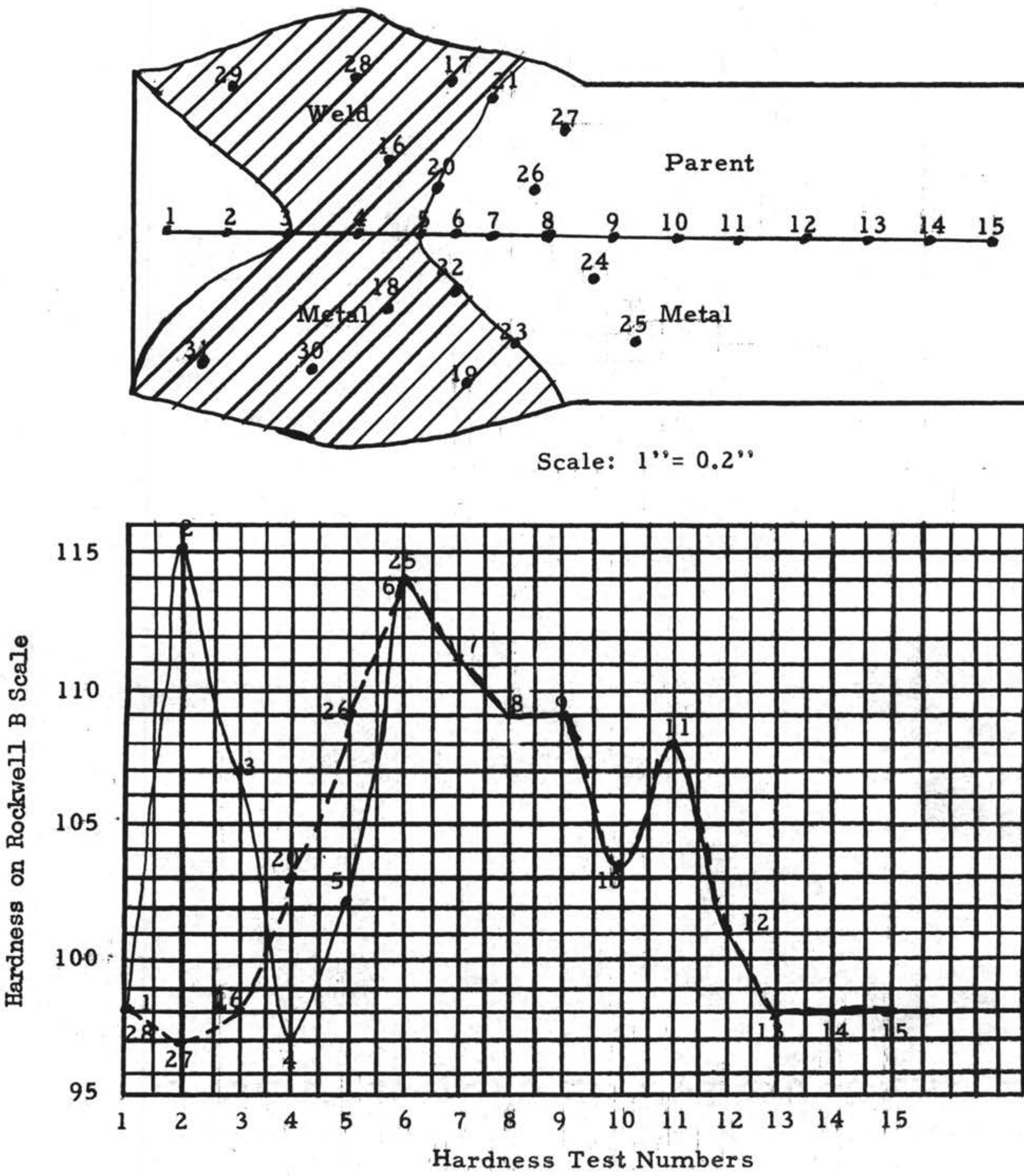


Figure 24. Hardness tests on a preheated arc weld specimen.

Figure 24 represents a specimen from a preheated arc weld enlarged five times as cut through the weld, the heat affected zone, and into the parent metal. This figure shows where each of the thirty different hardness tests were made. The graph shows the relative hardness, on Rockwell B scale, plotted against hardness tests in different areas.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

Conclusions. Of the four welding methods used the preheated oxy-acetylene fusion weld had a flexural strength of almost five per cent greater than any of the others and ten per cent greater than the one of least value. The least individual variation among the four operators, which was eight and six tenths per cent, occurred when using the oxy-acetylene fusion method. This would indicate that of the four values used the preheated oxy-acetylene fusion weld produces the best physical values. The highest individual value obtained, 85.7 per cent, was incurred in this method.

The preheated brazed joint, with an average of 75.65 per cent compared to 80.25 per cent for the preheated oxy-acetylene fusion weld, was second in physical strength. The highest value attained by brazing was 83.1 per cent, which was second in the whole series. In instances where speed is necessary and strength is of less importance brazing would be the best method to use because of less preheating and faster welding.

From the values of the arc welds it may be seen that the highest value of the non-preheated weld is lower by almost two per cent than the lowest value of the oxy-acetylene fusion weld. Of the preheated arc weld values, the highest was as high as, or higher, than two of the values of oxy-acetylene fusion welding. In a microscopic examination cracks were noticed in the arc welded specimens, and especially in the non-preheated ones. Individual differences of 12.7 per cent and 11.5 per cent resulted in the preheated and non-preheated welds, respectively. This large amount of difference is accounted for by the fact that although the welds were made under the same preheat conditions different power settings were used among the operators. The welds made with lower power settings had higher strength than those made at higher power settings.

Recommendations. It is strongly recommended that the work on this study be continued and not left where it now stands for there is much research work to be done before final conclusions can be reached. It is recommended that photomicrographs 12, 13, 14, 15, 16, and 17 be retaken at higher magnifications and with a better etch. For a better metallographic study several photomicrographs should be taken in the fusion zone of each specimen. More welds should be made by each method. Several additional methods should be used also, for example: stainless steel electrode, with and without preheat; cast iron electrode with preheat and postheat; nickle electrode, with and without preheat; bronze electrode without preheat. These are a few of the many methods that remain untouched, and by varying preheating and postheating the possibilities multiply. Another thing that should be done is to record the amount of time necessary to do each type of cast iron welding as this data is pertinent from the standpoint of determining welding costs.

In many instances the welded parts have to be machined, hence, machinability tests should be made to determine the methods to use when this factor is involved. It is recommended also that measurements of the fusion zone and heat affected zone be made for a comparison with the results of the hardness tests.

Tensile and compression tests should be made as cast iron is used in many places where these factors are involved. On the flexure tests it is recommended that the flange of the T beam be up instead of down as was the case in this study.

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