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ELECTRIC ARC WELDING OF GRAY CAST IRON

WITHOUT PREHEATING

A Thesis

Presented to the

Department of Mechanical Engineering Sciences

Brigham Young University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Ramon Prestwich

May, 1968

This thesis, by Ramon Prestwich, is accepted in its present form by the Department of Mechanical Engineering of Brigham Young University as satisfying the thesis requirement for the degree of Master of Science.

12 December 1967
Date

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CHAPTER I

INTRODUCTION

Cast irons are iron-carbon alloys with greater than 1.7% carbon. Although white, malleable and ductile cast irons are used extensively for casting work, this study is concerned with only the gray cast irons.

Gray cast iron contains enough silicon or nickel to cause carbon flakes to form in the melt before the molten metal is poured into the molds. Thus all the carbon does not form cementite (iron carbide) as in white cast iron.[1]

Cast irons in general are brittle with the tensile strength being reached before yielding occurs. This results in fracture rather than yielding when localized stress reaches the tensile strength.[2]

The extreme spot heating and cooling with subsequent localized contraction of a welded region can cause very large localized stresses. As one example of this, assume that an area .5 inches wide and several inches long is heated to 700°F during welding. (A reasonable assumption as shown later by actural experiment.) For this situation, assuming a final bulk plate temperature of T_p = 100°F the stress on the welded region can be calculated as follows:

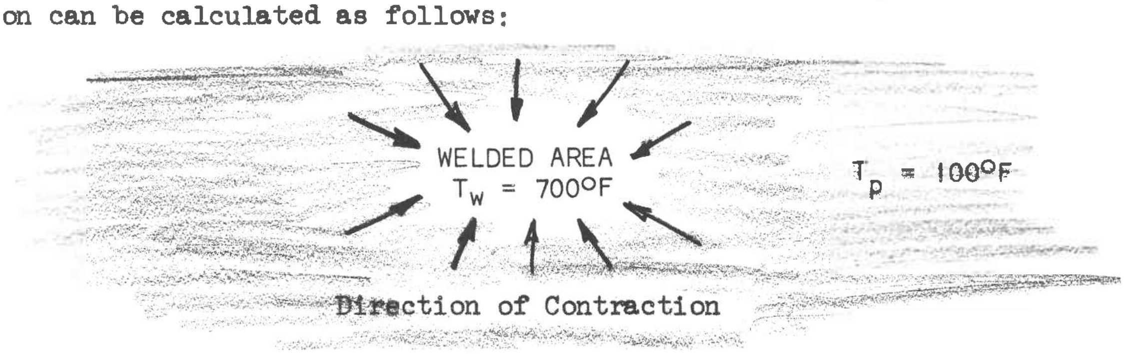


Figure 1.1. Locally Heated Area

ΔT = Temperature Difference ($T_w - T_p$)

E = Young's modulus of elasticity

α = Coefficient of thermal expansion

$$\sigma = E \alpha \Delta T$$
$$= (1.3)(10^7)\left(\frac{lb}{in^2}\right)\frac{(6.7)(10^{-6})}{^\circ F}(600^\circ F)$$
$$= 52{,}260 \frac{lb}{in^2}$$

This stress is well above the tensile strength of most cast iron. Thus, the critical factor is the localized temperature differential ($T_w - T_p$).

In mild steels, the large localized stresses can cause yielding (before fracture) with a subsequent stress relief. However, in brittle cast irons the large localized stresses can cause a small localized fracture. Once the fracture begins, it propagates throughout the region that is highly stressed.

Thus, the question presented is: How can cast iron be most successfully repaired considering its brittle nature?

To date, most successful repairs have been achieved by oxy-acetylene bronzing (hard soldering) or by heating the casting to some predetermined temperature (preheating) and using electric arc or oxy-acetylene welding. However, there are definite problems associated with both of these. In the bronzed specimen the filler metal melts at 1400-1700°F which is a lower temperature than the 2000-2600°F cast iron melting temperature.[3] Thus, this welding method cannot be used for high temperature applications. In the preheating technique a furnace is required. This limits the size of the casting that can be welded. The casting must also be dismounted and shipped to the nearest furnace which may mean large financial expenditure for shipping and down time.

Consequently, a method for welding cast iron without preheating to obtain strengths nearly equal to the cast iron strength is needed. Such a method is described in this thesis.

CHAPTER II

RESULTS AND CONCLUSIONS OF OTHER INVESTIGATORS

Recommended Preheat Temperatures

Several authors of texts, welding manuals and papers agree that the best method for welding cast iron is to preheat above 400°F. However, the preheating temperature recommended varies considerably among the authors. It depends upon the method of welding, the filler metal used and the degree of weld constraint. For example: for a highly constrained weld region, the preheat temperature recommended by the Huntington Alloy Products Division of the International Nickel Co.[4] and Rossi[5] is 900°F. The lowest preheat temperature recommended by Rossi is 750°F while that of the Huntington Alloy Products Division is 600°F. Kihlgren and Waugh[6], welding engineers for International Nickel Company, recommend a preheat of 550-600°F for high stress and 300-350°F for general applications. The Eutectic Welding Alloys Corporation[7] recommends a preheat of 400°F or 500°F depending on the electrode to be used. The Welding Data Book[8] simply recommends a preheat above 400°F, and Althouse[9] recommends a preheat of 1500-2000°F. (Althouse's recommendation is in the minority and is probably excessively high.)

Conclusively, most investigators seem to agree that it is necessary to preheat cast iron before welding; however, they do not agree on a reasonable preheat temperature. This may be attributed to the extremely variable nature of cast iron and the limited amount of research and data correlation available.

Experimental Results Using Preheat

The research of Townshend and Porter[10] led them to several conclusions regarding production welding of highly constrained cast iron joints. They investigated the welding of ASTM A278-53 class 30 gray cast iron using several combinations of welding electrodes and processes. The results of their investigation for a preheat of 600°F are shown in Table 1. Note particularly that the only shielded metal-arc electrode that did not fail this initial general test was 55% nickel-45% iron.

As a result of their initial tests, work on all shielded metal-arc electrodes except 55% nickel-45% iron was discontinued. Their further experimental work was done to determine the preheat temperature necessary for production welding of the noted cast iron using the 55% nickel-45% iron electrode. Also, they determined relative strengths of welds obtained from methods other than the shielded metal-arc process. The results of this research are shown in Table 2..

It is significant to note (Table 2) that with a cast iron bulk or interface temperature of 300°F the tensile strength of the weld was "nil"; and, that on cast iron having a bulk temperature of 70°F the weld broke before it was completed. Further, that a preheat of at least 550°F was considered necessary to obtain a sound weld.

It must be remembered that these results were for a highly constrained joint using production or continuous weld techniques.

For the strongest shielded metal-arc deposited weld:

$$\eta_w \text{(weld efficiency)} = \frac{\text{mean weld tensile strength}}{\text{mean cast iron tensile strength}} \times 100\%$$

$$= 97\%$$

For the bronze weld:

$$\eta_w = 71\%$$

TABLE 1

RESULTS OF WELDING 37,000 PSI GRAY CAST IRON BLOCKS AT 600°F USING VARIOUS FILLER MATERIALS AND WELDING PROCESSES

Process	Electrode Type	Appearance of Welded Cross Section
Shielded metal-arc	55Ni-45Fe	Sound weld
	98 Ni Co (Type A)	Weld cracks
	98 Ni Co (Type B)	Weld cracks
	68 Ni-15 Cr-11Fe	Fusion-line cracks
	14Ni-75Cr	Fusion-line cracks
	9Ni-29Cr	Fusion-line cracks
	66Ni-4Mn-20Cu	Weld cracks
Inert-gas tungsten-arc	55Ni-45Fe	Weld cracks
	98Ni Co (Type A)	Weld cracks
	68Ni-15Cr-11Fe	Weld and fusion-line cracks
	14Ni-75Cr	Weld and fusion-line cracks
	9Ni-29Cr	Weld and fusion-line cracks
	Low-C steel	Weld cracks
	Cast iron (3¼ C-3 Si)	Weld cracks
Oxyacetylene	Cast iron (3¼ C-3 Si)	Sound weld
	60Cu-35Zn	Sound braze
	97.5Ni-1Co	Poor bond to cast iron

TABLE 2

WELDING OF 37,000 PSI GRAY CAST IRON TEST PLATES

No. of Sampls Welded	Interpass Temp. °F	Electrode Material	Varied Condition	Tensile Strength psi	Location of Tensile Fracture
Shielded metal-arc with postweld treatment of 1200°F, 2-4 hr.					
1	70	55Ni-45Fe	Plate temp.	Cracked during welding	---
2	300	55Ni-45Fe	Plate temp.	Nil	---
5	550-600	55Ni-45Fe	Medium arc (3/16 in.)	36,100	Fusion line
2	600	55Ni-45Fe	Long arc (1/4-5/16)	29,950	Voids at fusion line
1	600	55Ni-45Fe	Short arc (1/16-1/8)	36,250	Fusion line and weld
4	900	55Ni-45Fe	Temp.	33,250	Fusion line
Oxyacetylene with no postweld treatment					
1	Est. 1300	Cast iron	None	23,500	Fusion zone
1	900-1200	Bronze	Grit-blast surface	26,250	Bronze interface
1	900-1200	Bronze	Ground surface	26,500	Bronze interface

Results using no preheat will be compared to these results of Townshend and Porter at the conclusion of this paper.

Recommendations for Welding Without Preheat

Although most authors indicate that preheating is necessary for shielded metal-arc welding of cast iron, some authors indicate that electric arc welding of cast iron without preheating is also possible. They list specific recommendations to make it possible, but give no experimental or engineering evidence to substantiate their claim. For example, Barr[11] lists the following procedure for welding the joint between cast iron pieces that have not been preheated. Clean the surface and make a V (Figure 2.1) in the joint to be welded. Use a chamfering electrode and make stress relieving grooves separated not less than .25 inch for the entire crack length. Fill the stress relieving grooves with electrode metal, then fill between the grooves. Finish filling the V using short one to four inch stringer beads (no weaving). (It is important to note that no specific experimental data is listed to indicate weld strengths that might be expected using the prescribed procedure.)

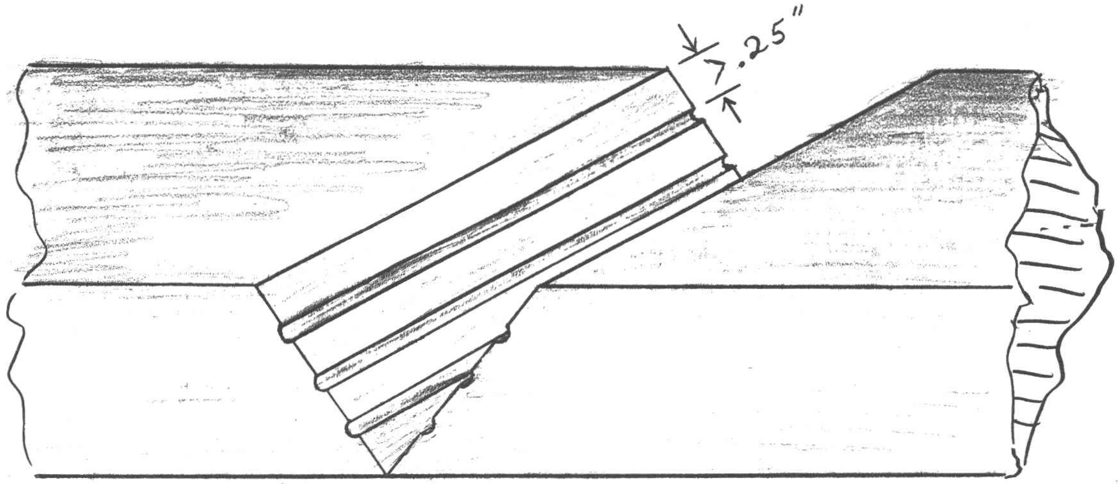


Figure 2.1. Single V with Stress Relieving Grooves.

CHAPTER III

RESEARCH GUIDELINES

General Goals and Procedures

As indicated previously, the general aim of the research performed for this thesis was to determine the weld strength which might be expected when non-preheated cast iron is electric arc welded. All the weld tensile strength data presented are for electric arc welded specimens that were not heated before being welded. Also, the bulk of the cast iron in the welded specimens did not exceed 204°F at any time during welding. This is a much lower temperature than any of the previously mentioned preheat temperatures.

The general experimental procedure used was to: first prepare two surfaces for joining. The surfaces were then joined using shielded metal-arc welding. Several tensile test specimens were then prepared as will be described in the next section. Finally, the specimens were placed in a tensile testing machine (see the appendix for the tensile testing machine specifications) and stressed to failure. (A standard flat grip with teeth was used to hold the specimens in the testing machine (Figure 3.1).)

Preparation of the Test Specimens

The small test specimens were not each individually welded. Instead, a plate one-half inch by eight and one-half inches by twelve inches with flanges on the ends was used (Figures 3.2 and 3.3). This

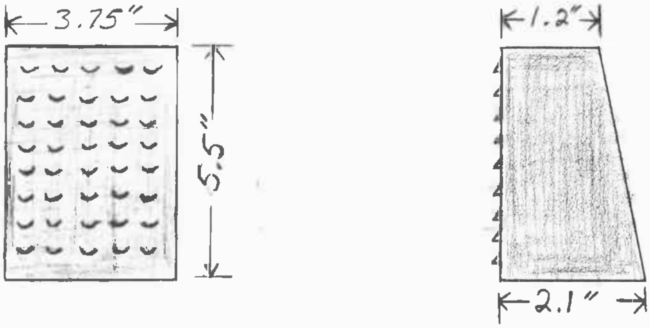


Figure 3.1. Grips for the Tensile Testing Machine.

was sawed through the eight and one-half inch width to make smaller plates as in Figure 3.4. Some of the resulting smaller plates were then sawed through the length as shown by the saw blade on the plate in Figure 3.5. The sawed surface of each half was next ground to one of several shapes (Figures 3.6 and 3.7) in preparation for welding. The halves were then welded back together. (It should be noted that the saws, the grinder, the welder and other equipment used to obtain data for this thesis are listed in the appendix.)

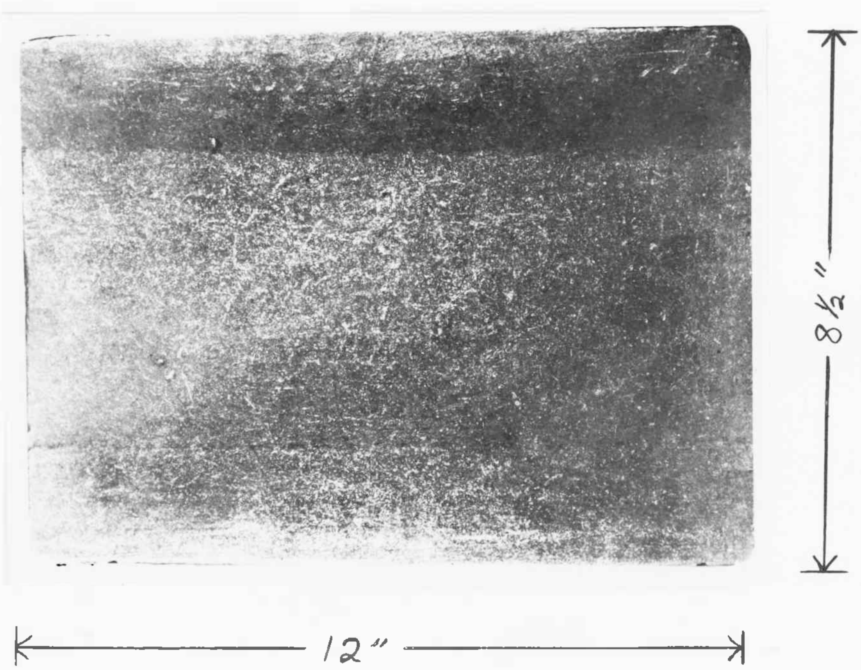


Figure 3.2. Top View of the Plate

Figure 3.3. End View

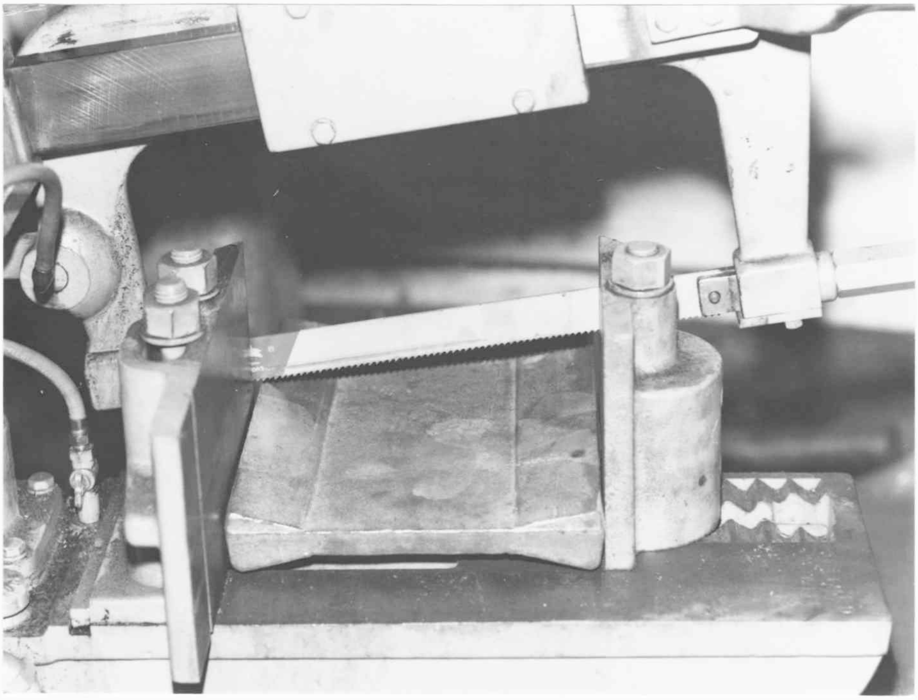


Figure 3.4. Reducing the Large Plate to Smaller Plates

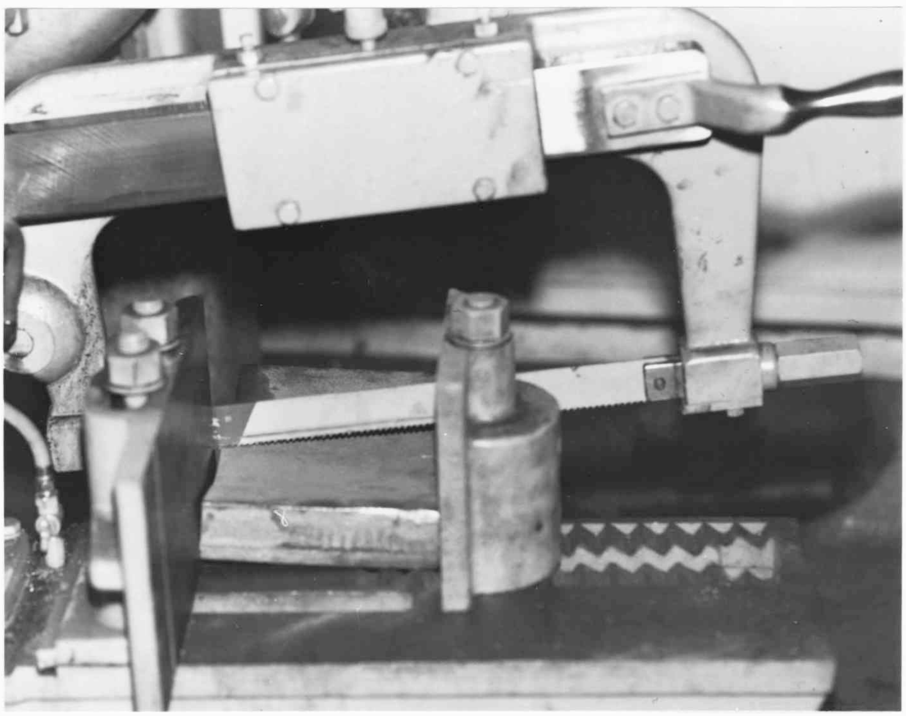


Figure 3.5. Sawing the Small Plates to Obtain a Welding Joint

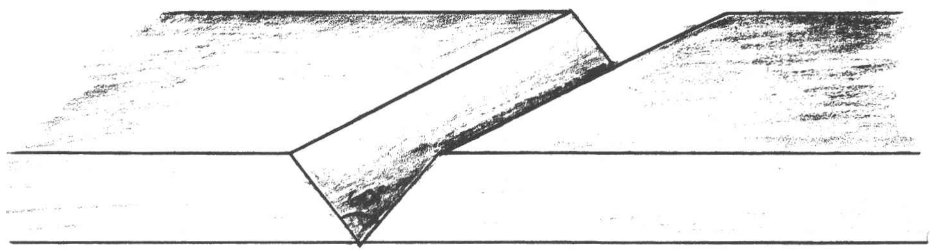


Figure 3.6. Single 60° V

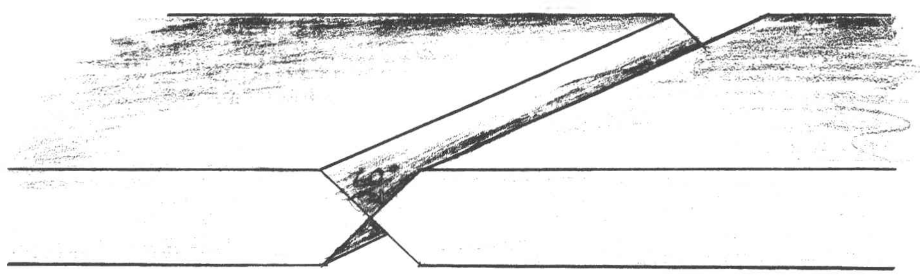


Figure 3.7. Double 60° V

The two sides of the welded plate were then ground on a surface grinder as shown in Figure 3.8 to obtain a uniform cross section. (See the appendix for the grinder specifications.) Next, the plate was sawed into strips (Figure 3.9) approximately .6 inches thick. These were then ground on both sides on the surface grinder to produce the finished test specimen (Figure 3.10).

It should be noted that in some cases the wider flange at the end of the specimen had to be partially removed to facilitate sawing each specimen. (Compare Figures 3.3 and 3.9.) This did not in any way affect the test results.

Figure 3.8. Grinding the Welded Plate

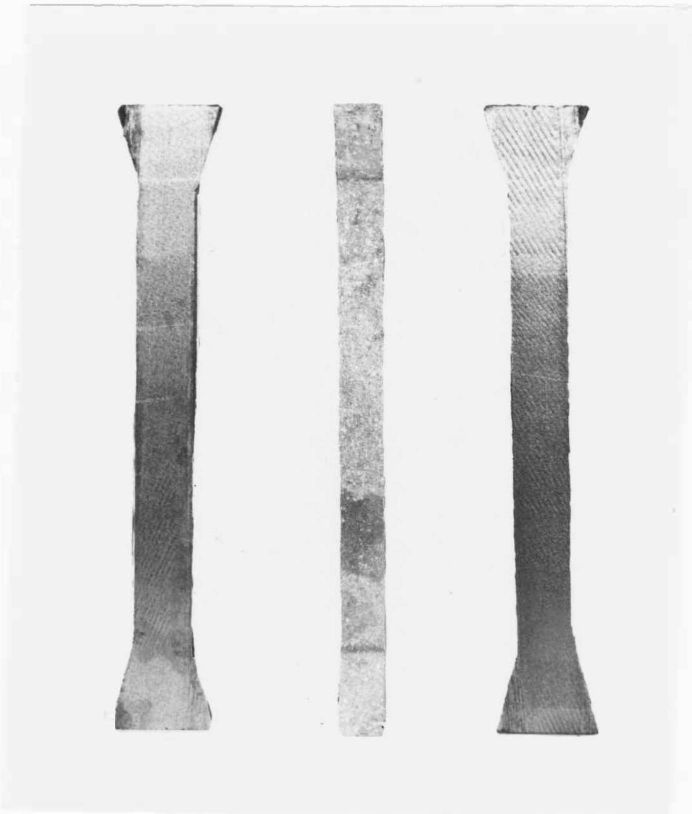


Figure 3.9. Unground Specimens

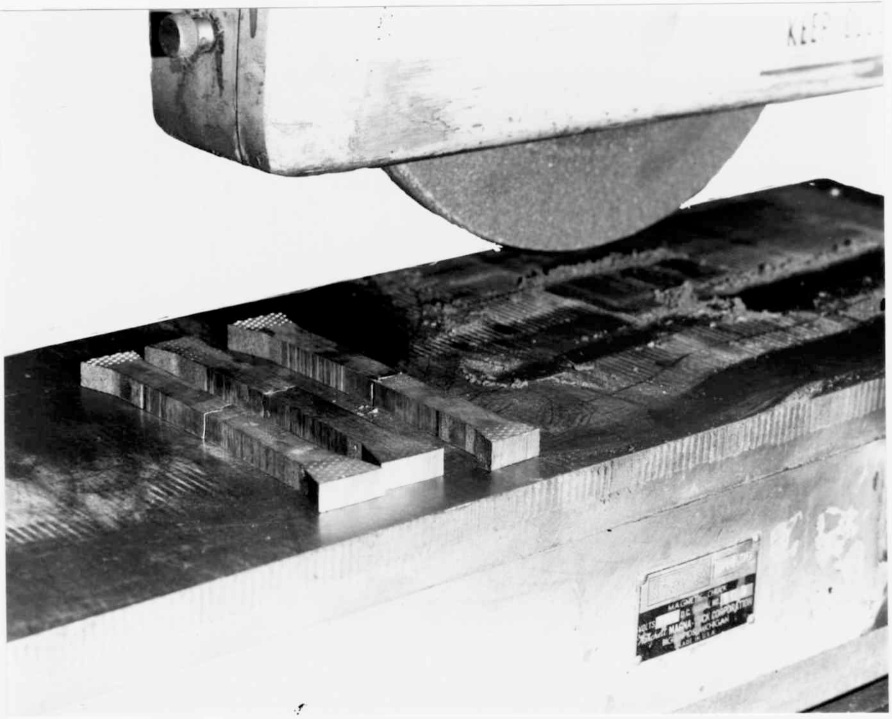


Figure 3.10. Specimens Prepared for Testing

CHAPTER IV

WELDING WITH NICKEL ELECTRODE

Major Conclusions

Three major conclusions were obtained using a 95% nickel, shielded metal-arc electrode. The first conclusion was that three to four minutes cooling time was necessary between the finishing of one bead and the beginning of the next. This conclusion emerged from a temperature history of the welded region. An indication that a temperature history was necessary was obtained using one inch stringer beads and the skip weld method to fill a single 60^{o} V (Figure 3.6). (Leaving an unwelded region between the end of one bead and the beginning of the next is the skip weld method.) Extreme localized heating occurred because the beads were laid as rapidly as they could be peened. The result was that the welded region cracked through before being completed. The same result was obtained using a double 60^{o} V (Figure 3.7), giving further proof that a temperature history was needed.

To obtain the temperature history a Leeds and Northrup Multi-channel recorder was attached to iron-constantan thermocouples which were welded to the plate (Figure 4.1). (See the appendix for the recorder specifications.) The temperature results of six specific test welds are shown in Figures 4.2 through 4.7. Included are the temperature-time response and the weld location for each specific test. The current was 63 amperes and the potential was 20 volts during the welding operation. The speed of travel was 9 inches per minute using a three-thirty second inch electrode.

It can be seen from Figure 4.6 that welding for 17 seconds raised the surface temperature to 720^{o}F. This gave some indication of the extreme localized heating involved. (Note that radiation from the electric arc had little direct effect.) An even more important consideration was the time required for the dissipation of the thermal energy away from the high temperature region after each bead was completed. In order for two extreme points to reach the same temperature it took at least four minutes in all cases. A severe temperature differential remained for two to three minutes. Thus, the indication

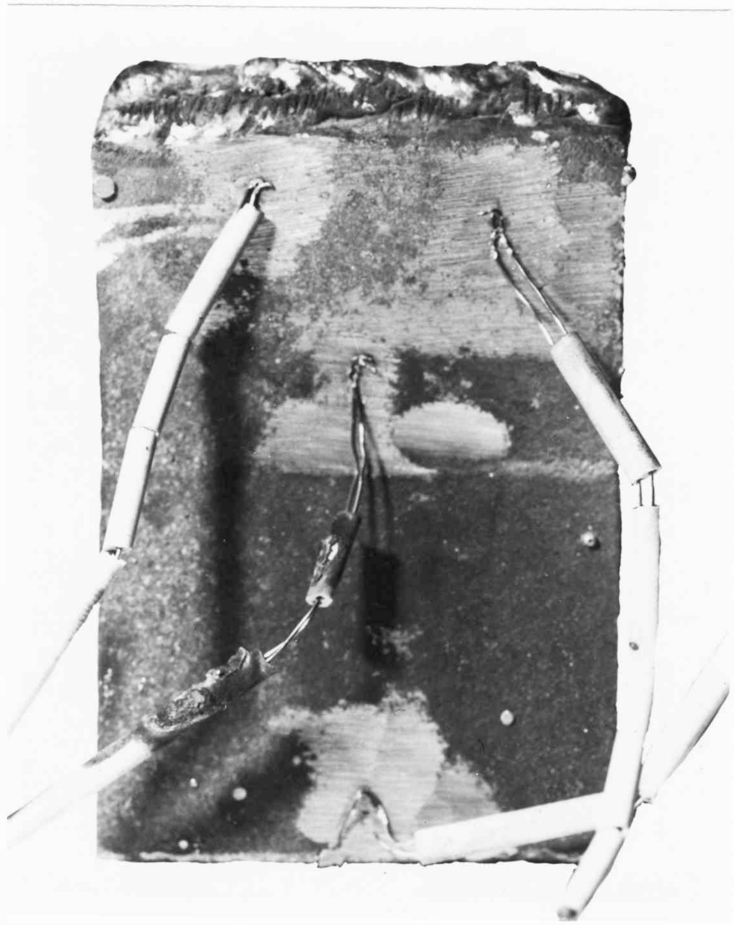
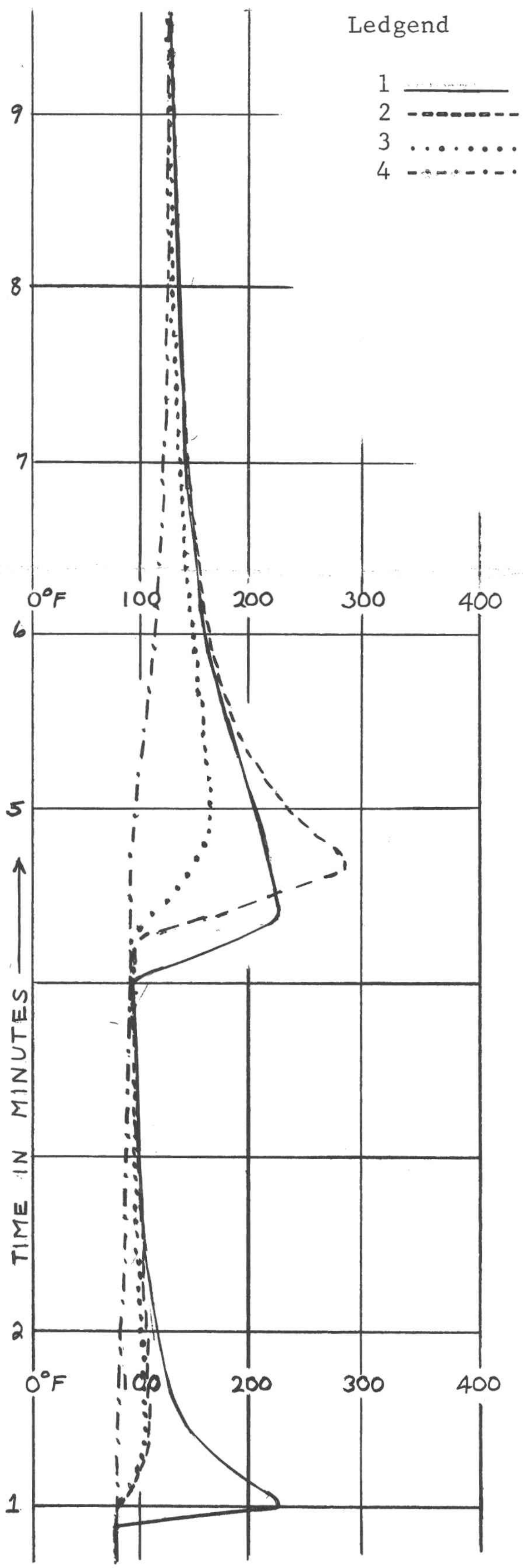
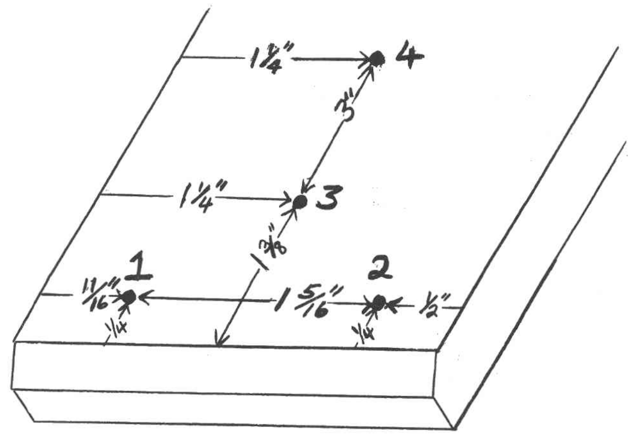


Figure 4.1. Thermocouples Attached to a Plate





Position of Thermocouples on the Plate

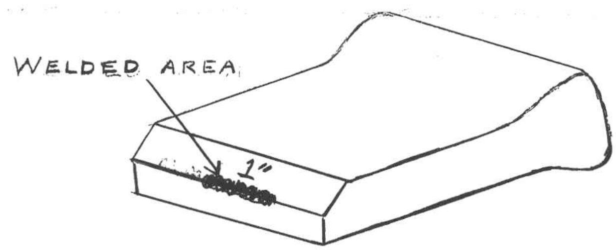


Figure 4.3. Temperature History

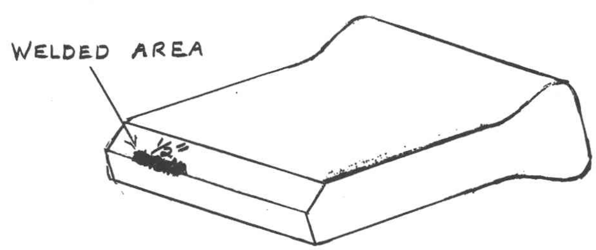
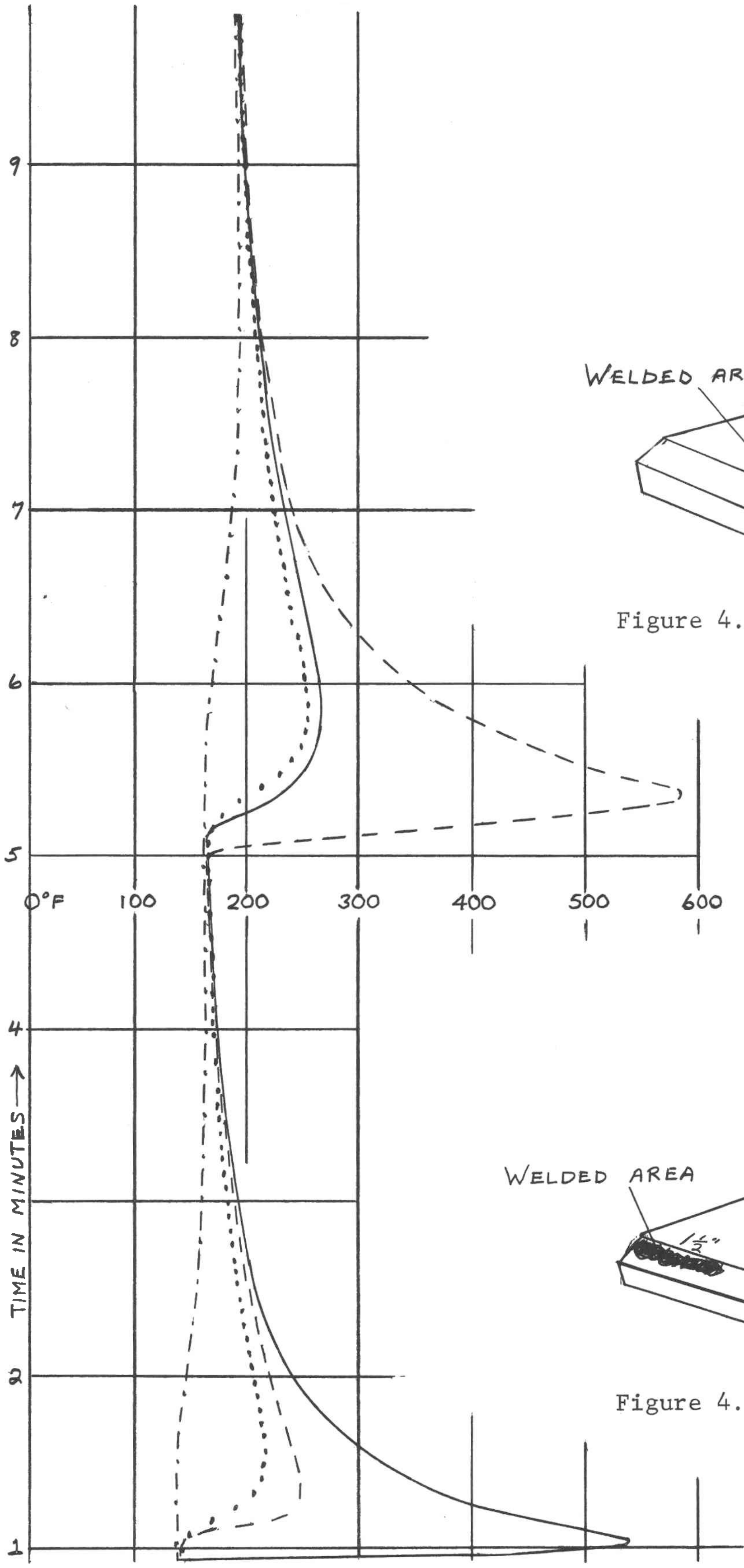


Figure 4.2. Temperature History



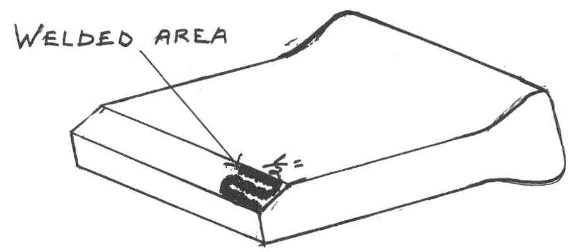


Figure 4.4. Temperature History

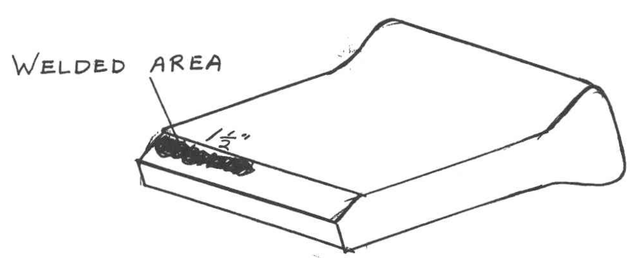


Figure 4.5. Temperature History

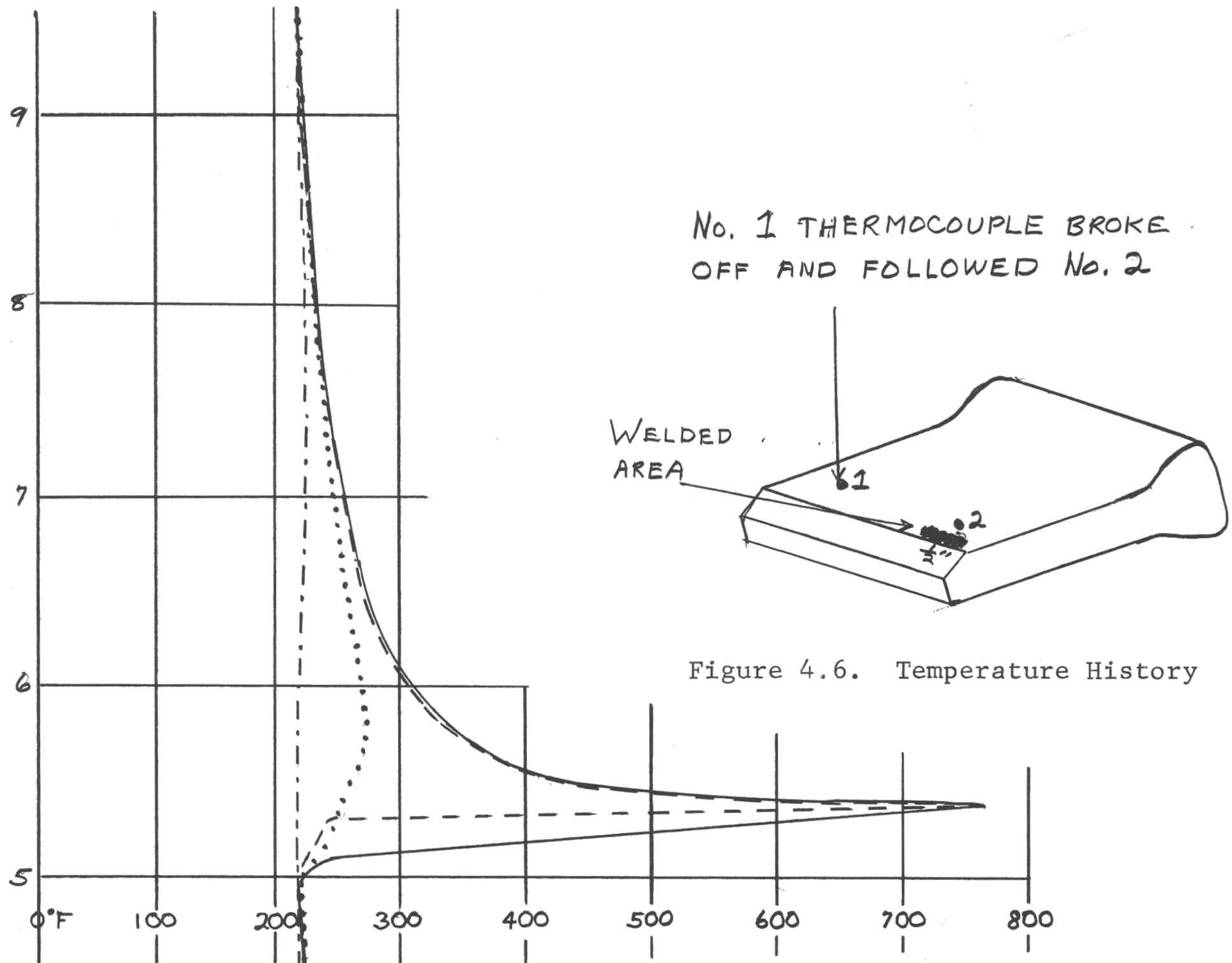


Figure 4.6. Temperature History

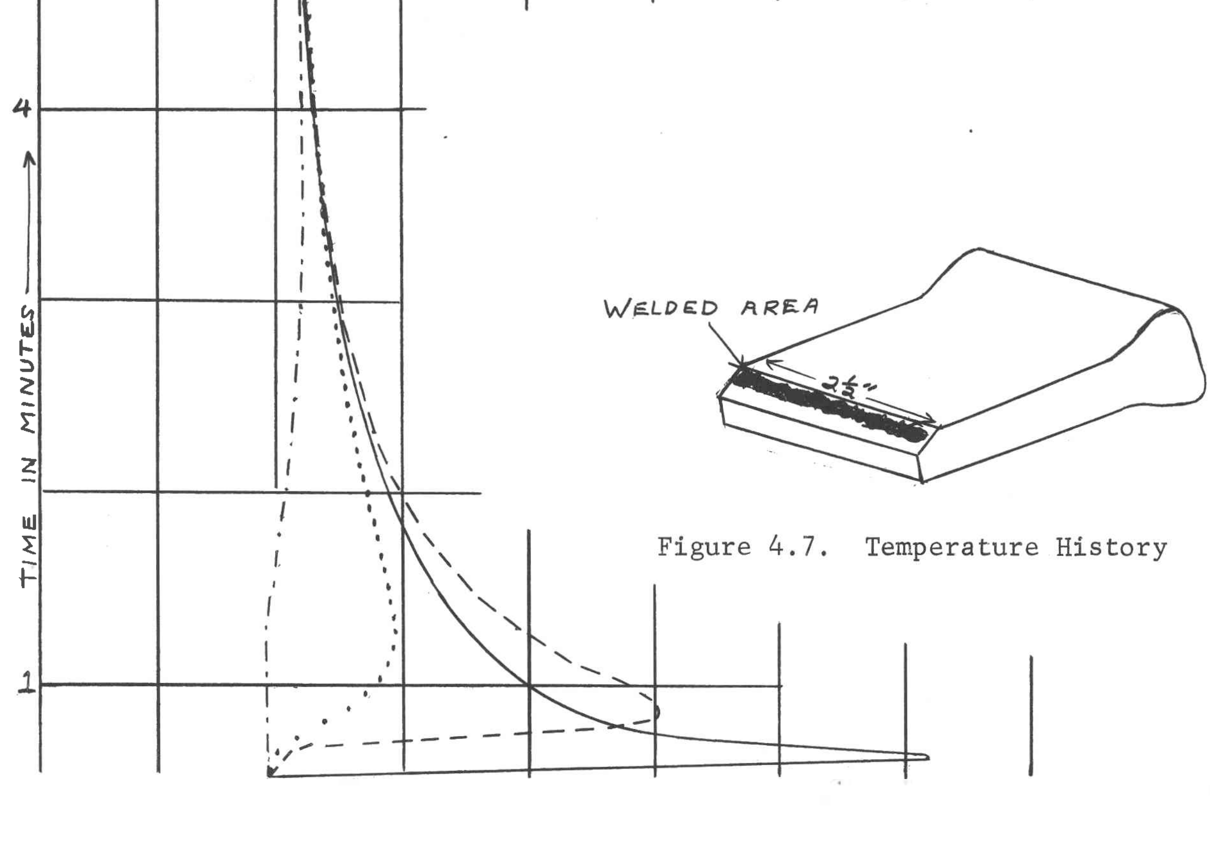
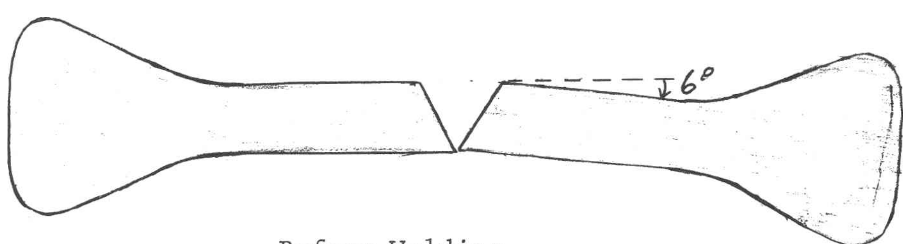


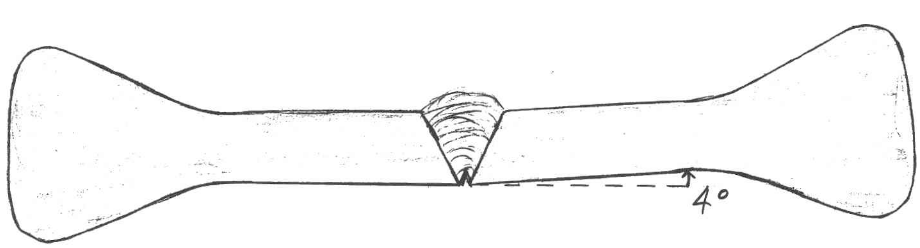
Figure 4.7. Temperature History

was that three to four minutes cooling time were required between beads. This conclusion was confirmed by making two welds with one minute cooling time and one with four minutes cooling time. Both welds which were not allowed sufficient cooling time cracked the entire length of the weld. The weld which was allowed sufficient cooling time showed reasonable strength, as may be seen in Table 5.

The second conclusion was that peening was very important. Two plate halves were prepared with a single 60° V and angled upward 6° to compensate for anticipated warping. The previously investigated four minute cooling time between beads was maintained. The plates were found to be angled downward 4° upon completing the weld and a crack was evident along the bottom side of the welded plate (Figure 4.8).



Before Welding



After Welding

Figure 4.8. Warping of the Unpeened Weld Region

The weld did have some strength however, as indicated in Table 4. The conclusion was drawn by comparing the warping of the unpeened section to that of the peened section. For the peened case no initial upward angle was placed on the plate halves; and upon completion of the weld, no downward angle existed as in the unpeened case. Also, there was no cracking. This confirmed the necessity of peening. A general conclusion was also drawn involving the peening point. The more pointed the peening object, the less impact energy necessary for the same result. (This could help eliminate fracture due to peening, especially on thin sections.)

The third conclusion reached was that the smallest electrode that would melt the base metal should be used. There were two reasons for this conclusion. First, a lower amperage could be used, thereby reducing the severity of the localized heating. Second, a thinner bead resulted which was more easily peened.

The above three conclusions should be carefully noted. They were used in obtaining the successful welds made with the 55% nickel electrode. Also, they were used on one final 95% nickel electrode weld and welds made with mild steel and brazing electrodes.

Numerical Results

Two sets of weld tensile strength data were obtained for the 95% nickel shielded metal-arc welding electrode (Ni-Rod). The electrode specifications are given in Table 3.

Given in Table 4 are the welding conditions, cast iron specifications and weld tensile strengths for the first set.

TABLE 3

ELECTRODE SPECIFICATIONS

Ni-Rod[a] 3/32 Shielded Metal-arc

Chemical composition:		
	Nickel	95.0 %
	Iron	3.0
	Carbon	1.0
	Silicon	0.7
	Manganese	0.2
	Sulfur	0.005
	Copper	0.1
Flux:		
	carboniferous lime-spar[b]	
Tensile strength:		
	40,100 pounds per sq. inch	

[a]"Welding Cast Irons with Ni-Rod and Ni-Rod 55 Welding Electrodes"

[b]T.E. Kihlgren and H.C. Waugh, "Joining of Ductile Iron by Several Arc Welding Methods", Welding Journal, 32 (Oct. 1953), 948

TABLE 4

WELDING CONDITIONS

Current - 65 amperes D.C. reverse polarity
Potential - 20 volts
Bulk plate temperature less than 204°F
One inch stringer beads
Three minute cooling time between beads
Single 60° V profile
No peening
No pre or post weld heat treatment

CAST IRON CHEMICAL COMPOSITION[a]

Carbon	3.70 %
Silicon	3.09
Manganese	.67
Phosphorus	.318
Sulfur	.132

CAST IRON TENSILE STRENGTH

Specimen	Fracture stress (psi)
1	17,355
2	19,425
3	16,551
4	15,853
5	16,695
6	17,815
7	15,157

TABLE 4--Continued

$$\text{Mean tensile strength} = \frac{\text{sum of fracture stress}}{\text{number of samples}}$$

$$= 16{,}979 \text{ psi}$$

WELD TENSILE STRENGTH

Specimen	Fracture stress (psi)
1	5308
2	818
3	2539
4	Previously cracked throughout
5	"
6	3119
7	3955
8	4404

Mean weld strength = 3357 psi

η_w = 19.8%

[a]The cast iron Chemical Compositions were obtained from a wet-lab analysis at the United States Steel-Geneva Works chemical laboratory.

It should be noted that the above data is important because the welded specimens were not peened; and, the resulting strength was low because of this.

Given in Table 5 are the welding conditions, cast iron specifications and weld tensile strengths for the second set.

TABLE 5

WELDING CONDITIONS

Current - 65 amperes D.C. reverse polarity
Potential - 20 volts
Bulk plate temperature less than 204°F
One inch stringer beads
Four minute cooling time between beads
Single 60° V profile
Peened
No pre- or postweld heat treatment

CAST IRON CHEMICAL COMPOSITION

Carbon	3.30 %
Silicon	1.70

TABLE 5--Continued

Manganese	.490
Chromium	.500
Phosphorus	.308
Sulfur	.128

CAST IRON TENSILE STRENGTH

Specimen	Fracture Stress (psi)
Z1	24,818
Z2	24,444
Z3	25,560

Mean tensile strength = 24,941 psi

WELD TENSILE STRENGTH

Specimen	Fracture stress (psi)
X1	14,746
X2	11,742
X3	7,438
X4	11,322

Mean weld strength = 11,312 psi

$\eta_w = 45.4\%$

Note that the peened specimens of Table 5 had much better strength than the unpeened specimens of Table 4. All other conditions were the same in the two tests except the cast iron chemical compositions and cooling time between beads which were not significantly different.

CHAPTER V

WELDING WITH 55% NICKEL-45% IRON ELECTRODE

Major Conclusions

When the conclusions of the previous chapter were employed in welding with the 55% nickel-45% iron electrode, two more major conclusions appeared. The first conclusion involved the profile of the section to be welded. Because of both the thickness of the iron section and the electrically conductive electrode flux coating, a single 60° V preparation made it difficult to obtain good cast iron to weld metal bonding in the root area. The arc would strike on one side of the V and it was difficult to shift the conductance and penetration to the opposite side (Figure 5.1).

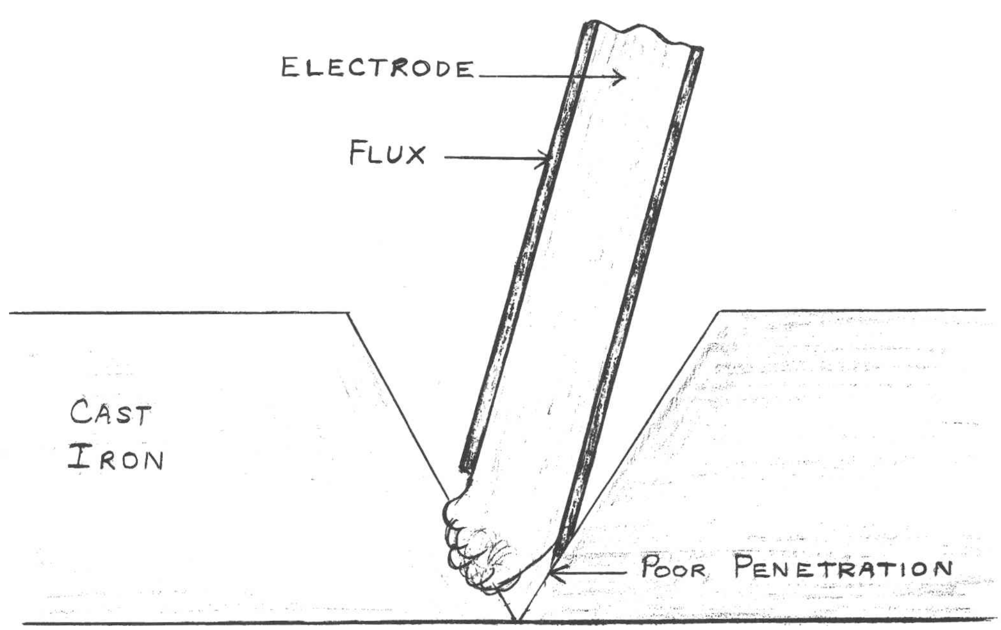


Figure 5.1. Electrode Arc and Penetration Areas

However, with the double V the problem was not as severe and a better cast iron-weld metal bond was obtained. Also, it was easier to peen the double V area to ensure stress relief. A comparison of strength using the single and double V can be made by referring to Tables 7 and 8. The strength using the double V is higher and more uniform than the strength using the single V.

The second conclusion involved an additional surface preparation. It was found that the electrode metal penetrated and bonded with other electrode metal better than with the cast iron. Therefore, the entire cast iron surface was coated (buttered) with electrode metal before any attempt was made to join the two pieces (Figure 5.2). This produced a much stronger weld because the root area was more easily welded.

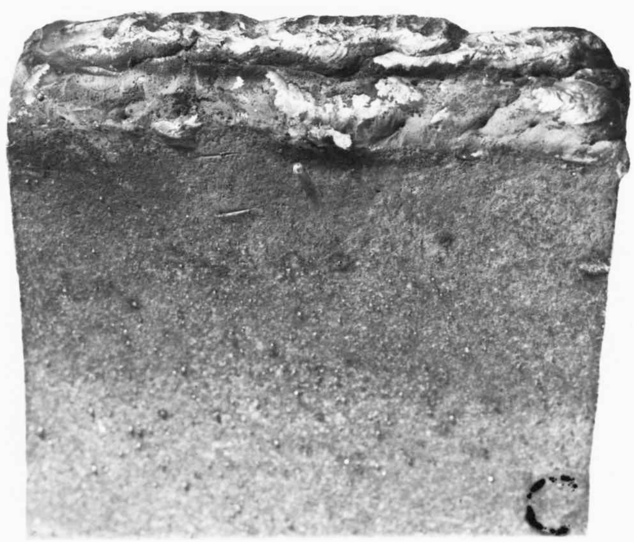


Figure 5.2. Buttered Weld Surface

Also, a good bond was assured at the cast iron-electrode metal interface. This was important because most fractures occured here. A comparison of weld strength with and without this buttering is shown in Tables 9 and 10.

Numerical Results

Four sets of weld tensile strength data were obtained for the 55% nickel-45% iron welding electrode (Ni-Rod 55). Electrode specifications are given in Table 6.

TABLE 6

ELECTRODE SPECIFICATIONS

Ni-Rod 55[a] 3/32 Shielded Metal-arc		
Chemical composition:		
	Nickel	53.0 %
	Iron	45.0
	Carbon	1.5
	Silicon	0.5
	Manganese	0.3
	Sulfur	0.005
	Copper	0.1
Flux:		
	carboniferous lime-spar	
Tensile strength:		
	58,000 psi	

[a]"Welding Cast Irons With Ni-Rod and Ni-Rod 55 Welding Electrodes"

Given in Table 7 are the welding conditions, cast iron specifications and weld tensile strengths for the first set. All welds except the three with the largest tensile strengths showed weld cracks before being fractured in the tensile testing machine. The specimens all failed at the cast iron-weld metal interface.

TABLE 7

WELDING CONDITIONS

Current - 65 amperes D.C. reverse polarity
Potential - 20 volts
Bulk plate temperature less than 180°F
One to three inch stringer beads
One to two minute cooling time between beads
Single 60° V profile
No pre- or postweld heat treatment

CAST IRON CHEMICAL COMPOSITION AND TENSILE STRENGTH

(See Table 4)

WELD TENSILE STRENGTH

Specimen	Fracture stress (psi)
1C	11,059
2C	7,759
3C	2,624
4C	3,400
5C	2,021
6C	278
7C	11,054
8C	1,880

Mean weld strength for three largest = 9,957 psi

η_w = 58.6%

Given in Table 8 are the welding conditions, cast iron specifications and weld tensile strengths for the second set.

TABLE 8

WELDING CONDITIONS

Current - 65 amperes D.C. reverse polarity
Potential - 20 volts
Bulk plate temperature less than 180°F
One to three inch stringer beads
One to two minute cooling time between beads
Double 70° V profile
No pre- or postweld heat treatment

CAST IRON CHEMICAL COMPOSITION AND TENSILE STRENGTH

(See Table 4)

TABLE 8--Continued

WELD TENSILE STRENGTH

Specimen	Fracture stress (psi)
1A	8,798
2A	8,172
3A	9,568
4A	8,868
5A	10,099
6A	8,924
7A	10,100
8A	8,621

Mean weld strength = 9,144 psi

η_w = 53.8%

Given in Table 9 are the welding conditions, cast iron specifications and weld tensile strengths for the third set.

TABLE 9

WELDING CONDITIONS

Current - 65 amperes D.C. reverse polarity
Potential - 20 volts
Bulk plate temperature less than 204^{o}F
One inch stringer beads
Peened
Double V 80^{o} profile

CAST IRON CHEMICAL COMPOSITION

Carbon	3.38 %
Silicon	1.75
Manganese	.52
Phosphorus	.322
Sulfur	.152

CAST IRON TENSILE STRENGTH

Specimen	Fracture stress (psi)
1	19,315
2	25,476
3	22,941
4	22,704

Mean tensile strength = 22,609 psi

TABLE 9--Continued

WELD TENSILE STRENGTH

Specimen	Fracture stress (psi)
1E	8,588
2E	8,790
3E	20,290
4E	17,352
5E	15,108
6E	22,704
7E	Badly cracked
8E	16,788
9E	9,144
10E	10,173

Mean of five largest weld strengths = 18,448 psi

$\eta_w = 81.6\%$

Mean weld strength = 14,326

$\eta_w = 63\%$

Given in Table 10 are the welding conditions, cast iron specifications and weld tensile strengths for the fourth set.

TABLE 10

WELDING CONDITIONS

Current - 65 amperes D.C. reverse polarity
Potential - 20 volts
Bulk plate temperature less than 204^{o}F
Stringer beads - .75 inch
Severly peened
Buttered double V 80^{o} profile

CAST IRON CHEMICAL COMPOSITION AND TENSILE STRENGTH

(See Table 9)

WELD TENSILE STRENGTH

Specimen	Fracture stress (psi)
1R	15,379
2R	21,212
3R	21,739
4R	19,000
5R	20,702
6R	18,333

TABLE 10--Continued

Mean of five largest strengths = 20,197	
	η_w = 89%
Mean weld strength = 19,394	
	η_w = 81%

Table 10 lists the specimens welded using the five previously discussed general conclusions. It can be seen that good strength resulted in all specimens except the one cut from the end of the test plate. These results are very important because they indicate that this particular type of cast iron can be successfully welded without pre-heat.

CHAPTER VI

WELDING WITH EUTECTIC 244, EUTECTIC[12] 2-25, AIRCO[13] No. 77 AIRCO No. 70 AND 6011 ELECTRODES

All test welds discussed in this chapter were obtained using the techniques noted in the previous chapters. No data was obtained for Eutectic 244, 2-25 or for the 6011 and Airco No. 77 mild steel electrodes. The test welds were broken by hand before they were even cut into test specimens. The Eutectic 244 weld was extremely porous and there was poor bonding between the cast iron and weld metal. The Eutectic 2-25 weld cracked before being completed. It is suggested that the failure of the 2-25 weld occured for two reasons. First, a large localized heating resulted from using a large current to melt the one-eighth inch diameter electrode. Second, the electrode probably had a high nickel content which would make it more crack susceptible. (Data on chemical composition was not made available by the Eutectic Corporation so this could not be verified.)

Dense welds were produced by the two mild steel electrodes, Airco No. 77 and 6011, but the deposited metal could not be adequately peened due to its hardness. Consequently, the weld could not be stress relieved and it cracked.

The strength obtained using the bronze electrode is shown below. All of the bronzed specimens fractured at the cast iron to weld metal interface. The fracture area was estimated to be .30 gas pockets and .70 dense weld.

Given in Table 12 are the welding conditions, cast iron specifications and weld tensile strengths for the bronze welds.

TABLE 11

ELECTRODE SPECIFICATIONS

Airco No. 70 Shielded Metal-arc

Chemical composition:

Copper	94.3 %
Tin	5.0
Phosphorus	0.2
Other	0.5

TABLE 12

WELDING CONDITIONS

Current - 75 amperes D.C. reverse polarity
Potential - 21 volts
Bulk plate temperature less than 204°F
Severely peened
Stringer beads - .75 inch
Double V 80° buttered profile
Short arc length

CAST IRON CHEMICAL COMPOSITION AND TENSILE STRENGTH

(See Table 5)

WELD TENSILE STRENGTHS

Specimen	Fracture stress (psi)
V1	8,078
V2	11,695
V3	11,017

Mean weld tensile strength = 10,295 psi

η_w = 41.3%

CHAPTER VII

OBSERVATIONS, CONCLUSIONS AND RECOMMENDATIONS

Observations

Several observations were made concerning both crack detection and weld machinability. There were two methods used to determine where micro-cracks occurred in the welded section. Cracks could be detected before actually fracturing the specimen by placing the specimen on the magnetic chuck of the grinder and sprinkling iron filings over it. The iron filings would group along the crack path. In the second method, the welded cast iron was soaked in water. It was allowed to dry for several days before testing its tensile strength. If there was a micro-crack at the point of fracture and the fracture was at the cast iron to weld metal interface, a definite rust stain was evident.

The plates welded with the 95% nickel or 55% nickel-45% iron were easily sawed using the reciprocating power hack saw. The plates welded with bronze electrode were sawed with difficulty on the same saw. The continuous blade band saws easily sawed the 95% nickel welds, but were dulled by an occasional hard spot in the 55% nickel-45% iron welds.

Conclusions and Comparative Tensile Strengths

The most consistent weld strength obtained by Townshend and

Porter was for the 55% nickel-45% iron electrodes using a preheat of 550 - 600°F. The five samples so pre-heated had a weld strength of 36,100 pounds per square inch (Table 2). As shown earlier, weld efficiency was:

$$\eta_w = 97\%$$

The procedure for obtaining the test specimens was not listed and it might have been that the weld buildup on the specimen surface was not removed. This might possibly have increased the indicated weld strength resulting in the exceptional weld strength ratio.

For this study of welding without preheat the best weld efficiency obtained was 89% (Table 10). The carbon and silicon content of the cast iron used to obtain this data were correctly proportioned to obtain gray cast iron.[14] Also, the sulfur (greater than .1%) and phosphorus (greater than .3%) contents were within acceptable limits.[15] However, the strength of the cast iron as listed in Table 4 (16,979 psi) was below the lowest ASTM class of 20. The other irons used (Tables 5 and 9) were ASTM class 20.[16] Using a higher strength cast iron may have improved the efficiencies obtained.

Townshend and Porter obtained a bronze weld efficiency of 71%. In contrast, the efficiency obtained in this study using shielded metal-arc bronze electrode was only 41.3%. Neither of these efficiencies is comparable to those obtained using the 55 nickel-45 iron electrode.

Townshend and Porter did not obtain a good weld using the 95% nickel electrode. This was due to the cracking of the deposited filler metal. However, this study confirmed that some strength could be obtained, but it also confirmed that the high nickel deposit cracked easily. The best weld efficiency for the 95% nickel deposit was 45.4%. This efficiency is again much lower than that obtained using the 55% nickel-45% iron electrode.

Procedure Used to Obtain Good Weld Efficiencies

The procedure used to obtain good weld strengths, without pre- or postweld heating, was as follows:

(1) Grind or chamfer the region to be welded to the desired shape. (The author's best results were obtained using an 80 - 90° double V.)

(2) Butter the surfaces to be joined before actually beginning the bond between them.

(3) Make stringer bead welds not more than two inches long. Use very small electrodes (preferably three-thirty second or less).

(4) After each bead, let the location of the welding region cool three to four minutes; if there is a long region to be welded, use the skip weld technique.

(5) As soon as possible, after a bead is laid, peen it thoroughly using a hard pointed object. (A ball peen hammer is not recommended.)

The one major drawback of the outlined procedure is the time required to complete a weld. Unless the weld is very long making the skip weld method feasible, an intermittent weld schedule should be adopted. Another minor problem is the effort required to properly peen the weld. A mechanism for peening would certainly reduce the overall labor involved. It could not be expected to reduce the welding time, however.

Recommended Future Research

Future research might be directed toward welding higher strength and quality cast iron. Also, welding might be done using a constrained configuration such as that used by Townshend and Porter.[17]

Because of the successful welds obtained using 55% nickel-45% iron shielded arc electrodes, with and without preheat, it is suggested that any further research be done using electrodes with a similar composition. Before doing research using electrodes containing less than 55% nickel, the researcher should understand that machining may be rendered impossible. Also, he should be aware of the increased crack susceptibility of deposited metal containing high amounts of nickel. Further work using the shielded, bronze metal-arc electrode is not recommended.

Some metallurgical work might also be done. The structure of the matrix of the region welded, using especially the 55% nickel-45% iron, could be examined to determine the graphite flake structure and the amount of white cast iron present. (This can be done at USS Geneva Works chemical laboratory simply by doing what they refer to as a total vs: uncombined carbon analysis.) This could give some indication of the degree of brittleness to be expected of the region welded without preheat.

APPENDIX

DESCRIPTION OF EQUIPMENT

DC Arc Welding Machine
Lincoln 200 Ampere
Serial No. A2170826

Ammeter Shunt
50 MV 300 Ampere

Ammeter
DC Ammeter
Weston 4T

Voltmeter
Simpson Model 260
Inventory #0425

Do-All Surface Grinder
Serial No. D103-4052116

Racine Reciprocating Power Hack Saw
Serial #C9574
Model 66 W 4

Grob Steel Band Saw
Type NS24
Serial #2122

Riehle Testing Machine
Serial No. R-57450-1

Recorder
Leeds Northrup
Speedomax H
Serial No. 64-S5378-1-1

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17. Townshend and Porter

ABSTRACT

ELECTRIC ARC WELDING OF GRAY CAST IRON
WITHOUT PREHEATING

Methods for successfully and unsuccessfully welding gray cast iron without preheating are discussed.

A summary is made of the results of other experimenters. Then the results of the author's experiments are discussed. These experiments were conducted using the following shielded metal arc electrodes: 95% nickel, 55% nickel-45% iron, 6011 mild steel, and bronze.

A weld having a strength of 91% of the cast iron strength was obtained.