

PHYSICAL PROPERTIES AND STRUCTURE
OF
WELDS IN A DUCTILE CAST IRON

by

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INTRODUCTION

With the use of every new material comes the problem of fabrication and repair. The techniques of making ductile cast iron were introduced to the public by International Nickel Co., Inc. in 1948. Since that time many foundries, licensed by International Nickel Co., Inc., have been making ductile cast iron.

This metal has been successfully welded to itself and to steel, but there is still room for much study on its welding characteristics.

The purpose of this thesis was to study the physical properties and structure of welds in a ductile cast iron. The effects of pre-heats and post-heats were also studied.

REVIEW OF LITERATURE

For years metallurgists and engineers have been in dire need of an iron with high strength and ductility and the casting features of gray iron that will have these properties in the as-cast condition. This dream has finally come true in the form of ductile cast iron. Engineers are familiar with the properties and structure of gray and malleable cast iron. In gray iron the free carbon (graphite) is in the form of flakes which act as small cracks or checks which when put under a tensile load give low strength and low elongation. This condition has been improved in malleable iron by a heat-treatment process which transforms cementite to free carbon and ferrite. (Plate I) This improves the properties considerably but still the strength is not high enough in some cases, and it requires a long annealing process in the neighborhood of 60 hours. In ductile cast iron the graphite is in the form of nodule or spheroides in the as-cast condition. (Plate I) This is accomplished by the addition of small amounts of magnesium (12) or cerium (36) in the ladle before pouring. This graphite structure will give tensile properties in the neighborhood of 100,000 PSI and elongation varying up to 20 percent in two inches with small amounts of or no heat treatment. A great number of experiments have been performed by the British Iron Research Association on making

EXPLANATION OF PLATE I

- Fig. 1. White Cast Iron. Etchant, 4% Nital;
Magnification, 212.
- Fig. 2. Gray Cast Iron. Etchant, 4% Nital;
Magnification, 212.
- Fig. 3. Malleable Cast Iron. Etchant, 4%
Nital; Magnification, 212.
- Fig. 4. As-Cast Ductile Cast Iron. Etchant,
4% Nital; Magnification, 212.
- Fig. 5. Annealed Ductile Cast Iron. Etchant,
4% Nital; Magnification, 212.

PLATE I

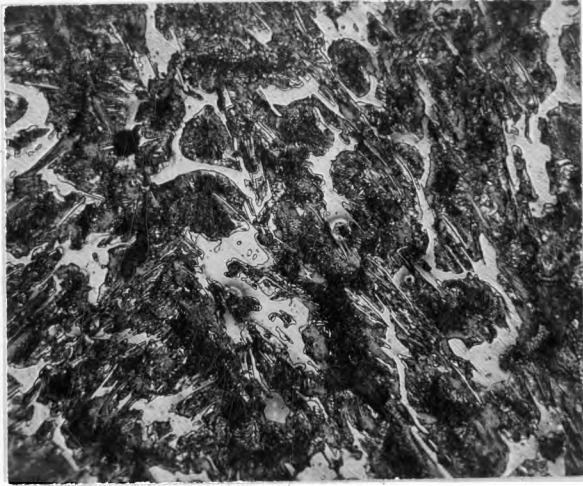


Fig. 1



Fig. 2

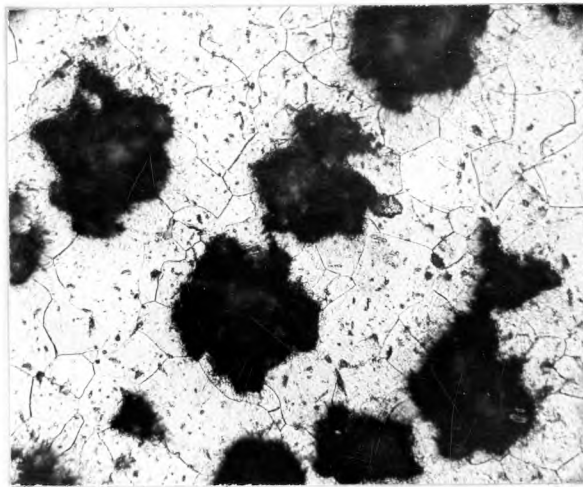


Fig. 3

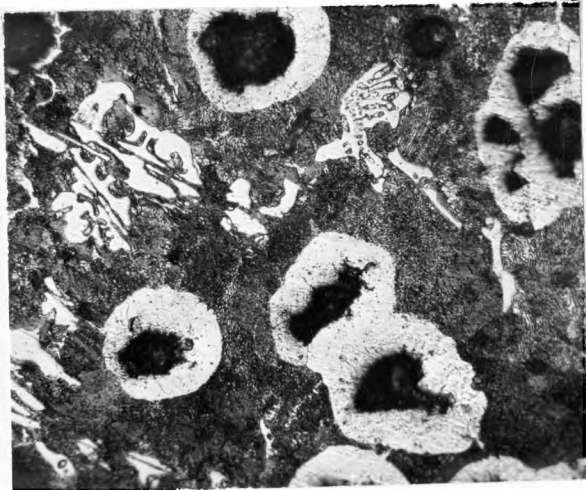


Fig. 4

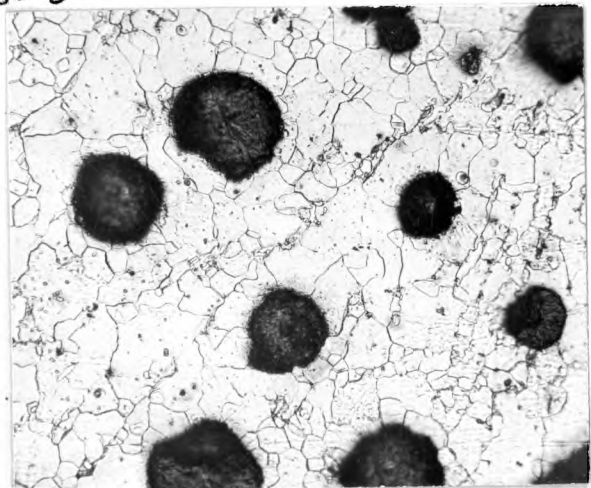


Fig. 5

ductile cast iron with the addition of cerium. Some of the requirements of the production of ductile cast iron with cerium are as follows:

1. The iron must solidify gray even without the cerium addition.

2. The iron must be of hypereutectic carbon content, that is, the carbon content should exceed the value 4.3 minus $1/3$ (percent Si plus percent P). When the nickel content of an iron exceeds 10 percent, it need not be hypereutectic according to this formula.

3. Silicon content can have any value, but is preferably within the range 2.3 to 7.0 percent.

4. Sulphur content of the metal to be treated should be as low as possible, and after treatment should be below 0.015 percent.

5. Phosphorus content should not exceed about 0.6 percent, and should preferably be below 0.1 percent.

6. Manganese, copper, nickel, chromium and molybdenum may be present in any amounts, singly or in any combination, provided condition No. 1 is observed.

7. After treatment with cerium the solidified castings must contain more than a certain minimum amount (0.02 percent) of the element dissolved in the metallic matrix.

In iron of suitable composition, the graphite can be made nodular by the addition of cerium to the molten metal

before pouring. Cerium is added in the form of Misch metal which is 50 percent cerium and the remainder earthly products. There is no explosive action when the cerium is added. In iron that would normally solidify gray, when the cerium is added the iron turns to white iron due to cerium being a powerful carbide former; then a ferro-silicon compound must be added to form gray iron again. When poured and cooled, the carbon will be in the form of spheroides. Of course, if the iron is cooled too fast, the carbon will be in the forms of flakes and cementite. If too small amounts of cerium is added there will be some flakes and some nodules. If too large amount is added carbides will be formed causing low strength and ductility. At the time of inoculation, if the sulphur is above 0.015 percent some of the cerium will be used in desulphurizing the metal, so unless extra cerium is added to take care of the high sulphur content, the free carbon will not be completely spheroidical. If the phosphorus content is also too high the cerium will not take effect. That is, the graphite will be completely in flake form. Due to these factors the sulphur and phosphorus content must be kept as low as possible.

This form of inoculation gives a very satisfactory metal; but due to the cost of cerium and the high carbon content, it has been found that the magnesium (12, 25, 40) type of inoculation is preferable. The production of this ductile iron is accomplished by a two-stage operation.

The first stage is the addition of magnesium or cerium, which are carbide formers, which promote the formation of white iron in an iron normally solidifying gray. The second stage is an opposing stage in which a ferro-silicon type of inoculant addition overcomes the tendency toward white iron causing the graphite to precipitate out in the form of small spheroides. The exact theory of how these graphite spheroides are formed is not known.

In the magnesium treatment the iron does not have to be hypereutectic. Sulphur, as in the cerium treatment, is also a problem. If the sulphur content is too high the magnesium will react with the sulphur to form magnesium-sulphide until the sulphur content is below 0.02 percent. Then the magnesium starts to form the graphite in the form of nodules and acts until the active magnesium is used up. This also necessitates keeping the sulphur content low to control the action of the magnesium. If the sulphur content is too high and extra amounts of magnesium is not added, complete spheroidal graphite will not be formed. On the other hand, if the sulphur content is low and too much magnesium is added, undesirable carbides will be formed. The phosphorus content is a major factor but it does not hinder the formation of the nodules, but it effects the strength and ductility of the iron.

The magnesium can be added in various forms from pure magnesium to a low percentage. Factors entering into this

are that the boiling point of magnesium is around 2,000°F, and when added to metal of a temperature of about 2,700°F it volatilizes quickly. Therefore, a large amount of the magnesium is lost. The action is quite explosive and great precaution must be taken to protect the workers from this action. (16) The magnesium is added to the molten metal and not the metal poured on the magnesium in the ladle as the reaction will give a definite explosion. Due to this effect, the magnesium is added in the form of an alloy with copper or nickel. The nickel or copper addition does not have any ill effects on the resultant metal. Of course later on the large amounts of nickel in the scrap will have ill effects.

Most foundries can make the ductile iron using scrap, or molten metal from the blast furnace, in cupola or electric furnace by inoculating with magnesium. Close control of various factors must be obtained. The sulphur content will be more of a problem in the cupola than in the electric furnace due to the pick-up from the coke, but this can be taken care of by normal means of desulphurization and the amount of magnesium added.

Satisfactory castings have been made of ductile iron from those of a few ounces to those weighing many tons. (19, 47) In small castings where high ductility is desired, they must be annealed as the rapid cooling will form pearlite and cementite giving high strength but low ductility. Past experience has indicated that to obtain high ductility the

structure must be completely ferritic. This is obtained by annealing or sometimes called heat treatment. (Plate I) In this process the cementite and pearlite decomposes with the graphite going to form spheroides or adding to the spheroides formed when cooled from the melt, leaving ferrite and the graphite in the form of spheroides. The graphite decomposed from the cementite and pearlite is formed as rings around the original spheroides.

There are two distinct types of ductile cast iron--high strength and high ductility. The microstructure of the high strength type consists of pearlite with graphite spheroides, (Plate I) and the microstructure of the high ductility type consists of pearlite, ferrite, and graphite spheroides. In the high ductility type, some of the ferrite forms rings around the graphite spheroides. The amounts of pearlite and ferrite present in both types depends upon the section thickness of the casting. The strength of various thicknesses is governed by the rates of cooling and the amount of residual magnesium present. The amount of residual magnesium present is effected by the cooling rate, due to the fact that the longer the metal sets the less magnesium will be present. A comparison of section size and strength is shown in Table 1. (47)

The magnesium process is applicable to a wide range of base irons and a number of compositions are used depending on the properties required and the service for which the

Table 1. Influence of Section Sizes and Thermal Treatment on Nodular Irons

Thermal Treatment		High strength						High Ductility					
		Y.P. PSI	T.S. PSI	Elong % 2"	R.A. %	B.H. x10 ⁶	E x10 ⁶	Y.P. PSI	T.S. PSI	Elong % 2"	R.A. %	B.H. x10 ⁶	E x10 ⁶
As Cast	1	67,500	87,200	1.5	0.5	269	23.0	52,800	74,700	11.0	8.8	187	22.1
	2	67,000	80,800	1.2	0.5	262	23.0	52,200	71,800	7.5	7.5	187	22.3
	4	63,100	70,700	1.2	1.0	241	23.6	40,000	50,900	2.0	1.8	175	19.7
	6	59,800	65,200	1.2	0	229	22.7	37,800	45,200	3.0	1.2	148	18.8
	8	59,000	61,400	1.2	0.5	229	23.5	31,400	41,000	2.5	1.0	141	17.4
Anneal 1320°F 2 Hrs. Air Cool	1	61,500	85,400	3.0	2.5	229	22.8	48,900	66,200	17.2	15.0	163	22.2
	2	56,600	74,700	3.2	2.2	197	21.5	47,500	63,300	12.5	11.0	163	21.9
	4	55,200	69,200	2.0	1.5	197	23.6	36,800	48,200	4.5	3.0	148	20.1
	6	57,500	65,900	2.0	1.0	217	22.2	37,200	42,800	3.0	1.5	144	18.8
	8	54,500	62,500	1.5	1.0	212	22.8	33,200	40,000	2.0	1.2	138	18.3
Anneal 1750°F 2 Hrs. Slow	1	51,200	78,700	7.0	4.5	187	22.4	45,500	63,300	19.0	16.0	148	21.1
	2	50,800	71,600	8.0	5.5	179	21.7	42,900	60,300	14.5	13.3	143	20.7
	4	50,200	69,800	3.5	2.5	183	23.1	34,000	44,100	4.0	3.0	134	17.8
	6	50,700	66,400	3.0	2.0	183	22.4	34,500	41,200	3.0	1.8	131	17.0
	8	50,200	66,800	4.0	2.8	183	22.3	34,100	36,600	2.0	1.0	128	17.0
1550°F 1 Hr. Oil Quench Draw 2 Hrs. to Brinell as shown	1	95,200	104,100	3.0	3.0	269	21.9	91,800	107,300	3.5	3.2	269	21.4
	2	94,500	99,800	3.2	2.5	269	22.5	87,000	101,900	3.0	3.0	269	21.4
	4	89,100	89,700	1.8	1.5	262	21.9	82,000	83,400	0.5	0.5	262	19.0
	6	88,200	89,700	1.5	1.2	255	23.1	63,000	66,800	1.0	0	214	17.3
	8	85,500	86,300	1.0	1.0	255	22.8	61,200	62,900	0.5	0	229	16.7

castings are intended. The broad composition range along with a few specific compositions are being used commercially as given in Table 2. (19)

Some of the specifications as set up by International Nickel Company for the mechanical properties of this ductile iron is shown in Table 3. (19)

The castability of the ductile iron after the treatment compares very well with the base iron in that the fluidity is as good or possibly slightly better. (25, 47) The gating and risering technique, because of the high liquid shrinkage, becomes a compromise between cast iron and steel. Pattern shrinkage depends somewhat upon the base iron whether high or low carbon, but in general may be said to be 1/8-inch per foot.

The machinability of ductile cast iron compares favorably if not better than gray iron.

The wear resistance of ductile cast iron compares favorably with that of gray iron. (19, 41, 47) Ductile cast iron is readily welded to itself, steel, or stainless steels. (43) Usual arc welding techniques developed for cast iron are applicable to the ductile cast irons also. In welding with the nickel rod there appears to be a narrow zone of increased hardness along the edge of the weld zone, but there is no reversion to flake graphite. Spheroidal graphite has been noted floating in the zone of fusion. (25)

Table 2. Composition Range.

	C	Si	Mn	P	Ni	Mg
Broad-range, %	3.2/4.2	1.0/4.0	0.1/0.8	0.10	0/3.5	0.05/0.10
Ferritic high-ductility, %	3.6/4.2	1.25/2.0	0.35	0.08	0/1.0	0.05/0.08
Ferritic high-strength, %	3.4/3.8	2.25/3.25	0.35	0.10	0/1.0	0.05/0.08
Pearlitic high-strength, %	3.2/3.8	2.25/2.75	0.6/0.8	0.10	1.5/3.5	0.05/0.08

Table 3. Representative Mechanical Properties of Commercial Heats of Ductile Iron.

Grade	T.S. PSI	Y.S. PSI	Elong. %	Bhn	Usual Condition
90-65-02	95/105000	70/75000	2.5/5.5	225/265	As-cast
80-60-05	85/95000	65/70000	5.5/10.0	195/225	As-cast
60-45-15	65/75000	50/60000	17.0/23.0	140/180	Annealed
80-60-00	85/95000	65/75000	1.0/3.0	230/290	As-cast

This iron may be flame-hardened to obtain hardnesses as high as 600 Brinnell. (41) This will give a hard surface with a ductile core.

This iron may also be heat-treated to obtain high strength and hardness for various uses. The heat treatment consisted of heating the specimens in an electric furnace to 1550°F, holding at that temperature for one hour, then immediately oil quenching. Following the quench, specimens were drawn in an electric furnace at the temperatures indicated in Table 4. Table 4 shows properties of the heat-treated iron as used by Black-Clawson Company of Hamilton, Ohio, in the paper-making industry. (43)

Chemical analysis of irons tested is shown in Table 5.

Industries are turning to the use of ductile cast iron in place of gray cast iron, steel castings and forgings for the making of pipe, gears, rollers, automotive equipment, and agricultural machinery (such as chilled plow shears). It is also used in high pressure applications where the strength of cast iron is not sufficient and where steel castings might require repair because of casting imperfections. (19) It is also used where the shock resistant characteristics are important, such as gears, hammer bases, and motor bases.

The damping characteristics lie about half-way between that of cast steel and gray cast iron. (41)

Table 4. Heat Treated Ductile Iron Properties.

	Original Properties					Heat Treat Properties				
	T.S. %	Y.S. %	Elon. %	BHn	Draw Temp. °F	T.S. %	Y.S. %	Elon. %	BHn	
Test 1 Sample 1	116,500	86,000	5	262	800	185,000	150,000	1	430	
2	97,000	69,000	10	228	800	218,000	167,000	1	418	
Test 2 Sample 1	106,500	82,000	4½	286	900	196,000	121,000	2½	402	
2	100,500	82,500	8	223	900	153,500	131,000	1½	302	
Test 3 Sample 1	96,500	73,000	7	228	1000	161,000	147,500	1½	351	

Table 5. Analysis of Samples.

Test	Si,%	Mn,%	P,%	S,%	Mg,%	Ni,%
Test 1 Sample 1	2.20	0.31	0.030	0.015	0.063	1.57
2	2.50	0.44	0.033	0.018	0.040	0.94
Test 2 Sample 1	2.21	0.33	0.051	0.015	0.049	1.59
2	3.26	0.27	0.033	0.010	0.068	1.48
Test 3 Sample 1	2.39	0.30	0.046	0.016	0.047	1.12

Mr. J. E. Rehder, in the laboratory of the Department of Mines and Resources in Ottawa, Canada, has been successful in hot rolling three-inch cast slabs in two heatings to 7/16-inch plate with a resultant tensile strength as rolled in the order of 140,000 pounds per square inch with four percent elongation. (47) This iron was hot-worked in the neighborhood of 1750°F. The structure of hot-worked material is very similar to that of wrought iron except that there is practically no pearlite in wrought iron, whereas the matrix in as-rolled ductile iron is completely pearlitic.

The comparative cost of ductile iron to other ferrous metals is shown in Table 6. (47)

Now that ductile iron has shown such promises and extra characteristics for use as a casting material, it is not replacing malleable iron at the present time. It is filling in the gaps of the present materials available and eliminating a number of welded steel structures. In its short infancy it has shown excellent promise for an important engineering material of tomorrow.

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EXPERIMENTAL PROCEDURE

Welding Jigs

The jigs used to hold the samples while being welded were made of one-inch gray cast iron plates of sufficient size, with $\frac{1}{4}$ -inch copper plate used as a heat conductor. Restraining clamps were made of $\frac{3}{8}$ -inch steel plate. Each clamp was held down by three $\frac{1}{2}$ -inch steel bolts. (Plate II) To cause the samples to warp straight when released from the jigs, two $\frac{1}{8}$ -inch rods were placed in $\frac{1}{16}$ -inch deep grooves $\frac{3}{16}$ -inch from the edge of each sample as shown in Plate III.¹ The purpose of the grooves were for constant positioning of the rods. This gave the samples a negative angle, so that on warping when released they became straight. The samples being welded were held down by the clamps during the first four beads but released before running beads five and six.

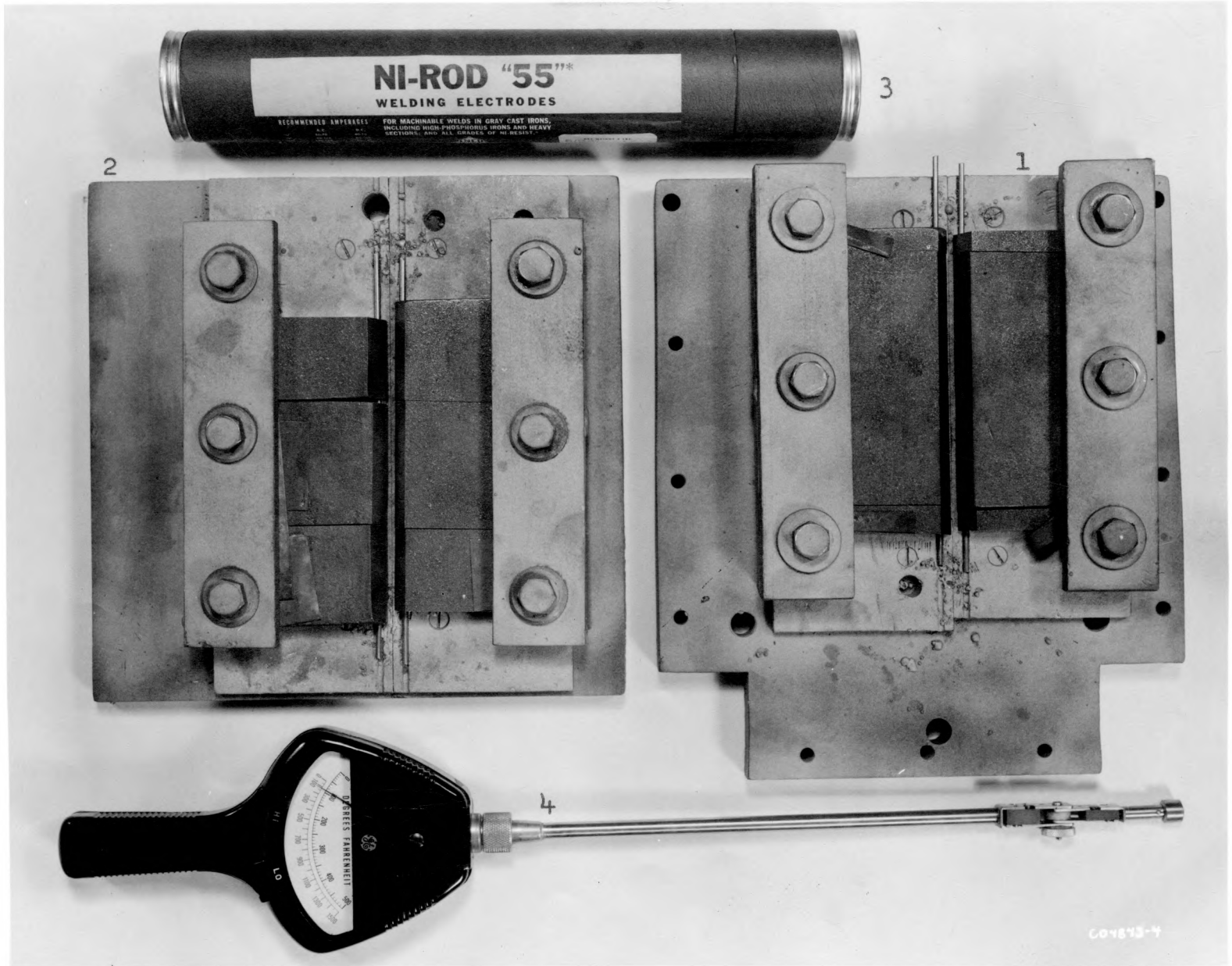
Approximately an 8-inch section of the welded test plate was required to obtain twelve $\frac{1}{2}$ -inch samples (three tensile and one metallographic for each of three post-heats--no, 750°F, and full anneal) (Plate IV) of the same weld with no waste except for cutting allowances. It was impossible to

¹Letter of Sept. 3, 1952 from H. C. Waugh, International Nickel Co., Inc., 67 Wall Street, New York 5, N. Y. to Prof. J. J. Smaltz, Dept. of Shop Practice, Kansas State College.

EXPLANATION OF PLATE II

1. Welding jig with large sample plates and $\frac{1}{2}$ -inch starting and stopping plates.
2. Welding jig with small sample plates and 2-inch starting and stopping plates.
3. Ni-Rod 55 welding electrodes.
4. General Electric Surface Pyrometer.

PLATE II

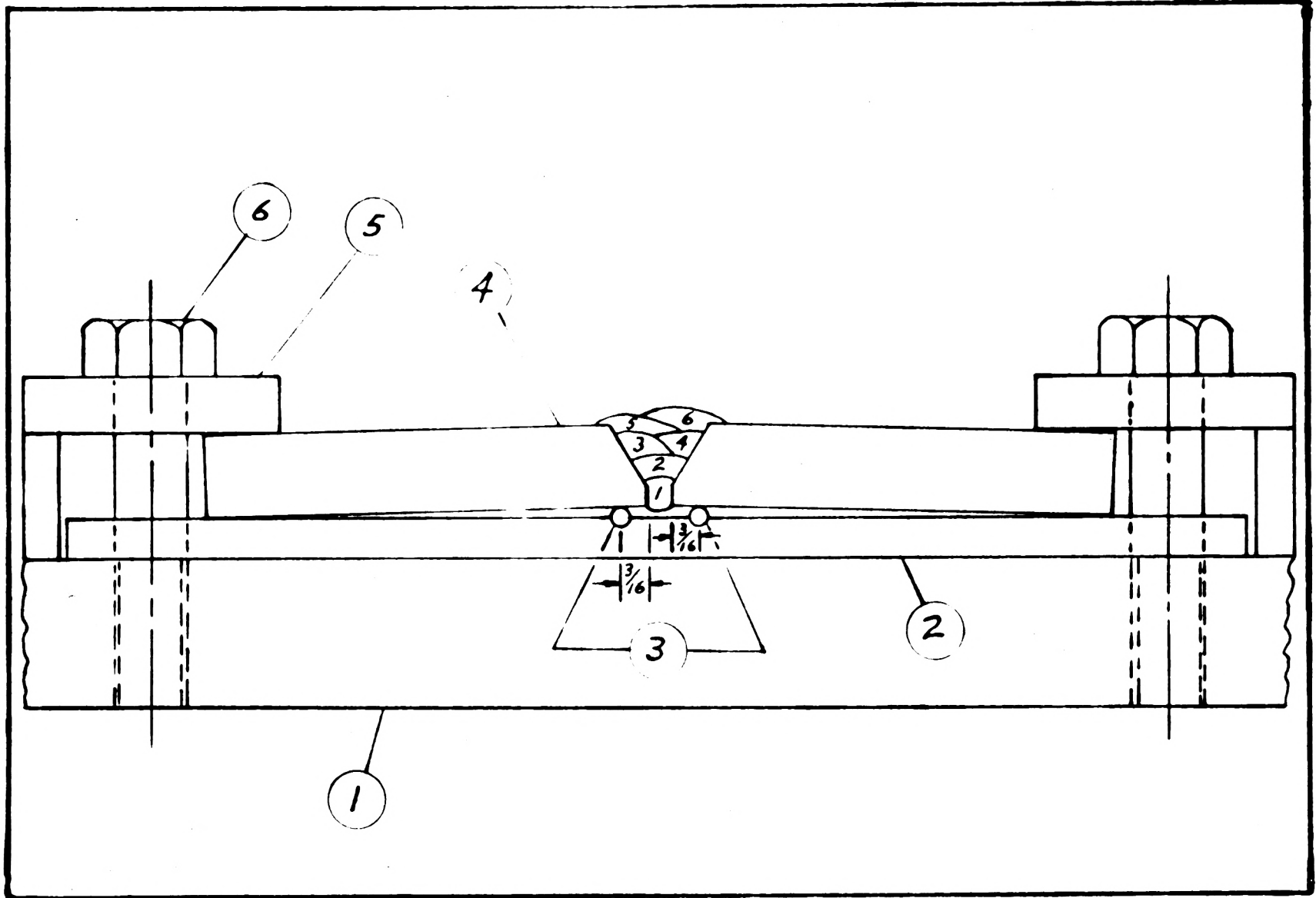


EXPLANATION OF PLATE III

Welding jig with beads in place.

1. Gray cast iron plate.
2. $\frac{1}{4}$ -inch copper plate.
3. $\frac{1}{8}$ -inch rods.
4. Ductile cast iron plates.
5. Steel restraining clamps.
6. $\frac{1}{2}$ -inch steel bolts.

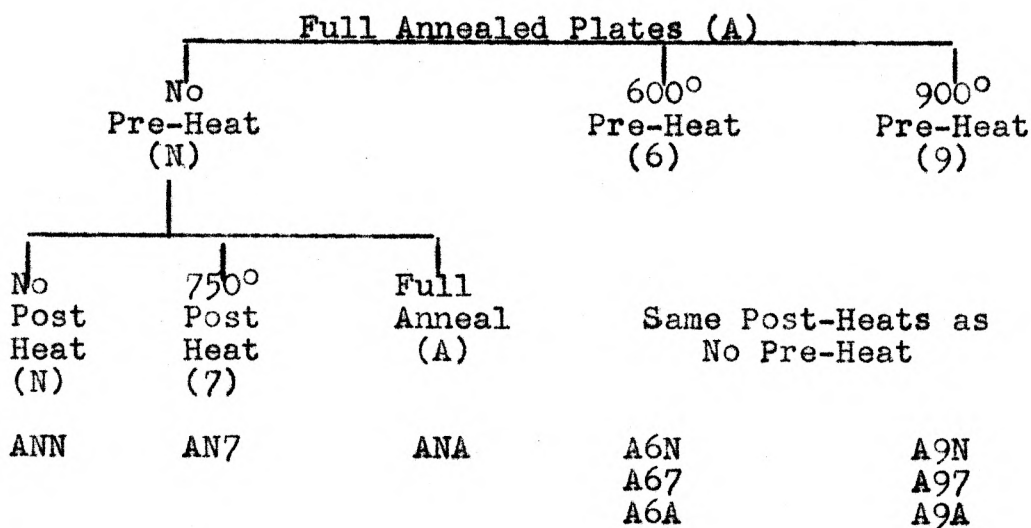
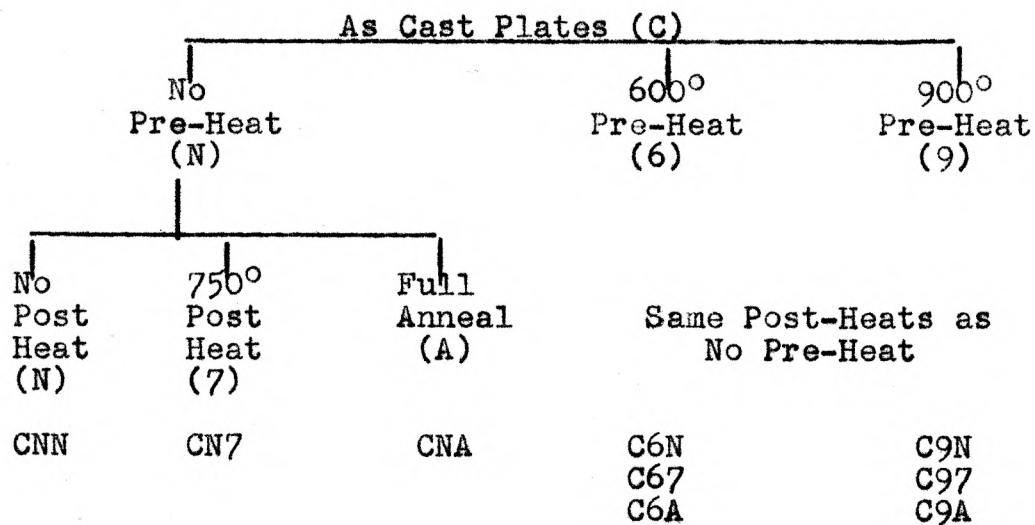
PLATE III



EXPLANATION OF PLATE IV

Codes used for marking samples.

PLATE IV

**Post heats**

750°F - 1 hour at temperature air cool

Full anneal

1650°F - 1 hour (at temp.) - furnace cool to 1275°F - hold 4 hours (at temp.) - furnace or air cool to room temperature.¹

1. Recommended by International Nickel Co., Inc. in letter of Oct. 25, 1951 to Prof. G. A. Sellers, Shop Practice Dept., Kansas State College.

get a 9-inch bead, allowing for a $\frac{1}{2}$ -inch gray cast iron starting and stopping plate on each end, without having to change electrodes. To overcome the possibility of having a slag pocket where a new electrode was started, two jigs were used. The first jig held two $5\frac{1}{2}$ -inch ductile cast iron sample plates with $\frac{1}{2}$ -inch gray cast iron starter and stopper plates at each end. The second jig held two $2\frac{3}{4}$ -inch ductile cast iron sample plates with 2-inch gray cast iron plates at each end, these larger plates were used to make the heat received from welding approximately the same in each jig. (Plate II) Samples in both jigs were welded at the same time.

Sample Composition and Plate Conditions

Samples of the composition (total carbon 3.54%, Si 2.40%, Mn .32%, Ni .78%, Mg .047%) were approximately $9/16 \times 3 \times 6$ inches.¹ They were prepared by grinding to a 60 degree angle with approximately $1/8$ -inch land. One-half of the samples were given a full-annealing treatment, the other half were welded in the as-cast condition. The samples were welded with Ni-Rod 55 (composition 60% nickel, 40% iron) electrodes.

¹Letter of Jan. 22, 1952 from Wm. Spear, International Nickel Co., Inc., to Prof. G. A. Sellers, Shop Practice Dept., Kansas State College.

Pre-heating and Welding

One-third of the samples were welded at room temperature while one-third were pre-heated to 600°F, and the remaining one-third were heated to 900°F. In the welding of the no pre-heat samples, the first bead was run at 110 amperes and the successive five beads were run at 120 amperes. In the welding, the samples were allowed to cool after each bead to jig temperature which was checked closely with the use of a surface pyrometer. The maximum jig temperature obtained was 150°F.

The 600°F pre-heat samples were welded in the same manner as the no pre-heat, except that the samples were not allowed to cool after each pass. The minimum temperature obtained was 500°F. The 900°F pre-heat samples were welded in the same manner as the 600°F except in that the first pass was made at 90 amperes and the remainder of the passes were made at 100 amperes. The lowest temperature obtained was 800°F. Both the as-cast samples and the full-anneal were welded in this manner.

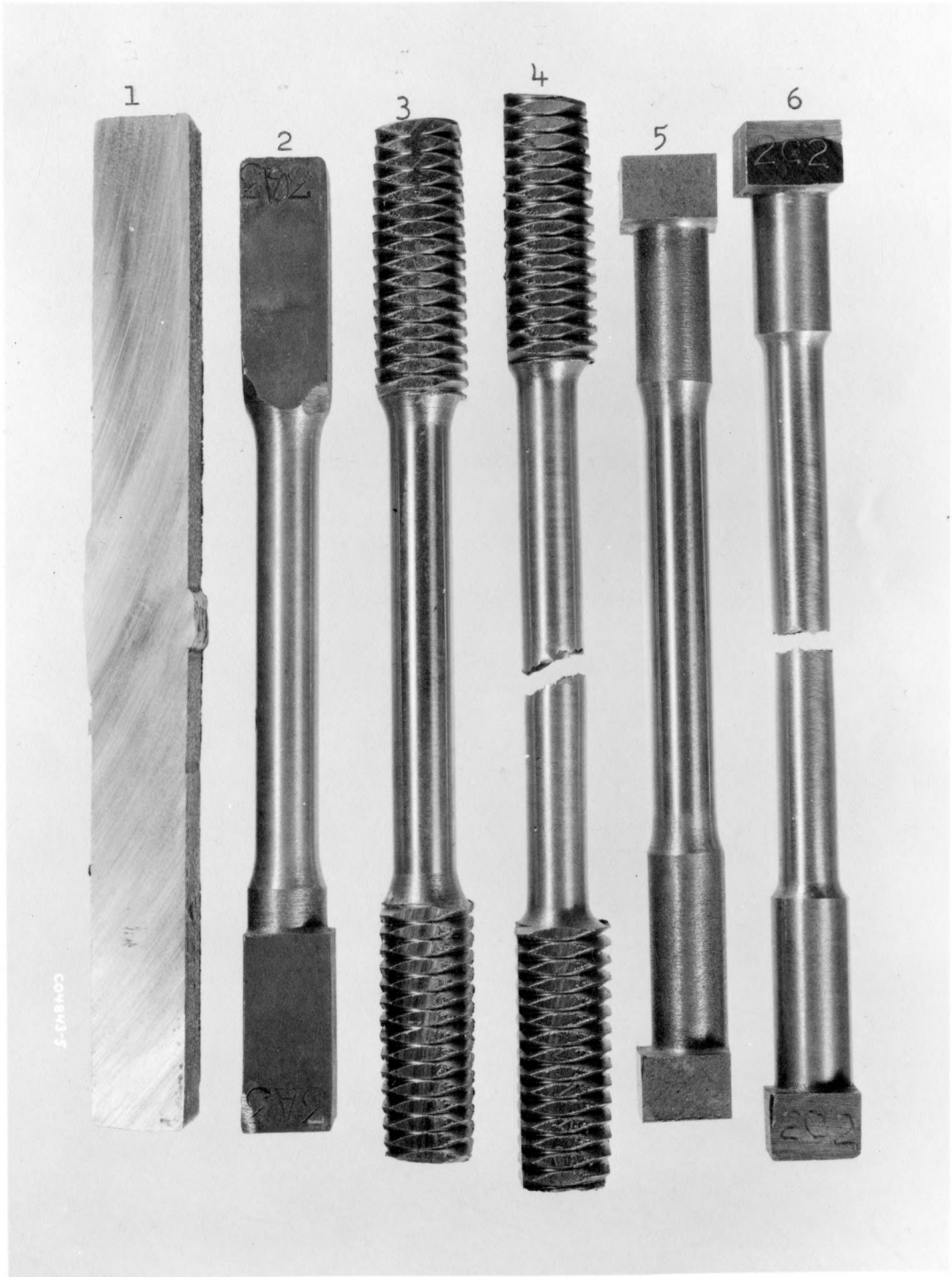
Cutting Samples

After welding, the samples were cut into $\frac{1}{8}$ -inch sections by the use of a Campbell No. 213 Abrasive Cut-Off Machine, and a special holding jig. (Plate V & VI) Difficulty was encountered in that the abrasive wheel (Allison No. 4980)

EXPLANATION OF PLATE V

1. Welded sample after cutting.
2. Sample ground to 0.375 inch diameter.
3. Sample threaded to $5/8$ inch + $1/32$ - 10NC.
4. Threaded sample after being broken.
5. Sample after being turned to form knobs on the ends.
6. Knobbed after being broken.

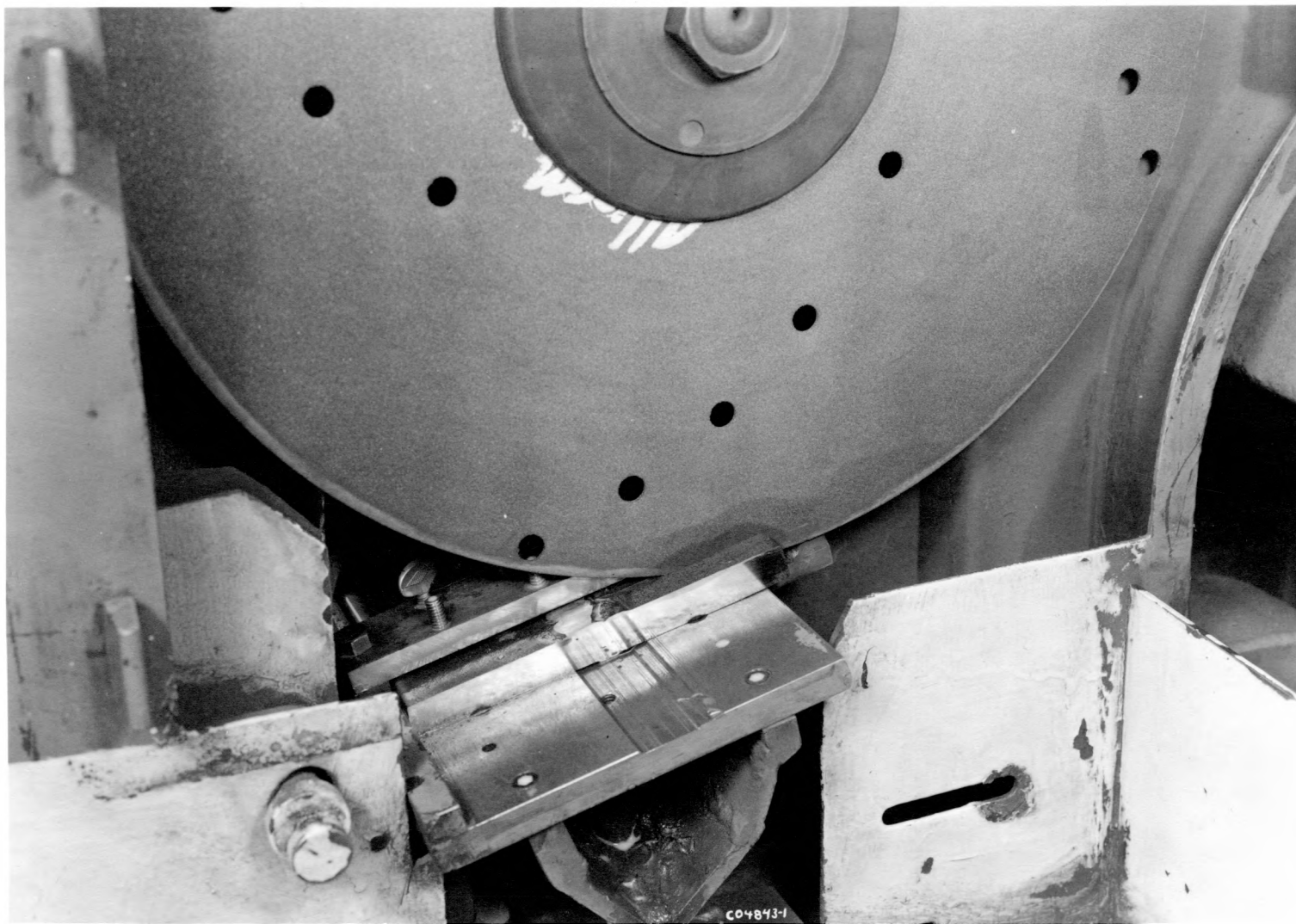
PLATE V



EXPLANATION OF PLATE VI

Welded samples being cut to size with abrasive cutoff wheel in special holding fixture.

PLATE VI



normally used for steel, heated the parts so that they checked. The manufacturer of these wheels, The Allison Co., Bridgeport, Connecticut, was contacted in regard to this matter. They suggested the use of Allison wheel No. 16067.¹ This wheel gave satisfactory results without causing the overheating and cracking.

Post-heating

All samples were coded (Plate IV) and after cutting to size, four sections of each weld, of each pre-heat (cast and anneal) were given no post-heat, four were given 750°F post-heat, and four a full anneal.

Grinding

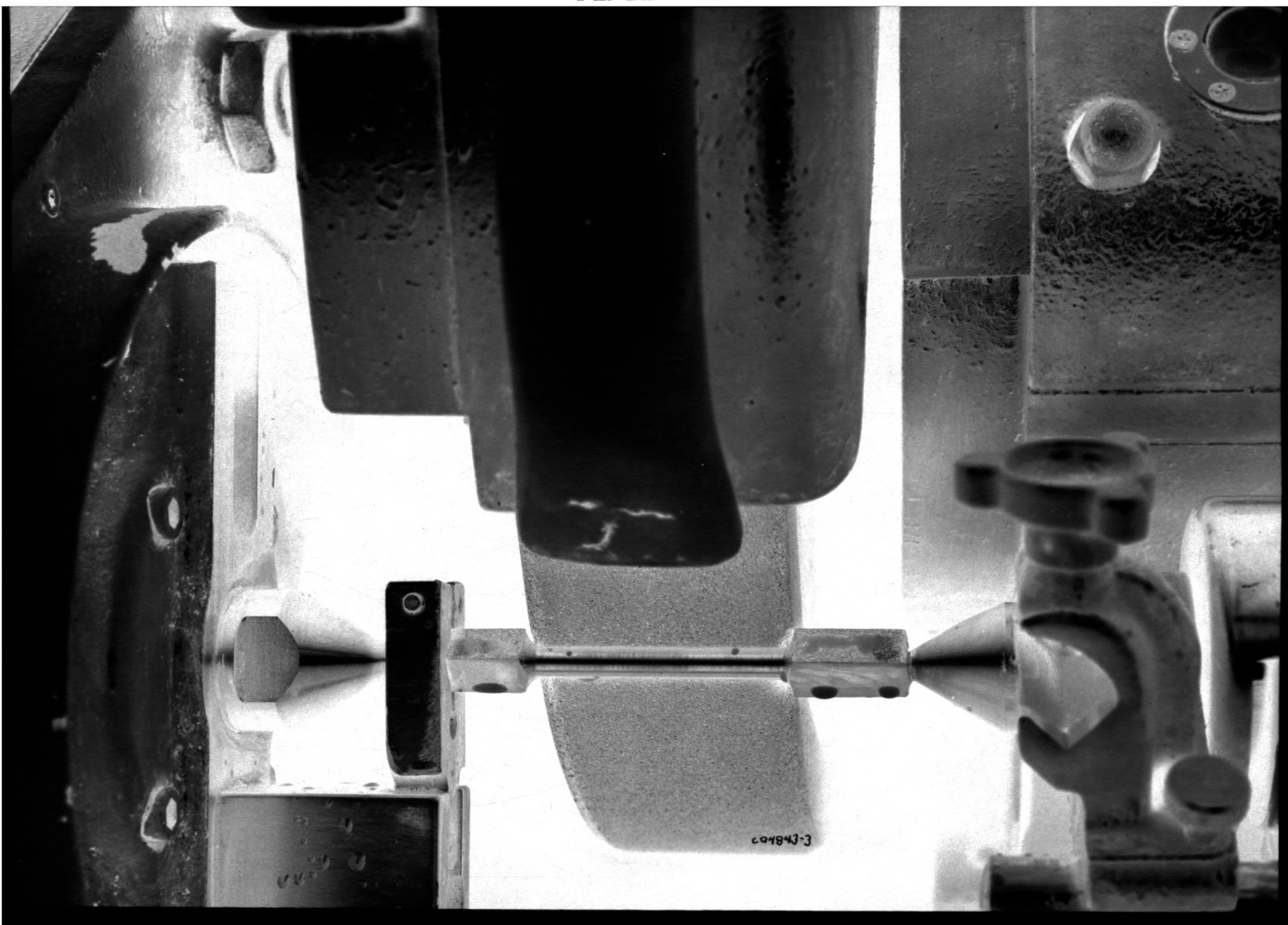
After the post-heat treatments, three samples of each group of four were center drilled, and ground to size (0.375 inch diameter) on a Norton Cylindrical Grinder. (Plate V & VII) Difficulty was encountered here in that grinding from a square, deep grooves were cut across the face of the wheel after a few samples, especially those not receiving a full-anneal treatment. This necessitated frequent dressing of the wheel.

¹Letter of Oct. 7, 1952 from C. D. Cummings, The Allison Co., Bridgeport 8, Conn. to Prof. G. A. Sellers, Head, Shop Practice Dept., Kansas State College.

EXPLANATION OF PLATE VII

Welded samples being ground in Norton Cylindrical Grinder.

PLATE VII



Threading

After grinding, part of the samples were threaded on both ends to 5/8-inch diameter plus 1/32 - NC 10 on a Hanson-Whitney 8 x 16 Thread Mill. (Plate V & VIII) Some of the cast samples with no annealing treatment were of such hardness as to cause the cutter to dull rapidly in the process of cutting threads on one end of the specimen. To overcome this the specimens were turned with knobs on each end and special adapters made enabling them to be pulled. (Plate V)

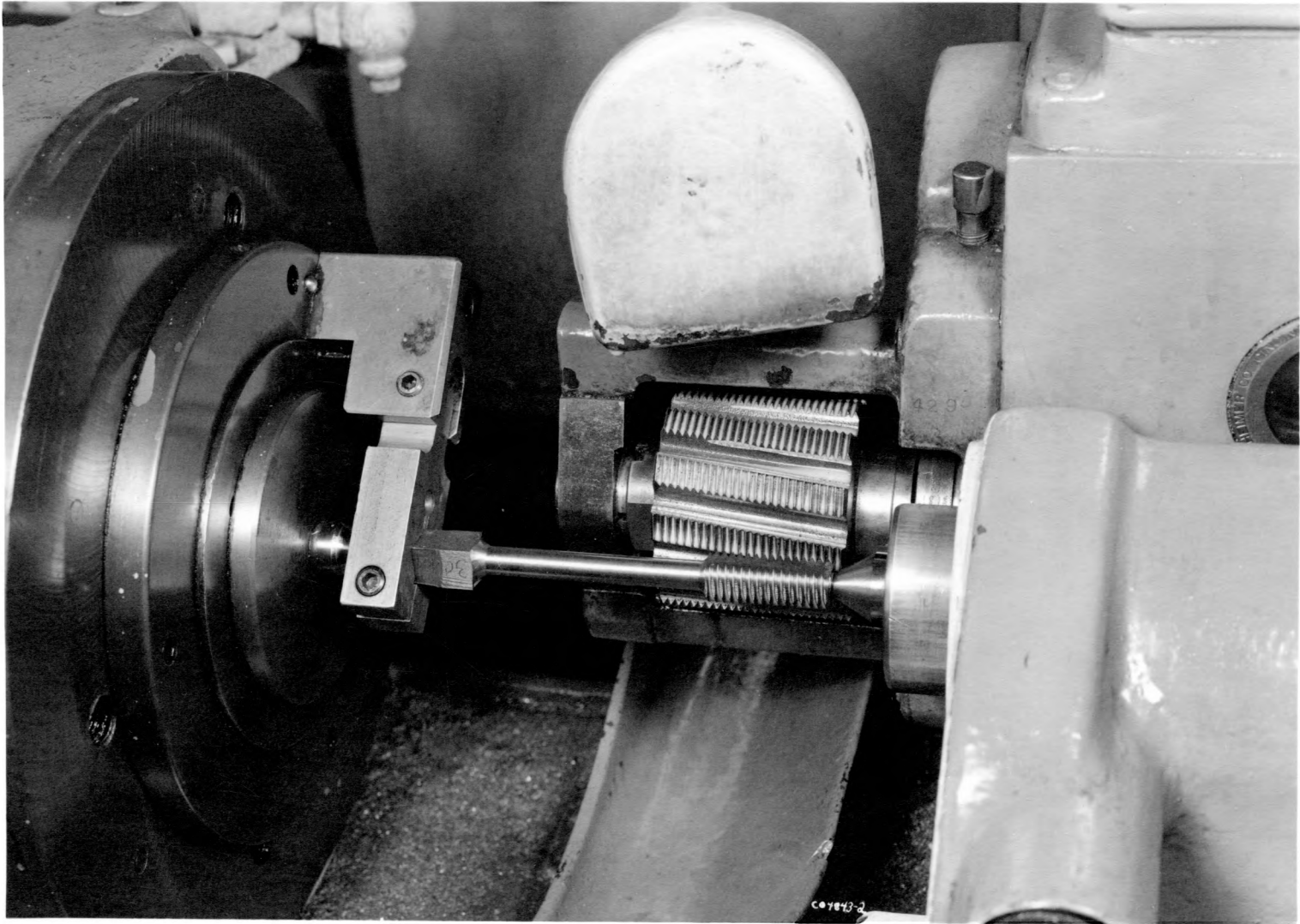
Tensile Tests

After machining, a Baldwin Southwart Hydraulic Testing Machine, 120,000 pound capacity, was used to pull the samples. During the process of pulling, a separating strain gauge and a Templin Stress-Strain Recorder were used to record the stress-strain curves. The stress-strain curve and the ultimate load was taken for each sample. After these data were taken, the percent reduction in area in the weld and the base metal, percent elongation, yield strengths at 0.1% and at 0.5% set, and ultimate tensile strength were calculated. (Table 7) From the broken samples, the location of fracture was determined.

EXPLANATION OF PLATE VIII

Welded and ground samples being threaded in a Hanson-
Whitney Thread Mill.

PLATE VIII



Hardness Tests

The metallographic samples of each weld were ground and polished. On these samples Vickers hardness tests were taken at 1/64-inch spacing across and perpendicular to the weld line at the center. (Plate IX) From this series of readings an average was calculated of the four readings across the weld line (see circled area Fig. 2, Plate VII) and these data were recorded. Vickers hardness readings were taken in the weld and base metal with a 20-kilogram load and charted. On each sample a maximum microhardness reading was observed and recorded with a 50-gram load and readings taken at 900 magnification. (Plate X)

EXPERIMENTAL RESULTS

The results given below have been summarized from the tabulated data in Table 7.

Cast and Annealed Plates Annealed after Welding
Samples: CNA, ANA, C6A, A6A, C9A, and A9A.

The ultimate tensile strength of these samples was practically the same as that of the non-welded sample.

The yield strengths at 0.1 and 0.5 percent set were practically the same or better than the non-welded sample.

The percent elongation was much less than that of the non-welded plate, (about one-third that of non-welded plate).

The maximum microhardness was approximately three times harder than the hardness of the base metal, this was due to

EXPLANATION OF PLATE IX

- Fig. 1. Photomacrograph of welded sample (ANN) showing Vickers hardness tests taken with 5-Kg load. Magnification 2x; Etchant, 4% Nital.
- Fig. 2. An enlarged view of Fig. 1. Magnification 15x.
- Fig. 3. Photomicrograph of hardness tests across weld and heat effected zone shown in Fig. 1 and 2. Magnification, 100x.

PLATE IX

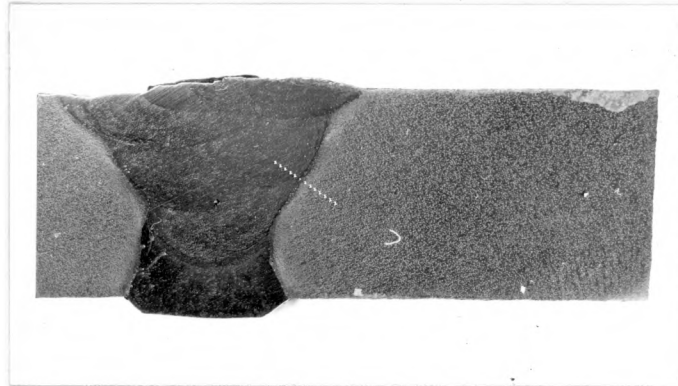


Fig. 1

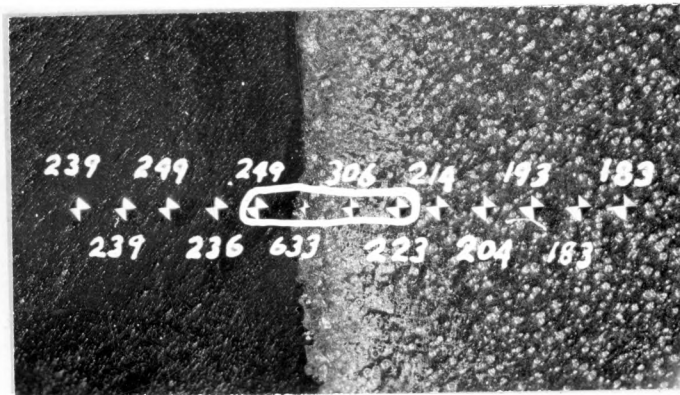
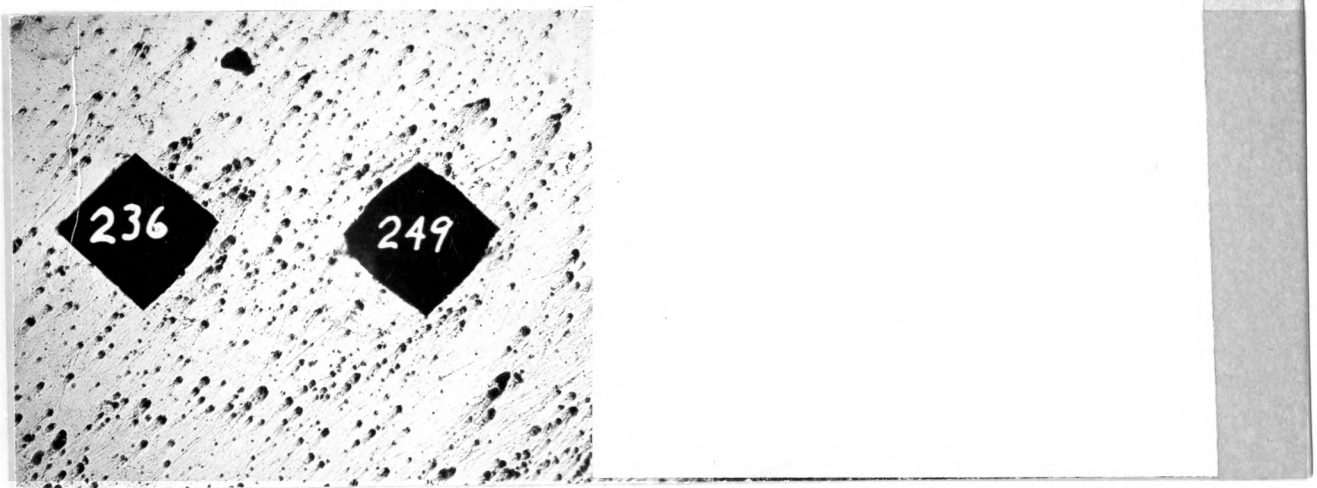


Fig. 2



Weld Metal

Heat Effectted Zone

Base Metal

Fig. 3

EXPLANATION OF PLATE X

Photomicrograph of welded sample (ANN) showing structure,
microhardness tests and DPH numbers. Magnification 492x;
Etchant, 4% Nital.

Indt. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
DPH No.	200	303	254	286	376	429	723	584	418	593	487	401	376	246

PLATE X

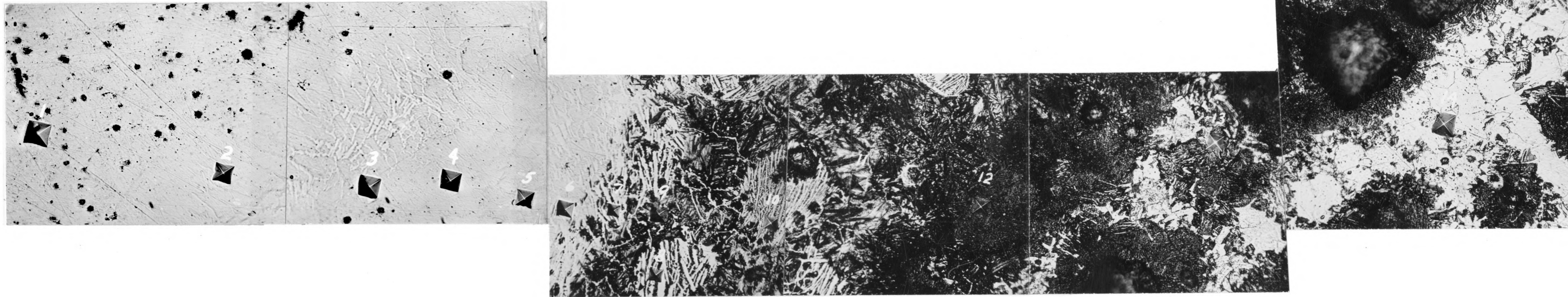


Table 7. Physical Properties of Welds on Ductile Iron.

Sam- ple No.	Cond. Be- fore Weld	Pre- Heat OF	Post Heat OF	Average Hardness D.P.H.			Maximum Hardness		Average					No. Tests	Location of Fracture	
				Weld 20kg	Base Met. 20kg	F.Z. 5kg	5kg	Micro 50g	R.A.%		Elong %	Y.S. 0.1% Set	Y.S. 0.5% Set			UTS PSI
									Weld	Base Metal						
Cast Non-Welded Plate										4.	4.25	61,779	70,881	101,263	2	
Annealed Non-Welded Plate										18.18	21.5	46,590	48,181	66,363	1	
CNN	Cast	None	None	198	329	364	495	762	0	0	0	58,705	N.R.	66,160	1	Radius outside gage limit
CN7	"	"	750°	191	277	400	473	800	2.75	.91	0	61,363	69,545	70,363	1	1/3 W 2/3 FZ
CNA	"	"	FA	169	164	178	206	490	7.287	18.33	8.67	48,790	52,427	65,632	3	1-CI; 2-W; 3-OG limit
ANN	FA	None	None	206	169	353	633	723	0	5.0	1.75	50,018	52,537	61,722	2	1-FZ; 2-CI
AN7	"	"	750°	191	167	267	460	613	1.81	8.79	5.00	51,439	53,182	66,803	3	1-FZ, HAZ; 2-FZ; 3-OG limit
ANA	"	"	FA	160	160	178	190	485	6.61	4.2	6.25	46,835	48,986	61,200	2	1-inc W; 2-FZ
C6N	Cast	600°	None	187	284	359	391	760	1.8	1.4	0	53,600	N.R.	59,910	2	1-FZ; 2-FZ-W
C67	"	"	750°	198	267	346	386	633	3.35	.3	0	54,728	65,319	67,867	3	1-FZ; 2-FZ; 3-1/3 W 2/3 FZ
C6A	"	"	FA	155	166	175	178	494	9.0	4.05	4.	45,000	50,500	60,820	2	1-inc W; 2-W
A6N	FA	"	None	189	161	311	558	766	5.88	3.4	3.18	52,008	53,252	61,160	3	1-FZ; 2-FZ; 3-inc W
A67	"	"	750°	176	171	226	263	739	1.83	2.75	1.75	49,311	51,605	54,518	2	1-CI; 2- 1/2 W 1/2 FZ
A6A	"	"	FA	164	158	177	210	532	5.88	9.95	7.75	48,414	50,679	62,089	2	1-CI; 2-FZ
C9N	Cast	900°	None	167	260	346	407	760	1.39	2.77	0	N.R.	N.R.	46,200	2	1-FZ; 2-FZ
C97	"	"	750°	172	244	366	494	739	4.07	2.26	1.5	48,188	62,600	60,036	2	1-FZ; 2-FZ
C9A	"	"	FA	149	165	204	286	552	7.49	4.19	5.5	43,412	50,747	62,042	3	All 3- 1/2 W 1/2 FZ
A9N	FA	"	None	166	173	317	502	600	0	0	0	N.R.	N.R.			No satisfactory samples tested
A97	"	"	750°	151	165	330	566	739	.915	0	0	N.R.	N.R.	47,170	3	1- 1/2 W 1/2 FZ; 2- 1/3 W 2/3 FZ; 3-FZ
A9A	"	"	FA	150	155	181	193	480	3.97	3.36	4.8	43,119	49,388	59,755	3	1-FZ; 2-FZ; 3-FZ

Abbreviations:

FZ--Weld-plate junction. (Fusion zone)
HAZ--Heat Affected zone.
W--Weld.
CI--Cast iron.
FA--Full anneal (Plate IV)
N.R.--Not reached.
OG--Outside gage.

the narrow hard zone on fusion line which the annealing treatment did not take care of. (Plate XI) This narrow hard zone would cause the difference to be more pronounced on impact tests than on ductility.

Cast Plates With Varying Pre-heats and No Post-heats
Samples: CNN, C6N, and C9N.

The maximum microhardness was the same for all three sets of samples. The pre-heats caused a slight but uniform drop in the base metal hardness.

The percent elongation was zero in these samples but four percent in the non-welded plate.

The yield strengths at 0.1 and at 0.5 percent set compared well to that of the non-welded plate, but showed a uniform drop with increasing pre-heats.

The ultimate tensile strengths showed a greater uniform drop than the yield strengths.

Cast Plates with Varying Pre-heats and
750°F Post-heats
Samples: CN7, C67, and C97.

Varying pre-heats caused uniform drops in the base metal hardnesses. Maximum microhardnesses showed no correlation with very little change.

There was a uniform decrease in both yield strengths and ultimate tensile strengths with an increase in percent elongation. This increase in elongation was caused by the reduction in the yield and ultimate tensile strengths.

EXPLANATION PLATE XI

Fig. 1. Photomicrograph of an annealed weld showing microhardness tests in narrow hard area.

Indt. No.	1	2	3
DPH No.	293	516	552

Etchant 4% Nital. Magnification 750.

Fig. 2. Enlarged view of an indentation similar to number 3. Magnification 1680.

PLATE XI

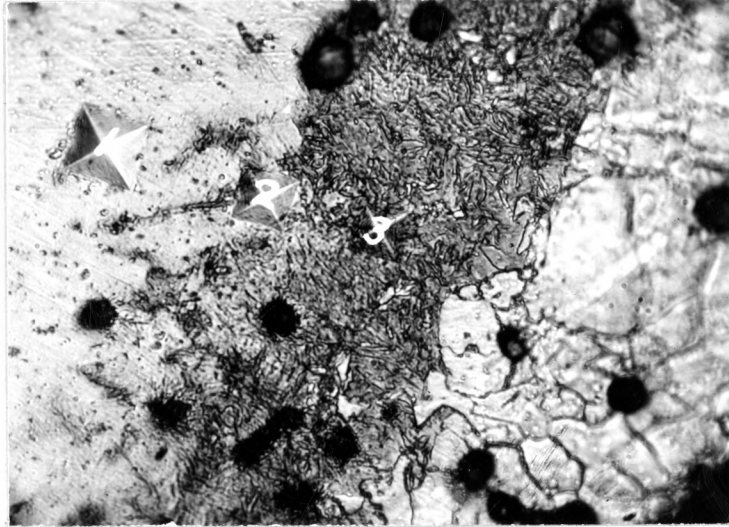


Fig. 1

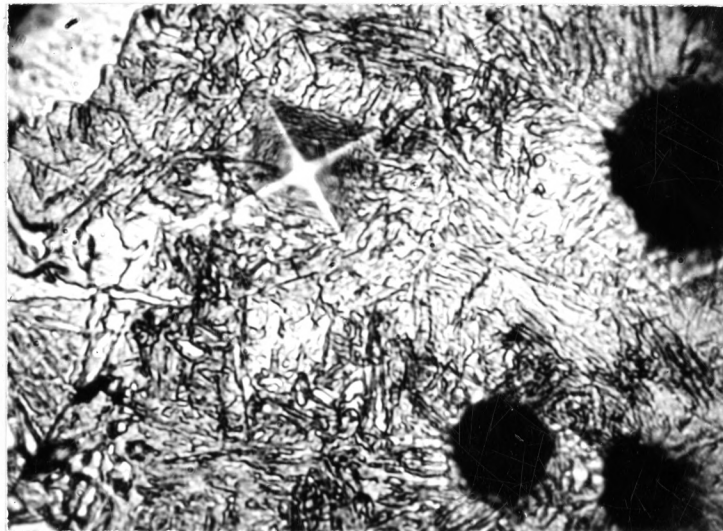


Fig. 2

Annealed Plate with No and 600°F
Pre-heat and No Post-heat
Samples: ANN, A6N.

There was no change in base metal and maximum micro-hardnesses, an increase in elongation and a slight increase in yield strengths and no change in ultimate tensile strength.

Annealed Plate with Varying Pre-heats
and 750°F Post-heats
Samples: AN7, A67, and A97.

In these samples there was no change in the base metal hardnesses, and the maximum microhardness except for sample AN7 which was low. This low reading was probably due to an experimental error. There was an appreciable decrease in the elongation, with a uniform decrease in both yield strengths and ultimate tensile strengths.

CONCLUSIONS

Ductile cast iron welded on an equal basis with gray cast iron but with less cracking.

It was rather difficult to machine, but was not compared with gray cast iron of equal hardness.

Good tensile properties were obtained in all of the welded samples except those with 900°F pre-heat. Three sets of the samples of this pre-heat (C97, C9A and A9A) gave good result, but the other three sets (C9N, A9N, and A97) gave low readings, with A9N giving unsatisfactory tensile specimens.

Most of the tensile specimens broke in the fusion zone, this correlates with the narrow hard zone in the fusion zone, especially in the post-annealed samples.

(Plate XI)

It should be noted that in the post-annealed samples that the tensile strength properties were as good or better than those of the non-welded plate.

PROBLEMS FOR FURTHER STUDY

Similar tests could be made on ductile cast irons of different compositions, so that a study and a comparison could be made of the various compositions and their properties.

A more extensive annealing treatment (hold at 1650°F for 5 hours, furnace cool to 1275°F, hold 5 hours)¹ could be used to try to eliminate the hard zone found in the post-annealed samples.

Other brands of electrodes could be used and compared with Ni-Rod 55.

¹ Letter of Feb. 11, 1953 from F. E. Allen of the International Nickel Co., Inc., 67 Wall Street, New York 5, N. Y., to Prof. G. A. Sellers, Head, Shop Practice Dept., Kansas State College.

ACKNOWLEDGMENT

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PHYSICAL PROPERTIES AND STRUCTURE
OF
WELDS IN A DUCTILE CAST IRON

by

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B. S., Kansas State College
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AN ABSTRACT OF A THESIS

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requirements for the degree

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1953

The iron welded in this experiment was ductile cast iron with a structural composition of free carbon (graphite) in the form of spheroids and pearlite in the as-cast state. This iron was made by adding a magnesium inoculant to the ladle of molten metal before pouring into the molds. This metal has good tensile strengths (80,000 to 100,000 PSI) and elongation (4 to 10 percent) in the as-cast state, and tensile strengths of around 65,000 PSI with an elongation of 15 to 20 percent with a short annealing treatment.

This iron may be machined and welded with no more difficulty than gray cast iron, its fluidity is practically as good as gray cast iron, and its damping characteristics lie about half-way between cast steel and gray cast iron.

As-cast and annealed samples of this ductile cast iron were welded at room temperature, 600°F and 900°F pre-heats. After welding the plates were cut into $\frac{1}{2}$ -inch sections and four samples of each weld were given post-heat treatments of no, 750°F and full anneal. The samples were prepared for tensile and metallographic tests.

The tensile properties of the as-cast samples compared well with the non-welded plate, but with a uniform decrease with increasing pre-heats.

It was noted that in the post-annealed samples the tensile strength properties were as good or better than those of the non-welded plate. In practically all of the samples the location of fracture was in the fusion zone,

except those with inclusions in the weld, which did not affect the tensile properties appreciably. In all probability the cause of the fracture in the fusion zone was due to the extremely hard zone found there, particularly in the post-annealed samples where the annealing treatment did not take care of this condition.