THE EFFECT OF CONTROLLING WELDING PROCEDURE AND PEENING ON THE PHYSICAL PROPERTIES AND TRANSITION CONSTITUENTS OF THE MATERIALS

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P R E F A C E

In the development that has taken place and processes pertaining to the various applications of welding fabricating trades during the past few years, most remarkable changes have been introduced as means of perfecting apparatus and welding materials. This field has, by no means, exhausted the process of metal working.

New developments are being continually recorded and it will be very difficult to establish any definite limit to the methods in the application of the process.

Special attention has been given to a number of methods very recently developed in an effort to improve the physical and constutuent properties of welds.

The object of the present work is to develop a practical method of determining the residual stresses and relieving them. At the same time methods were determined by which the physical and structural properties could be improved.

The writer wishes to acknowledge the assistance rendered by Mr. S. B. Slack, former bridge engineer for the Georgia State Highway Department, in checking the results previously run, also experimental work done in the shrinkage of welds.

-O.M.H.

THE EFFECT OF CONTROLLING WELDING PROCEDURE AND PEENING ON THE PHYSICAL PROPERTIES AND TRANSITION CONSTITUENTS OF THE MATERIALS.

Purpose of the Investigation

In studying the investigation made on welded materials, and knowing the action of the elements, carbon, silicon, phosphorus, sulphur, manganese, etc. when alloyed with iron, there will be a considerable change in the structure and physical properties of materials when welded, due to the effect of the rate of cooling through critical ranges. Knowing, too, that the deposited material is different than that of the parent metal in that it is cast rather than rolled material.

The rolled steel has improved properties over that of cast steel by having received a mechanical refining treatment while passing through the rolls in a plastic form. This imparts grain refinement, closes and welds blow holes, promotes soundness, increasing tensile strength and ductility. This is done by the destroying of the pre-existing coarse crystallization and producing a grain which is much smaller, and more uniform throughout the entire mass. In the case of the same steel in a cast form it is not possible to obtain these advantages.

To these facts that the deposited metal is cast steel, we also have to give consideration to non-metallic or oxidized impurities and gas impurities such as, nitrogen, which the metal will absorb from the atmosphere forming atomic nitrogen, which combines with the iron forming iron nitrides. These impurities are very detrimental to the ductile properties which are the desired qualities in a weld.

With these facts in mind it is the intention and desire to present in this paper a thorough knowledge and understanding of the practical application of the welding process and its possibilities, with relation to a practical method of relieving residual stresses caused by the sudden change of temperature of deposited and parent metals. This is based on the principles of the physics and metallurgy involved in making a good weld.

Method of Attacking the Problems.

(a) The machine was designed and built as shown in Fig. 2 and 3 which was used to control the effective blow of the air hammer, by the use of an air reservoir with a capacity of about 100 cubic feet connected between the air line and a regulator. This made it possible to regulate and to maintain a constant air pressure on the air hammer. Then the air hammer was placed in the carriage holder of the machine and clamped so as to prevent it from moving in the carriage. This carriage was designed to move in any direction at a constant speed and fixed so it could not move from the effect of the blow of the hammer, as shown in

Fig. 1 and 2. A special jig was made to hold the material to be welded firmly to the table of the peening machine to prevent any loss of the effective blow from the hammer through vibration. (See Fig. 8.)

When the machine was completed, several trial tests were run to prove that the full benefit of the effect of the blow of the hammer was obtained. It was desired to obtain data from which one could calculate the force of the blow given by hammer at different air pressures.

The method of calibrating the hammer is based on the work done by S. B. Redfield.[1] Redfield calculated the force of a blow from a drop hammer on the following basis; neglecting friction when a body of a given weight is lifted through a given distance, work is done upon that body against the action of gravity equal to the product of the weight by the distance lifted. When this body is allowed to fall again this work is transformed into energy of motion and when the body strikes an object, the act of stopping the body forces it to give up its energy of motion, resulting in deformation or breakage and heat, therefore, the work done by the blow must equal the work stored in the falling body, the product of the force of the blow and depth of penetration must be constant and equal to

(1) Ref. American Machinist. Vol. 33, 1910

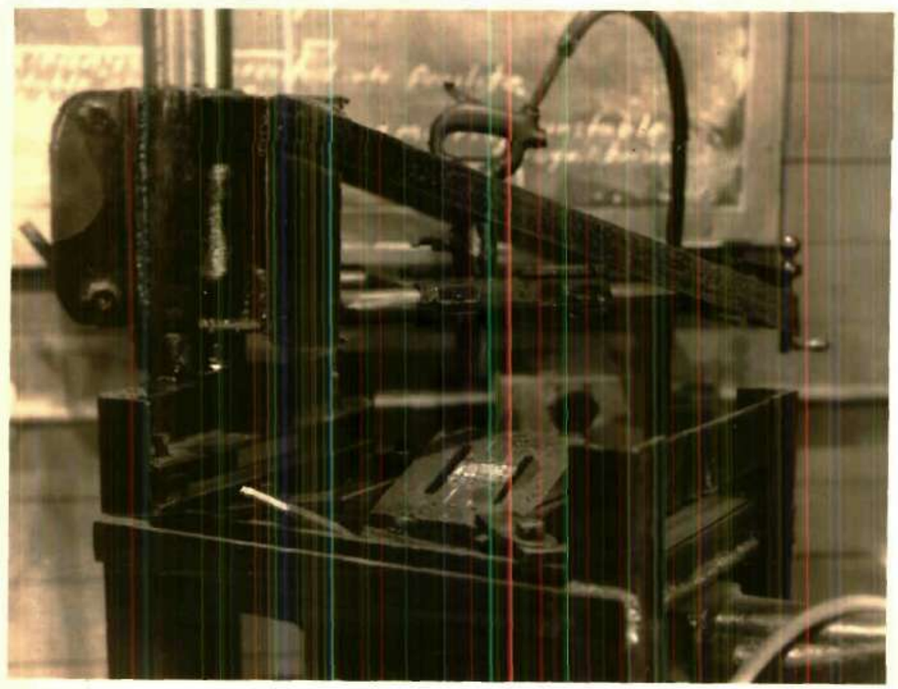


Fig. 1 A

This shows a more detailed construction of the peening machine.

In this photograph you will notice how the carriage can be moved to and from the weld. This makes it possible to weld the center bar of the plate without removing them from the clamps on the bed of the machine. By the use of a manually operated worm driven machinesum the carriage can be moved back and forth across the weld at a constant speed while peening.

Fig. 1 B

The above photograph shows a complete set-up in operation of equipment used in peening and recording temperatures. Note the position in which the hammer is held and manually operated across the welded area.

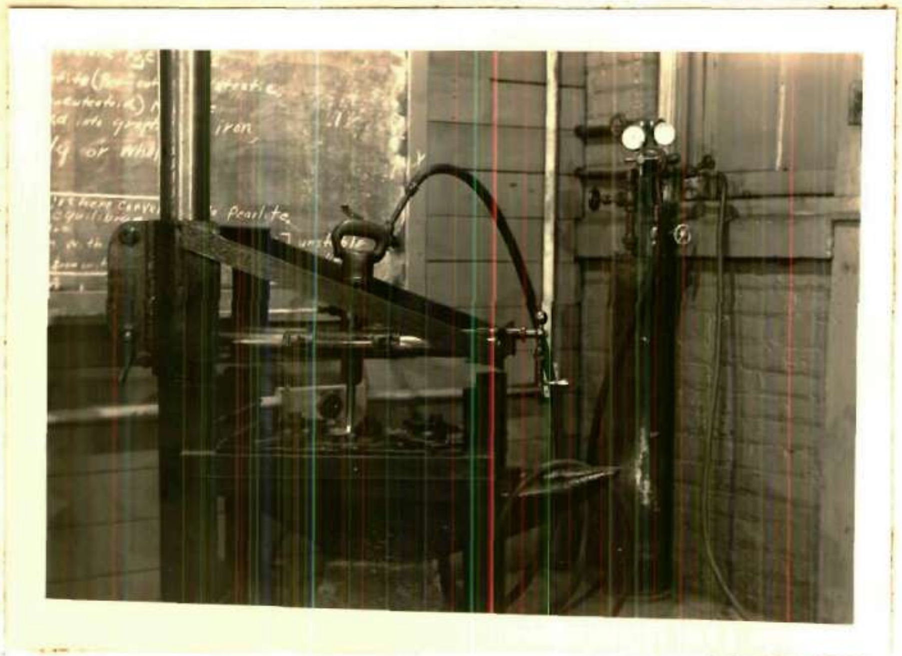


Fig. 2

Shows detailed construction of peening machine and air reservoir with air regulator.

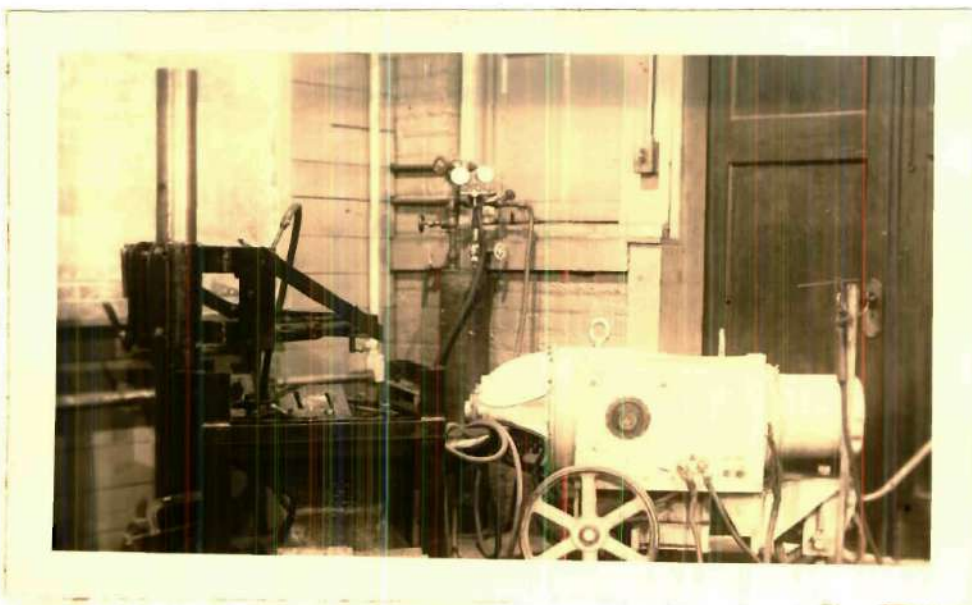


Fig. 3

Shows complete set-up of equipment used for welding and peening.

the stored work. If the substance is tough and penetration is slight, the force must be great. Similarly, if the bodies are soft and penetration is great, the force of blow must be small because the product of the two must be constant.

Now apply the above statement in calculating the effected blow of an air hammer. Suppose the hammer has a 3 1/2-inch diameter bore and a 9-inch stroke. Then applying an average effective air pressure behind the piston of 60 pounds per square inch, and the moving parts, piston weighs 100 pounds, the chisel will penetrate rock 1/16 inch at a single blow. Here the work is done by air on a downward stroke. We will simplify the case by assuming the air pressure is removed exactly at the instant of stopping of the piston and that there is no cushioning of air in the lower end of the cylinder.

In falling through the 9-inch stroke (3/4 foot) the 100 pounds of weight will be able to do 100 x 3/4 or 75 foot pounds of work. The average air pressure of 60 pounds per square inch above the 3 1/2 inch diameter piston will exert a downward force of 60 x 9.62 x .75 or 432 foot pounds. This would show itself in increased velocity of the moving parts.

From this the total work available in the descending machanism, again neglecting friction, which would be 75 + 432= 507 foot pounds. Since the penetration is 1/16 inch or 1/192 of a foot, the average blow will be 507 divided by 1/192 or

97,344 pounds. If the rock were soft the penetration twice that of the above the average force would be half as much, or 48,672 pounds.

On this basis, the following formula for finding the effective blow of an air hammer was derived.

$V^2 = 2\ a\ s \quad V^o = 0 \quad V =$ Final velocity at end of stroke.

Since $A = \frac{F}{M} \quad V^2 = 2\ \frac{P}{W}\ S \quad \therefore V^2 = 2\ \frac{P\ A\ S}{\frac{W}{g}}$

$\therefore V = 2\ g\ \frac{PAS}{W}$ On hitting Object force $F_2 = Ma = \frac{W}{g}\ \frac{V^2}{2S_2}$

Where $S_2 =$ Penetration in ft.

$\therefore \quad F_2 = \frac{\cancel{W}}{\cancel{g}}\ \frac{\cancel{2}\ \cancel{g}\ P\ A\ S}{\cancel{W}\ \cancel{2}\ S_2} \quad \therefore F_2 = \frac{P\ A\ (S\ \ S_2)}{S_2}$

Where $P =$ lb/Sq. in. of air on piston
$A =$ Piston area in Square Inches
$S =$ Stroke of piston in feet
$W =$ Weight of piston

Calculations for F_2 using 50 and 70 lb air pressure of hammer:
Piston travel is 4 9/16" or 4.562"
Weight of piston is 1.04 pounds
For 50-lb air pressure $S_2 = .006"$
For 70-lb air pressure $S_2 = .0086"$
$A = .8861$ Sq. In.
$S. = .38$ ft.

$F_2 = \frac{50\ (.8861 \times .38)}{.0006} = 33{,}500$ lb.

$F_2 = \frac{70\ (.8861 \times .38)}{.00086} = 33{,}500$ lb.

In addition to above named machine the following equipment was used: a small air hammer, a chromel-alumel thermocouple, a milli-volt meter, a Berry strain gage with a 2-inch gage length. An oxy-acetylene torch for cutting the material and preparing for welding, a drill press, and a special punch and jig for spacing and making the Berry gage holes.

Material used:

(1) Structural steel plates 1 1/4" X 6" X 14"

(2) Electrodes used:

5/32 Airco No. 41 bare using 145 amperes and 18 volts full load.

1/8 Westinghouse Flex-Arc, using 125 amperes and about 18 volts full load.

5/32 Airco No. 65 light coated using 140 amperes and about 20 volts full load.

5/32 Westinghouse Flex-Arc general purpose heavy coated, using 130 amperes and about 25 volts full load.

5/32 heavy coated Cresta Murex, using 130 amperes and about 25 volts full load.

5/32 Lincoln Fleetweld shield arc, using 130 amperes and about 25 volts full load.

Method for Preparing Material for Welding

By the use of the oxy-acetylene cutting torch the 1 1/4" X 8" X 14" steel plates were cut and then with a special jig duplicate punch marks on the faces of the plates were laid out. Then with scratcher marks from point to point gave the line of cut to form the center bar; as shown in Fig. 4. Then a second special jig was built for cutting the double bevel double V section in the center of the bar as shown in Fig. 5.

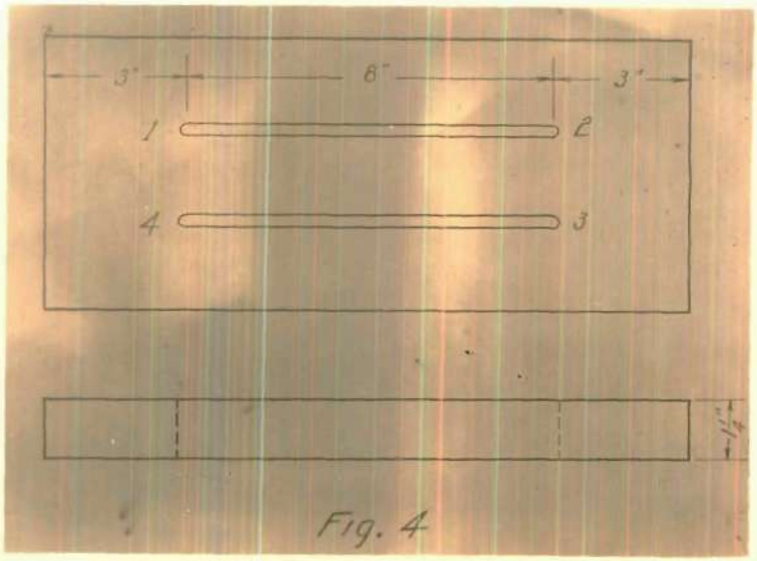


Fig. 4

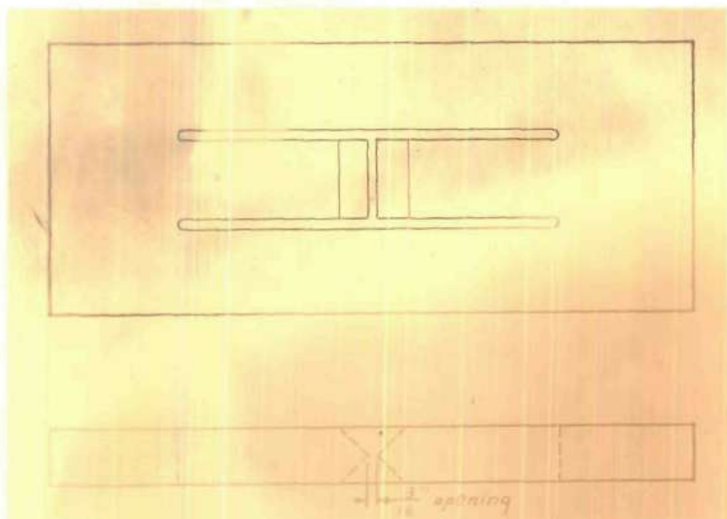


Fig. 5

With the use of the jigs these points were obtained accurately as shown in the figures above. Then with a smooth straight-edge jig and the oxy-acetylene cutting torch a smooth finish opening was cut from points 1 and 2 and 3 and 4. Then with a special jig double "VS" were cut with a smooth finish leaving a 3/16" gap between the two ends of the center bars as shown in Fig. 5.

After the center bars were formed, as shown in Fig. 5, a third special jig was made as shown in Fig. 6, for laying out and making accurately the strain gage hole. The accuracy of these holes were made possible by drilling and reaming holes in the jig to fit a special punch. The angle of the points on the punch is the same as that of the legs of the strain gage. This jig was clamped firmly on each side of the plates to be welded. Then by the use of the hammer and the special punch, the strain gage holes were made as shown in Fig. 7.

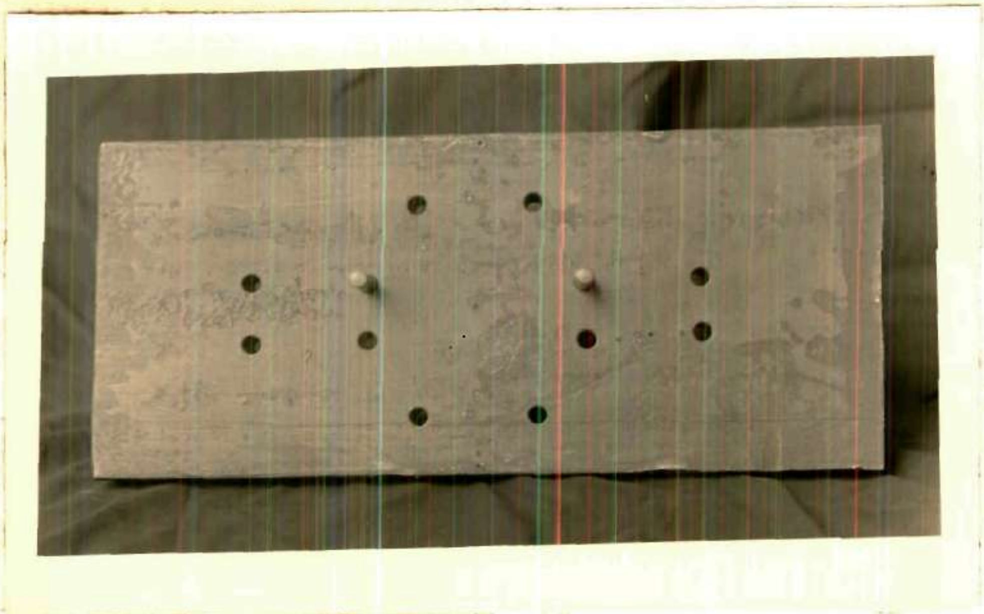


Fig. 6

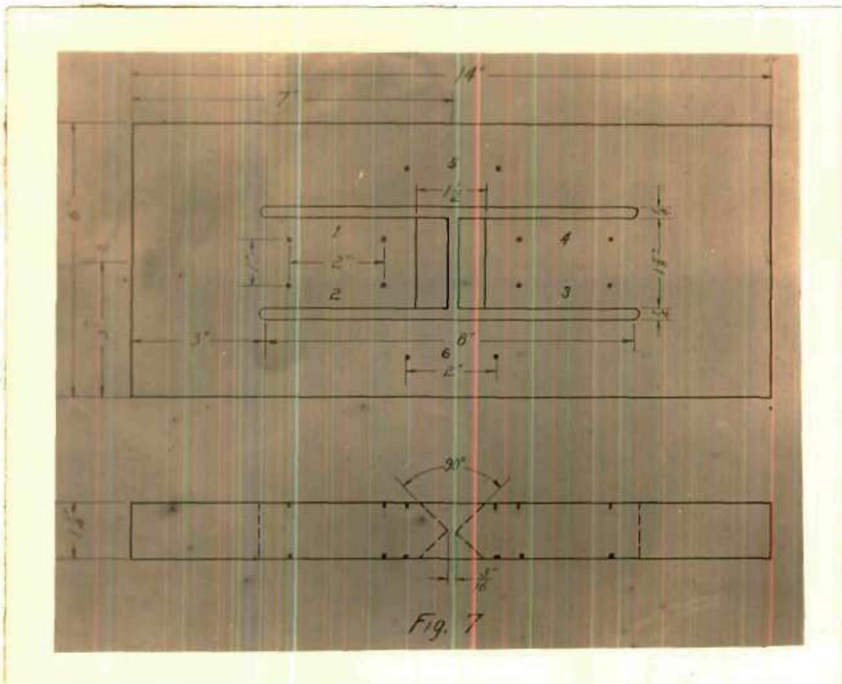


Fig. 7

When the preparation of the plates was finished, they were stored in a room with the Berry strain gage and allowed to age for about eight weeks before welding so as to allow the strain due to cutting temperature to localize them at room temperature. This would allow both the plates and Berry gage to have the same expansion due to atmospheric room temperature.

Method of Procedure and Results

The zero strain gage readings were taken at points 1,2,3,4,5, and 6 on both sides of the plate (A & B) and recorded as given in Table I.

The plate was then placed on the table of the peening machine, covered with a special metal templet, allowing none of the face of the plate to be exposed except that portion of the center bar to be welded. This protected the strain gage holes from being filled with iron-oxide given off from the molten metal in the arc crater.

Then the plate was clamped down to the table of the peening machine as shown in Fig. 8.

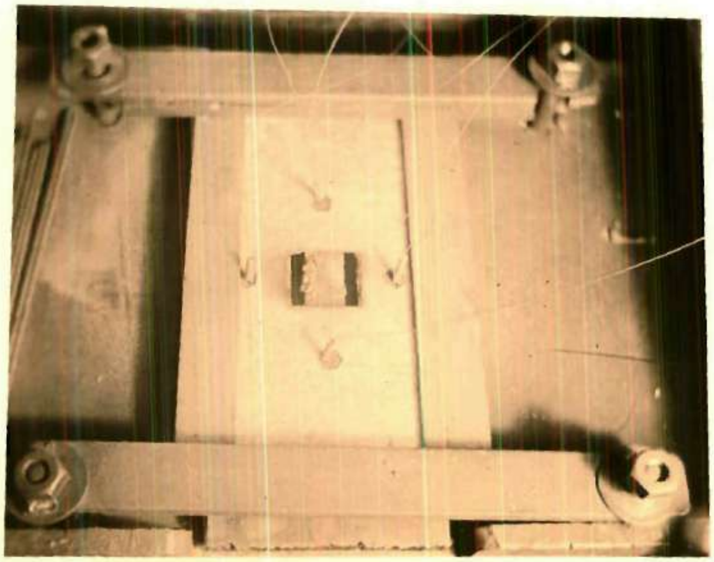


Fig. 8

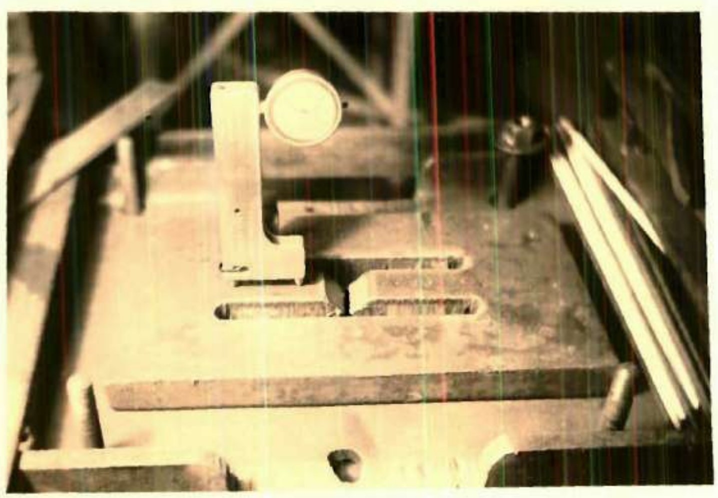


Fig. 9

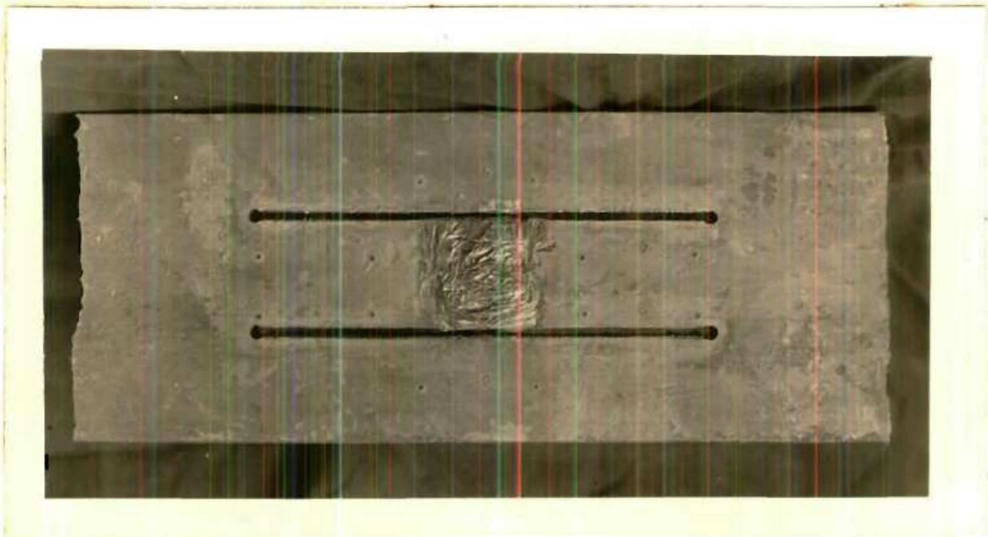


Fig. 9A

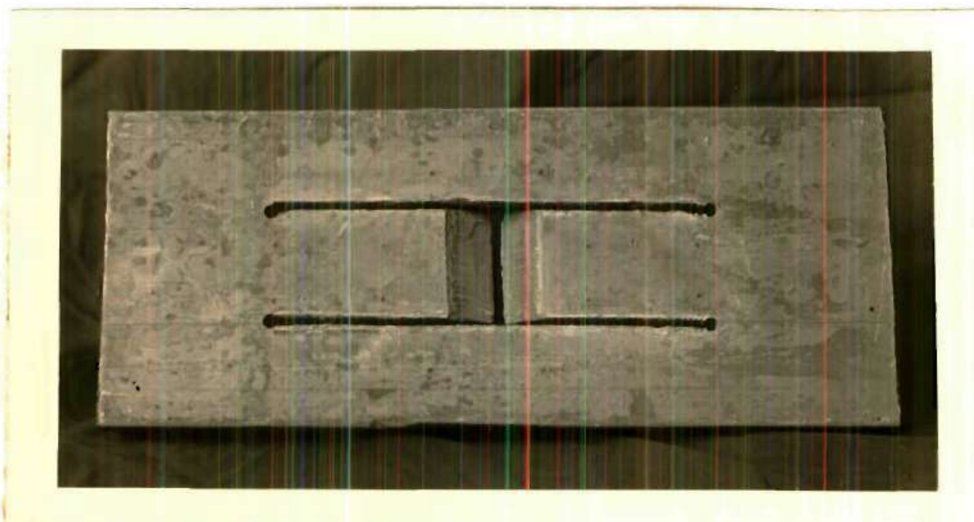


Fig. 10

of obtaining a more uniform distribution of the strains and a

The plate was welded to equally distribute the heat liberated in the arc stream and the arc terminals on both sides of the double "V" joint of center bar to maintain as near as possible a uniform stress in the plate due to expansion and contraction on both sides of center bar. When the weld was completed the temperature was taken and recorded, plate removed from clamps, (as shown in Figs. 8 and 9A) and strain gage reading A_h and B_h taken. Then the plate was allowed to remain in the same room for about 24 hours, allowing the plate to attain room temperature. Then the strain gage readings were taken again and recorded (in data) as A_c and B_c. This procedure was repeated identically for each test plate run.

The test plates used in the investigation consisted of 1 1/4" X 6" X 14" hot rolled steel plates prepared as stated and shown in Fig. 10. This type of joint was used because of its simplicity, its high degree of rigidity, and its adaptability for obtaining the strain gage reading with a fair degree of accuracy.

The 90-degree double V type joint was used for the purpose of obtaining a more uniform distribution of the strains and a large area of deposited metal. The large area of deposited metal made it possible to determine the actual physical properties of the deposited metal of center bars.

Strain gage holes were made on both sides of the center and outside bars of each specimen as shown in Fig. 7. These holes were so located that strain gage readings taken between them in a direction right angles to the axis of the weld and parallel to roll direction of parent metal, would measure unit deformation of the center bar, because the deformation of center bar is directly a function of the amount of contraction of the welds. This method of obtaining strain reading is adaptable and a satisfactory means by which the different welding procedures could be compared.

Two types of welding procedures were investigated and they are illustrated and described in detail as shown in Figs. 11 and 12. The different procedure was in the method of depositing the weld metal and the application of peening.

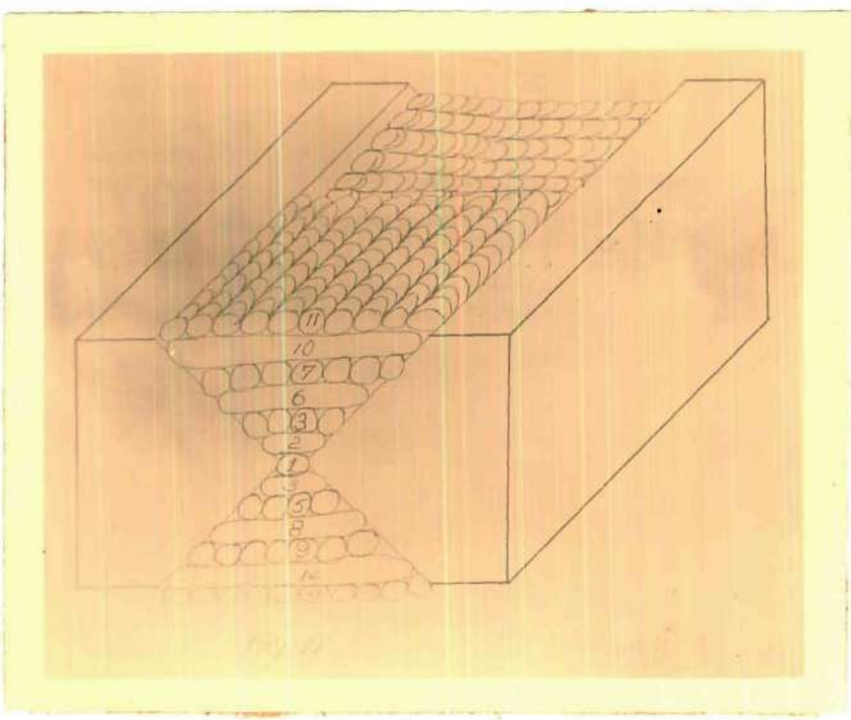


Fig. 11

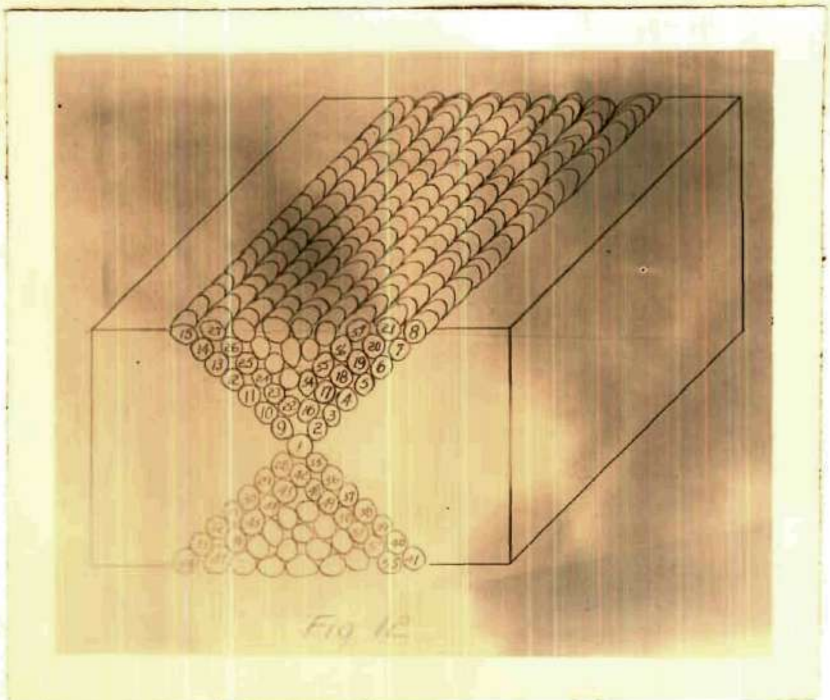


Fig. 12

The deposited metal was equally deposited in the upper and lower V's as shown, in an effort to eliminate bending stresses in center bar as much as possible.

The test procedure consisted of running several tests non-cleaned and non-peened, taking strain gage reading on each specimen with a Berry strain gage before and after welding, while weld was hot and after cooling to room temperature. Also the same procedure was carried out as follows:

(a) Cleaning and peening each deposited layer.

(b) Cleaning and deposited layer and peening every other layer.

(c) Cleaning each deposited layer and peening every third.

(d) Cleaning each deposited layer and peening twice in each V of joint.

(e) Recording temperature before and after peening all welds and taking strain gage reading as stated above.

The effective blow of the peening hammer was controlled by putting the hammer in a fixed position and regulating the air pressure as previously explained. Various pressures were used in order to determine from results what pressure is most effective on the peening of welds. The pressures used were 50, 60, 70, and 75 pounds per square inch. Results obtained show that an average effective pressure of 70 pounds per square inch give the most effective results on releaving residual strains and stresses in welded metals.

All welds were made controlling welding current, welding voltage, temperature, and peening with the purpose in view of making each weld identical.

This data plus actual strain gage is tabulated in Table No. I.

When all test specimens were welded and data recorded, oxy-acetylene cutting torch was used to cut the center bars out of plate as shown in Fig. 13-A. The test bars were then allowed to age at room temperature for about four weeks, then machined, and turned down in the weld proper as shown in Fig. 13-B for running the physical tests as shown in Tables II and V.

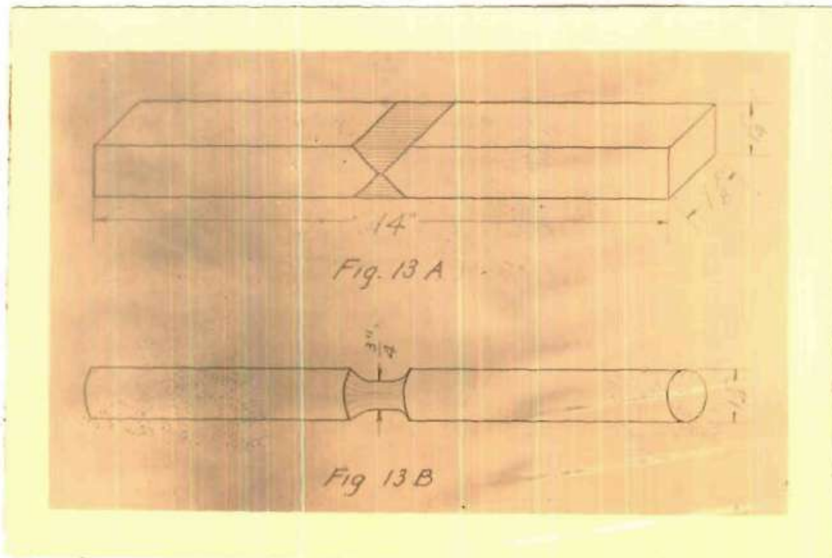


Fig. 13A & 13B

The reason for cutting the test bars down in the weld proper was to insure obtaining the results of the physical properties of the welded metal and not parent metal. This picture shows a few of the test bars after they were pulled, Fig. 14.

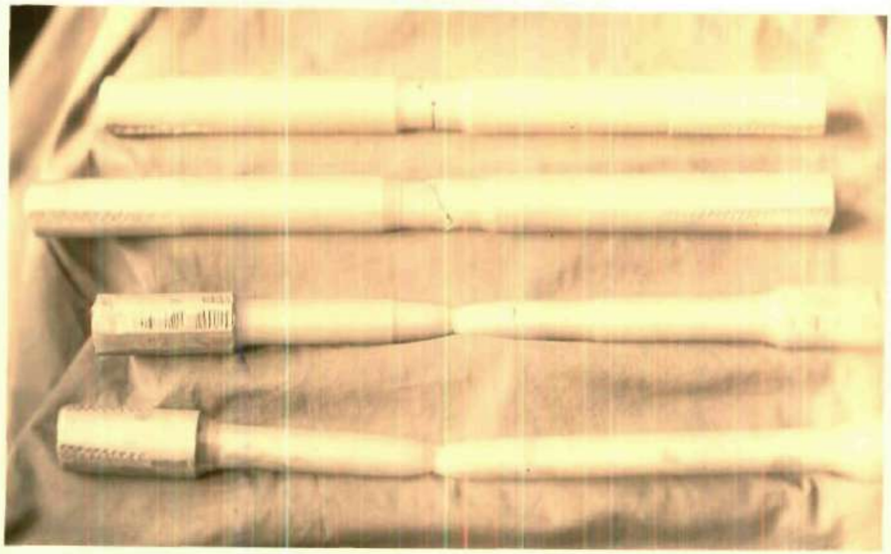


Fig. 14

From these bars and from other bars that were not pulled, a section of the weld has been cut out, polished, and etched for making a microphotographic study of the welded structure. Fig. 15 shows a few of the test bars that sections of welds have been cut from to prepare for microphotographic study.

Fig. 15

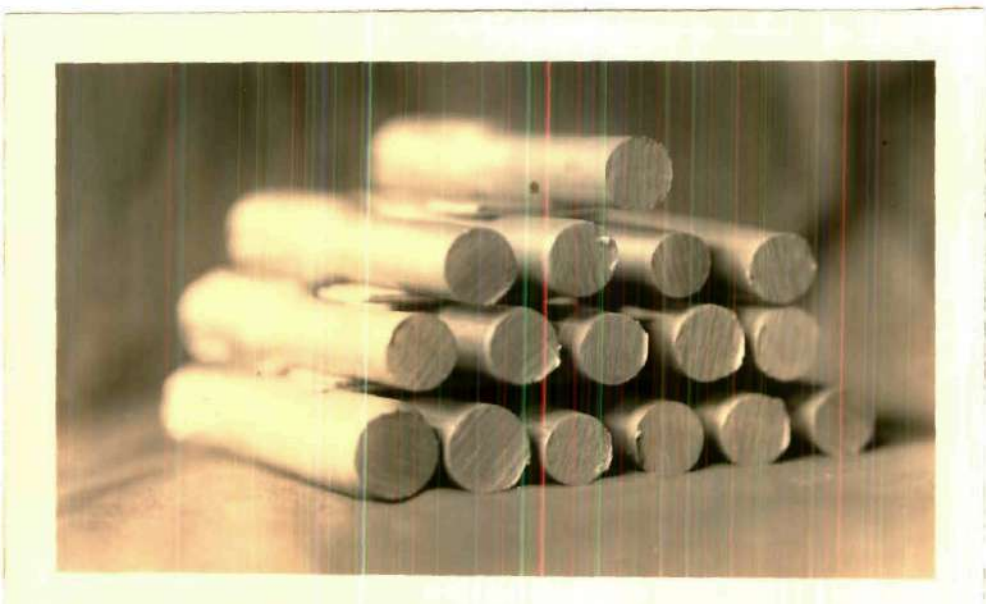


Fig. 16

Photomicrograph of Welded Joints

The object is to study the story revealed from the micro-structures of the welded joints with relation to the effect of the welding heat on structure and physical properties of steel.

Welding is a process by which, through one of the following methods, two metallic pieces may be fused together to form a solid homogeneous mass in the welded areas: autogenous welding, electric resistance welding, forge welding, and electric arc welding.

Arc welding is a process by which a high current is passed through an arc gap utilizing the total heat in the arc stream, and at the arc terminals to fuse the metallic pieces to be joined, in order that they may flow together to form a solid homogeneous mass. The structures of the deposited metal in an electric arc weld is to a certain extent that of cast steel with the loose course crystalline structure, therefore, the physical properties are similar to those of cast metals. Because through continuous heat-treatment the weld receives through the process of welding, the physical properties are improved over that of the cast metals. In fact it is found that the deposited metals are relatively lower in ductility than in strength. This has been proven from the microscopic examination of fracture and cut sections from welded areas, also the physical tests that the specimens have been subjected to.

The following micro-photograph (Fig. 1-28) show that the metals are unsound, in that they are contaminated with non-metallic inclusions, and lack of union and strong bond between some of the crystals. This offers the reason for the losses of ductility in welded metals. On the other hand, the increase in strength is no doubt due to the inherent method of welding. The method of building up a section by layers of beads will increase its area of resistance to strains as compared with the original section, and helps it to offer a greater resistance to breaking in the weld.

These micro-photographs also reveal many large black needles in the ferrite grains which is evidence that crystals of a nitride of iron are present, which make the crystals more brittle than the crystals they are imbedded in.

This will again help to increase strength and decrease ductility, although it has been proven from this investigation that the physical properties can be improved by control procedure of welding and peening which will offset some of the above named faults.

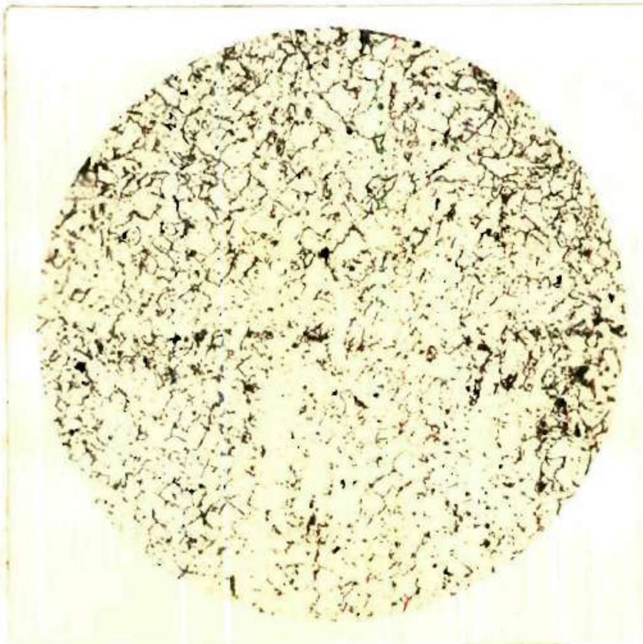


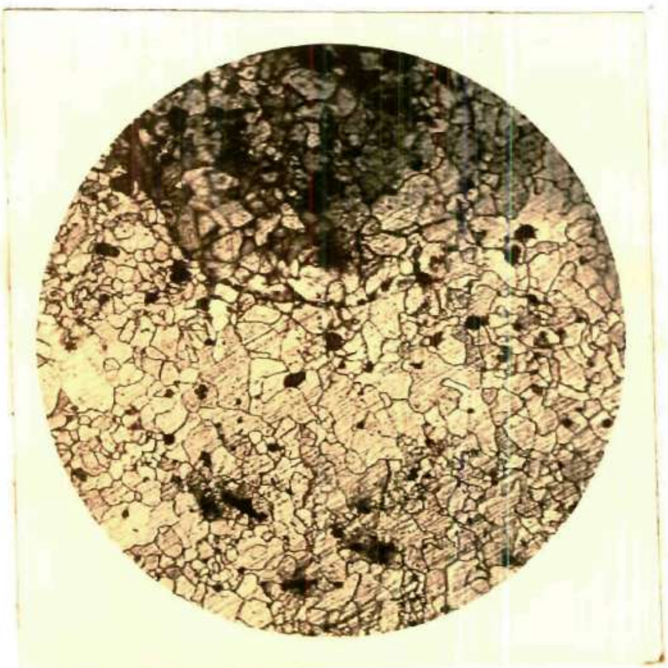
Fig. 1--188X Nitol Etch

Fig. 1--Welded Steel Non-Peened. Etched in Nitol.

This photomicrograph shows a cross-section of deposited metal and base metal. Upper section is deposited metal and lower half is based metal.

Structure shows a uniform aggregate of ferrite and pearlite, the little round dark spots in the ferrite grains are non-metallic inclusions. The white areas are ferrite, and the dark areas following the grain boundaries are pearlite. The black needles that are seen in the (white) ferrite grains in the upper section are nitride of iron and the black streak shown in the center is the junction of weld which is non-metallic impurities. The dark gray substance is an eutectoid structure of Fe & $Fe\ N_4$.

This micro-photograph is of a section taken from test specimen No. 1 as listed under Table III, page 71. This micro relates why the physical properties are as given in Table III.



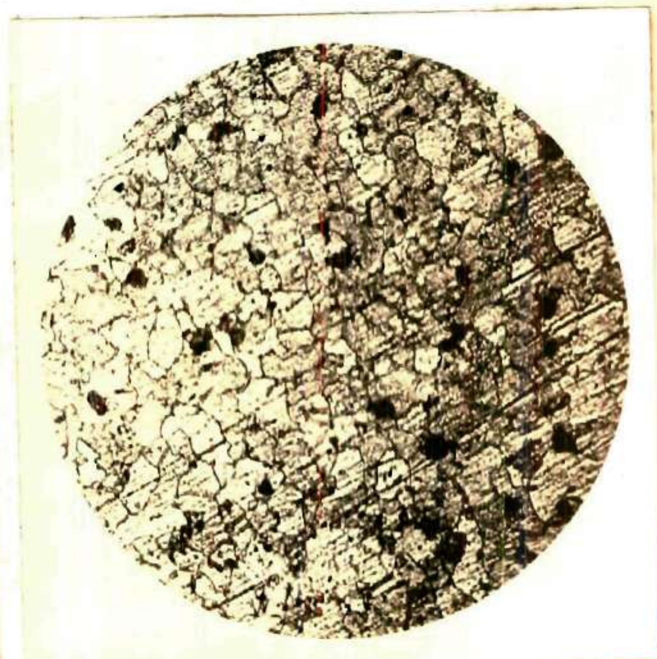


Fig. 2A--150X Nitol Etch Fig. 2B--150 Nitol Etch

Fig. 2A--Welded Steel, Non Peened. Etched in Nitol.

This photomicrograph shows a cross-section of deposit and base metal. The upper section is the deposited metal; the lower section is the base metal. The black areas are slag and cavities due to imperfect welding and cleaning of each deposited layer of metal. The fracture as shown near the weld junction accrued during the tensile test on test bar. The reason for the failure in this manner was due to the distribution of the non-metallic inclusion.

The structure shows white grains of ferrite and black grains of sorbito pearlite. The small clusters of ferrite grains, as shown below the fracture, are ferrite bonds due to improper rolling.

Fig. 2B--Section of Deposited Metal of Same Specimen as that of 2A Etched in Nitol.

The black areas are slag and cavities due to imperfect welding. White areas are ferrite, dark gray areas are sorbito pearlite. The black needles, as seen in the ferrite, are nitride of iron.

These micro-photographs as shown indicate why the physical properties of Spec. No. 2 are as listed in Table No. III.

Fig. 3--150X Nitol Etch

Fig. 3--Welded Area of Test Bar No. 4 as Listed in Table No. III, Non-Peened.

This photomicrograph shows a cross-section of welded area. The black areas are slag and cavities due to improper welding and cleaning of each deposited layer. Structure is an aggregate of ferrite and sorbito pearlite. The black needles as seen in the white areas are nitride of iron known as nitride needles.

This microphotograph relates why the physical properties are so low as shown in Table No. III.

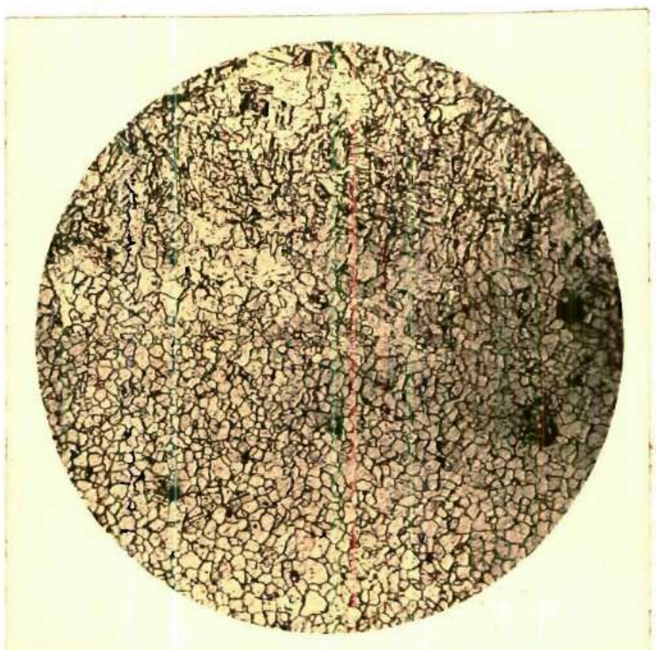
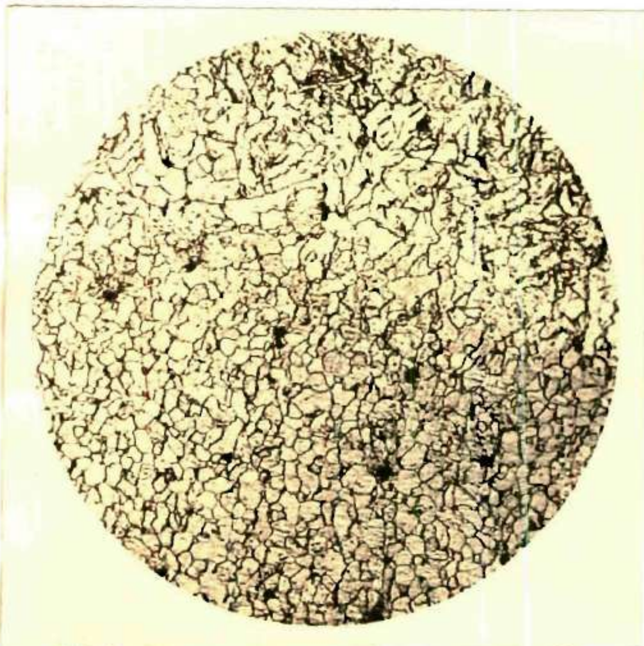


Fig. 5A Nitol Etch



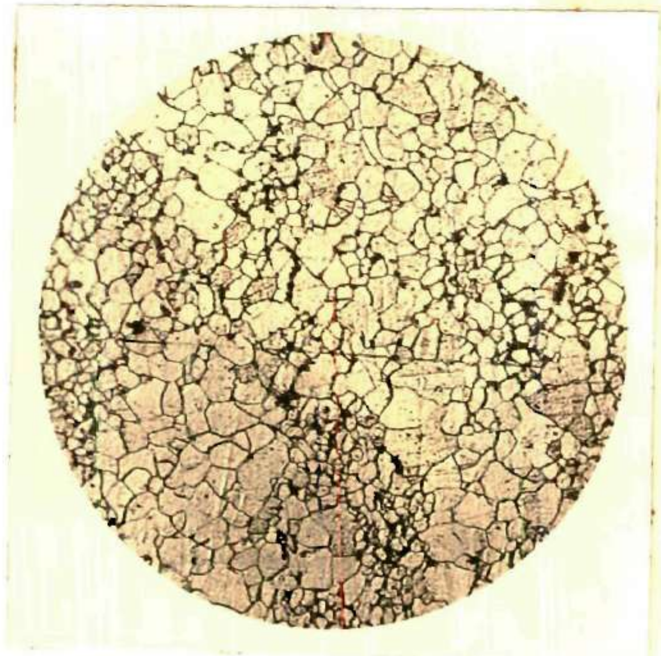


Fig. 5B Nitol Etch Fig. 5C Nitol Etch

Fig. 5A (Foregoing Page)--Base metal near the bond of welded area. This photomicrograph shows a cross-section of test bar just outside the bond between the base and deposited metal. The effect of the heat has refined the crystals. The clusters of small grains as shown in the photograph are not due to the effect of the arc heat, but was faulty rolling. This is what is known as ferrite bonding which is usually due to rolling at or near the lower point of steel.

The structure is an aggregate of ferrite, laminated pearlite, and sorbito pearlite. The dark areas at high magnification show up as laminated pearlite and sorbito pearlite.

Fig. 5B--Photomicrograph shows welded junction of a bare electrode weld on low carbon steel, non-peened.

The upper section is the welded area which is an aggregate of ferrite, nitride of iron, and sorbito pearlite. The white areas are ferrite. The black needles which may be seen in the white areas are nitrides. The dark areas are sorbito pearlite. The distorted grain structure is due to the puddling of the metal and recrystallization below the critical point.

The lower section is the junction of base metal. Structure is an aggregate of ferrite and pearlite. The fine grain structure is due to the sudden heating and cooling of the first layer of deposited metal. The dark round areas are non-metallic inclusions.

Fig. 5C--Photomicrograph shows another section of the welded area of the same specimen as that of 5A.

The upper right side section is the deposited metal. Structure is an aggregate of ferrite, nitride of iron and sorbito pearlite. The distorted grains of ferrite are no doubt due to the evolution of heat which is a sudden change of internal energy, probably resulting in internal strains in turn causing recrystallization, hence, the coincidence of the two phenomena.

The lower left section is the junction of base metal. Structure is a very fine aggregate of ferrite and pearlite.

These micro-photographs are taken from a cross-section of test bar No. 5 as shown in Table III. The high percentage of nitriding and non-metallic inclusion is responsible for its loss in physical properties.

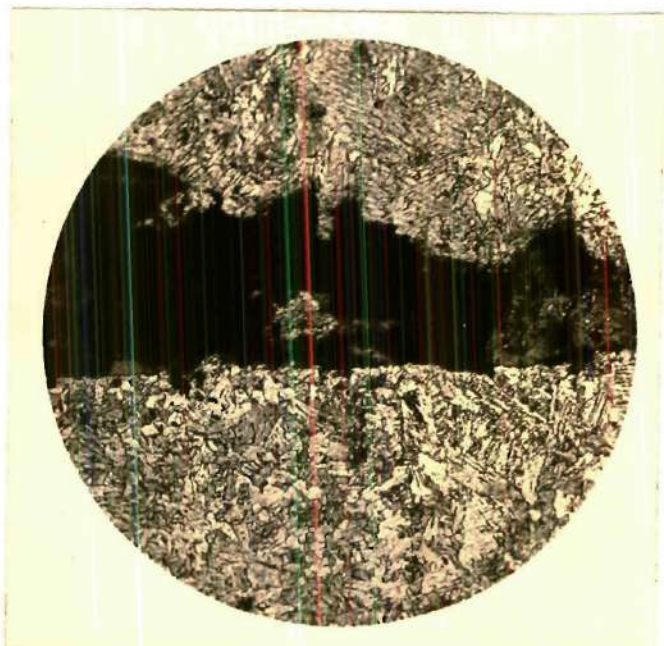


Fig. 6A--188X-----Nitol Etch

Fig. 6A--Photomicrograph shows fracture in welded area of test bar No. 6 which resulted from a tension stress. This fracture occurred in a straight line from grain to grain which indicates inter-crystalline brittleness. This is caused by the ferrite grain assuming nearly the same crystalline orientation during the cooling of the deposition of metal. Structure is an

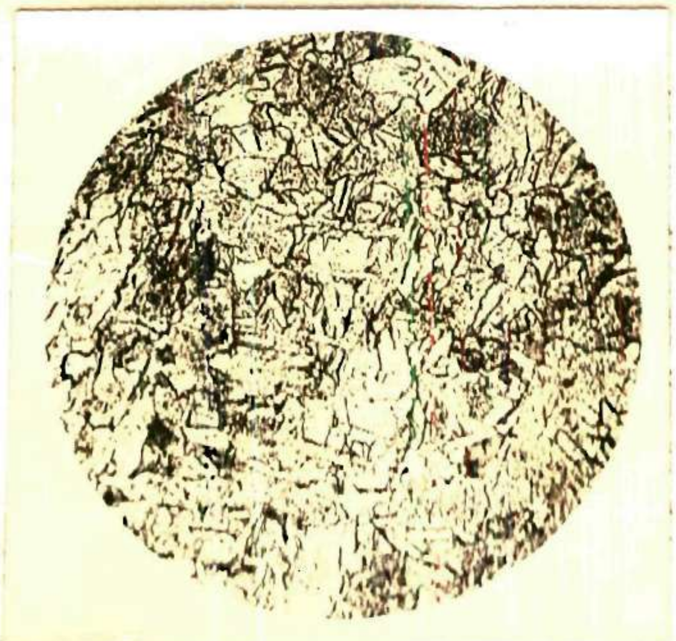


Fig. 6B

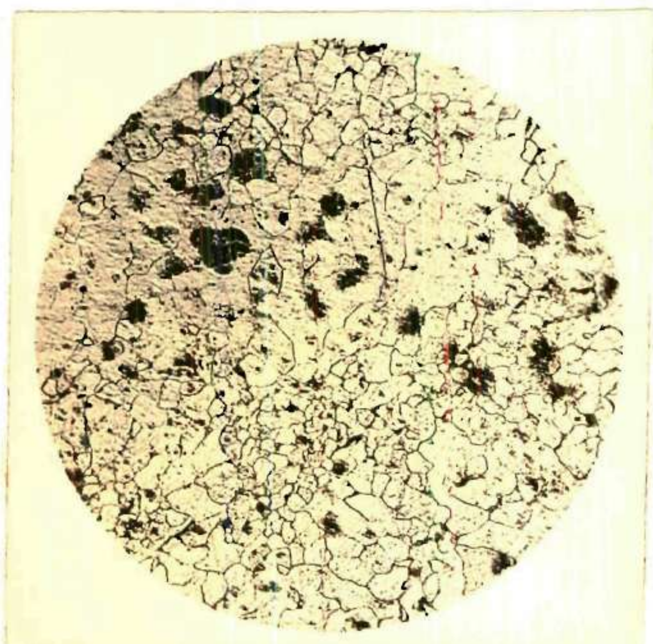


Fig. 6C

aggregate of ferrite, nitride of iron, and sorbito pearlite.

Fig. 6B--Photomicrograph shows a cross-section of the deposited metal of test bar No. 6 which was peened. Structure is a uniform constituent of ferrite, nitride of iron, and sorbito pearlite. The black needles that can be seen in the white ferrite areas are nitrides. The percentage of oxides seem to be less than in previous test bars.

Fig. 6C--Photomicrograph shows junction of base and deposited metal. Upper section is the deposited metal. Structure is a uniform aggregate of ferrite and pearlite. The little black needles seen in ferrite grain are nitrides. Lower section is the base metal. Structure is aggregate of ferrite and pearlite. The black spots are pits due to polishing although some of the small dark spots deposits are oxides.

These micro-photographs as shown indicate good physical properties which check with results as given in Table III.

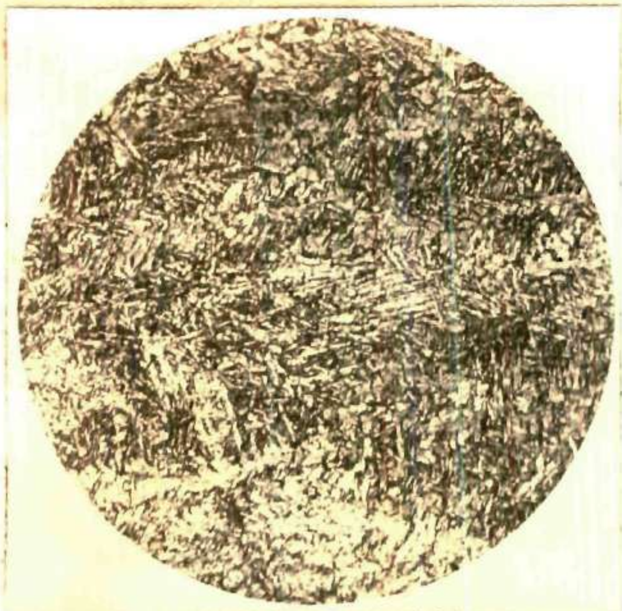


Fig. 7A--200X Nitol Etch

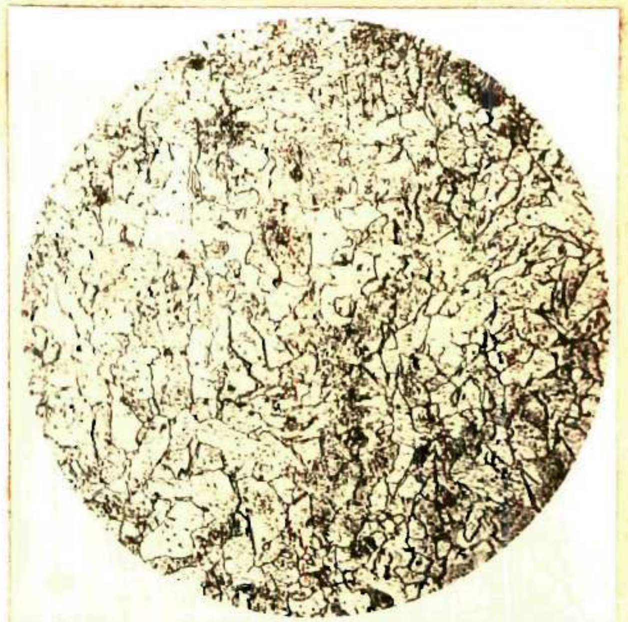


Fig. 7B--200X Nitol Etch

Fig. 7A--Photomicrograph shows outer layer cross-section of deposited metal in test bar No. 7 which was peened. Structure is an aggregate of ferrite and granulated pearlite or sorbito. There is also a eutectoid of Fe & FeN_4 present.

Fig. 7B--Photomicrograph shows the inner layers of the deposited metals near the junction of base and deposits. Structure shows a uniform aggregate of ferrite and pearlite. The white areas are ferrite and dark areas are pearlite, with the exception of the little round black spots that are seen in the white areas, which are oxides. The black needles that are seen in white areas are nitrides. These micro-photographs indicate good physical properties which check with results given in Table III.

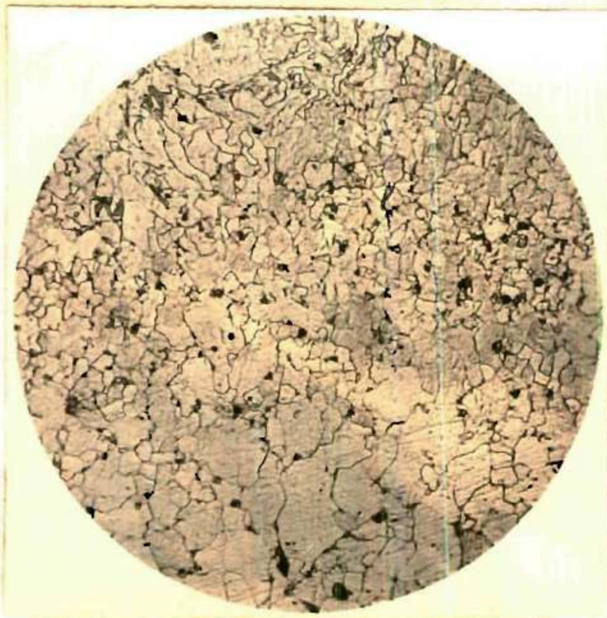


Fig. 8A--250X Nitol Etch

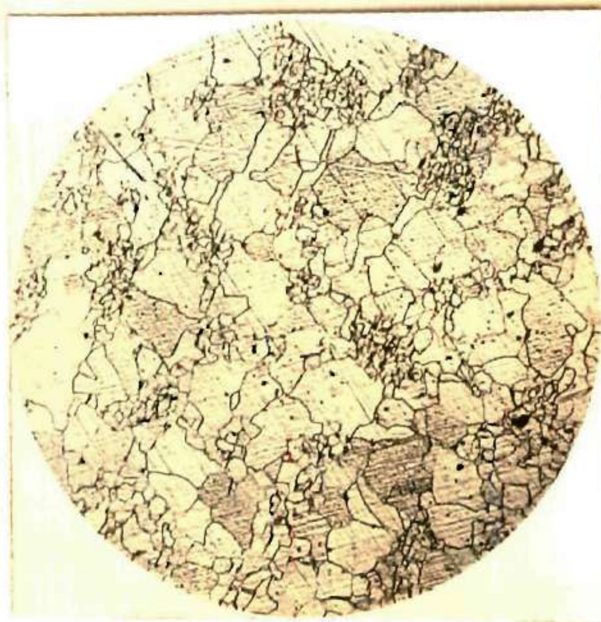


Fig. 8B--250X Nitol Etch

Fig. 8A--Photomicrograph shows a cross-section of the base metal of test bar No. 8.

Structure shows that bonding of the ferrite took place during rolling. The white areas are ferrite and dark areas are pearlite.

Fig. 8B--Photomicrograph shows a cross-section of the deposits and base metals of test bar No. 8 which was peened.

The upper section is the deposited metal. The microphotograph is a uniform structure of ferrite and pearlite. The dark pearlite-like areas are eutectoids of Fe & Fe N_4. The lower section is the base metal. The white areas are ferrite, and dark areas are pearlite.

The junction between base and deposited metal is perfect. The photograph shows that some oxidation took place, but due to its uniform distribution that did not materially affect the physical properties which may be seen in Table III.

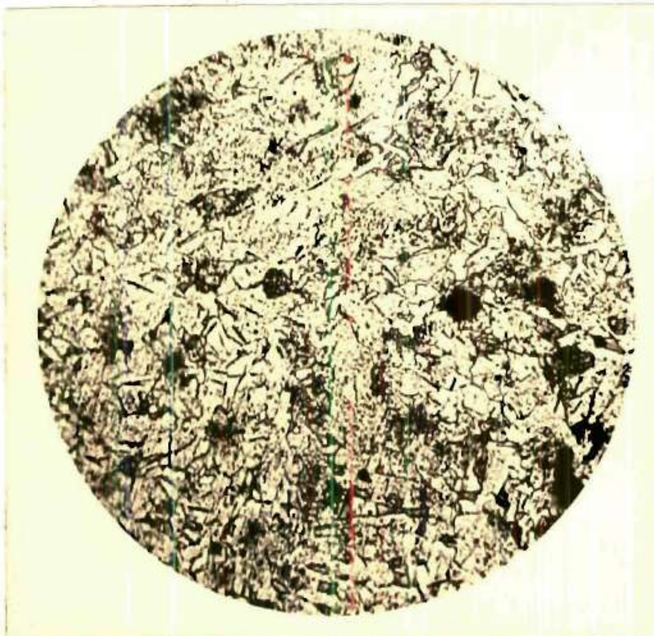


Fig. 9--150X Nital Etch

Fig. 9--This photomicrograph shows a cross-section of a welded area of a low carbon steel made with bare electrodes, and was peened.

The structure shows the outer layers which are subjected to internal strains that developed from recrystallization on cooling below critical points (Ax). This is also partly due to the inherent method of deposition of metal.

The internal strains caused the distorted grain structure, which probably results from a cold work process. The white areas are ferrite holding in solid solution nitride of iron which is shown by the presence of the black nitride needles. The dark areas are pearlite. The dark gray areas are no doubt a eutectoid of Fe & FeN_4.

This structure also shows the presence of some non-metallic inclusions which are evenly distributed. This structure would indicate loss in ductility and increase in tensile strength, which is shown in Table III. (See Test Specimen No. 9)

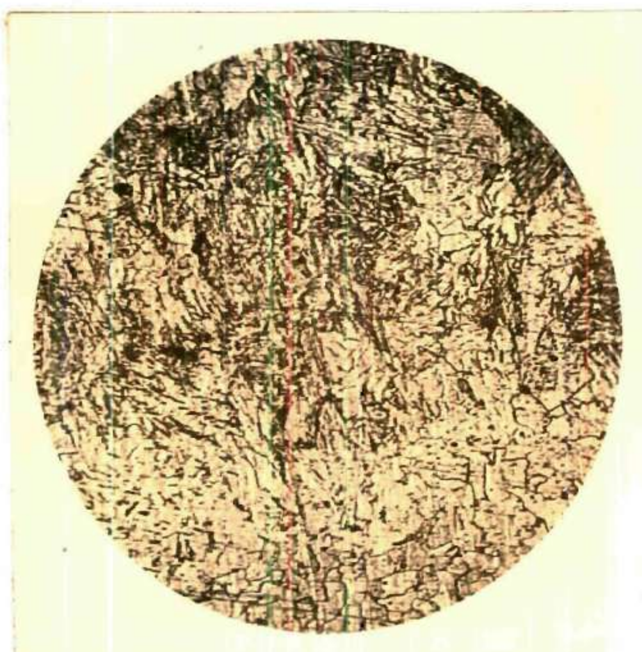


Fig. 10--200X Nitol Etch

Fig. 10--This photomicrograph shows a cross-section of a perfectly welded junction on a low carbon steel made with a bare electrode and peened.

The upper section is the deposited metal which is an aggregate of ferrite and sorbito pearlite. The non-uniform structure is the result of a strain set up during welding and tensile test made on bars. The structure also shows the presence of nitriding and some non-metallic impurities.

The lower section is the base metal. Structure is aggregate of ferrite and pearlite. This structure would indicate high tensile strength and fair ductility, which is shown in Table III. (See test specimen No. 10)

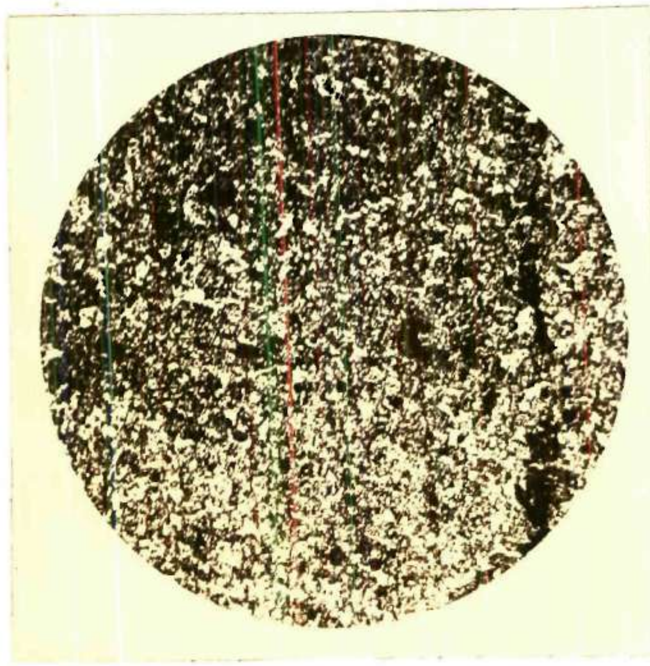


Fig. 11--200X Nitol Etch

Fig. 11--This photomicrograph shows a cross-section of deposited metal on a low carbon test bar made with Airco No. 65 light-coated electrodes non-peened.

Structure shows a granulated sorbito pearlite that has been subjected to high stresses, which would indicate high tensile strength and elastic limits with decrease in ductility. (See specimen No. 11 listed in Table III)

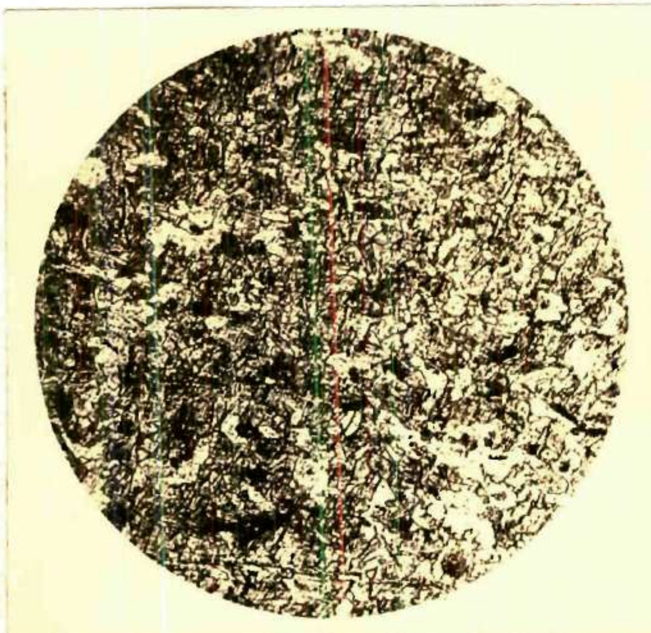


Fig. 12--150X Nitol Etch

Fig. 12--This photomicrograph shows the cross-section of a deposited metal on a low carbon steel test bar made with a light Airco No. 65 coated electrode.

Structure is an aggregate of ferrite, nitride of iron, sorbito and laminated pearlite. This structure would indicate a slight loss in tensile strength and a slight increase in ductility. (See specimen No. 12 listed in Table III)

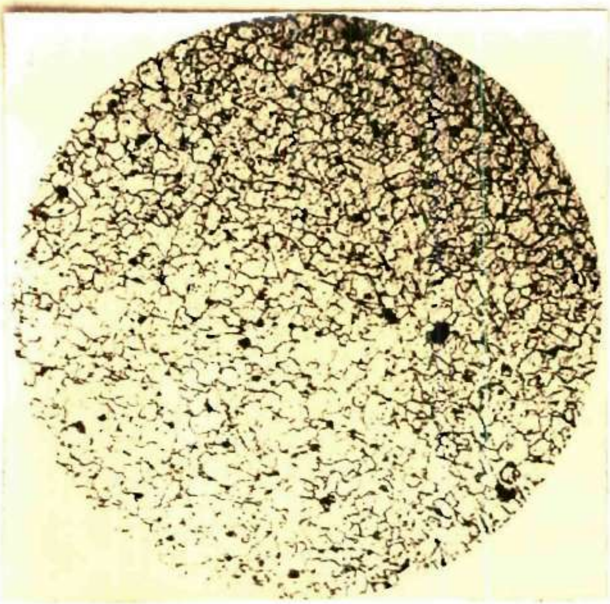


Fig. 13A--200X Nitol Etch

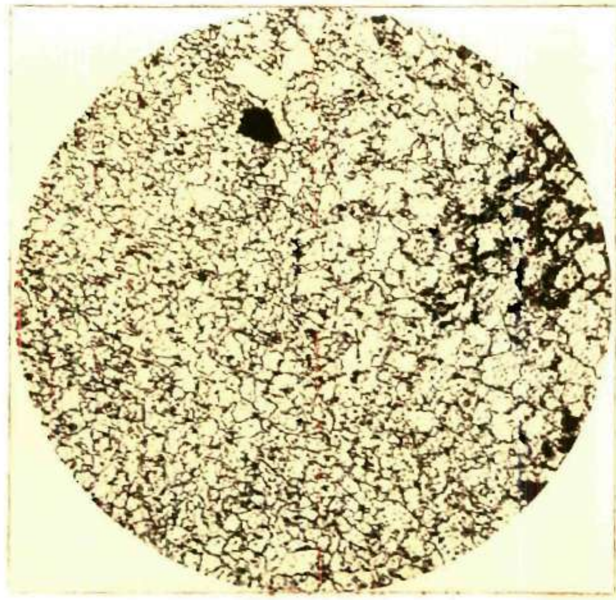
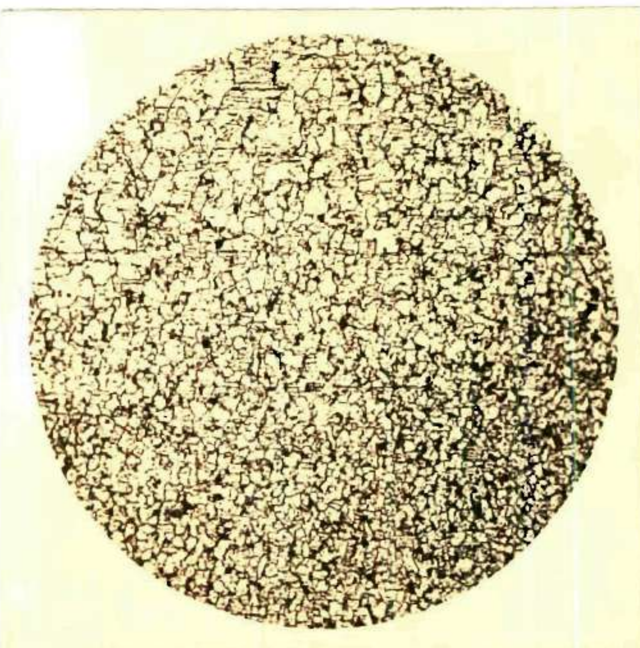


Fig. 13B--200X Nitol Etch

Fig. 13A--This photomicrograph shows a cross-section of a welded junction on a low carbon steel made with a Westinghouse Flex arc general purpose electrode, peened. The upper left side section is deposited metal. Structure is a fine aggregate of ferrite and pearlite. Also the presence of some nitriding which is shown by the little black needles that appear in the ferrite. There are also some non-metallic impurities which appear as little round dark spots in the ferrite grains. Due to the presence of the nitride of iron there is no doubt but that a eutectoid of Fe & FeN_4 present. The lower right side section is the base metal which is a fine aggregate of ferrite and pearlite. This fine structure is due to the heat treatment received from welding procedure.

Fig. 13B--This photomicrograph shows a section of weld proper of same specimen as 13A. Structure is a fine aggregate of ferrite, nitride of iron, and sorbito pearlite. These structures would indicate a high tensile strength and ductility. (See specimen 13, Table III)



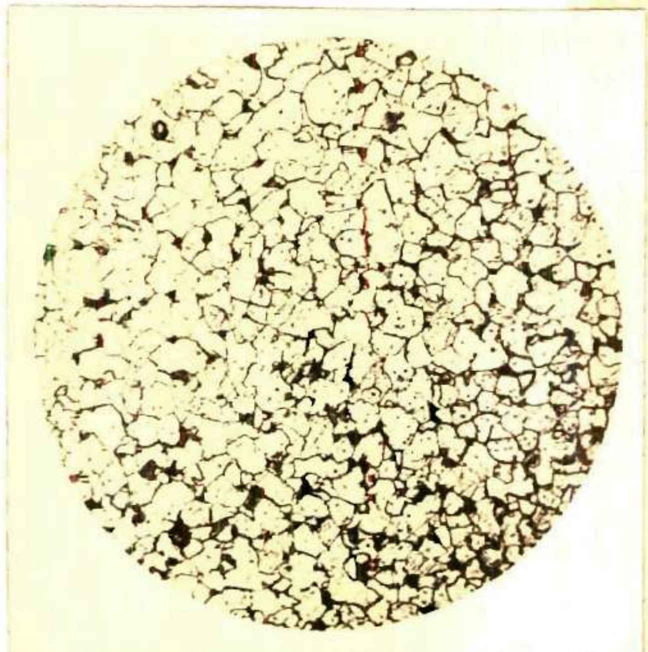


Fig. 14A--150X Nitol Etch   Fig. 14B--300X Nitol Etch

Fig. 14A--This photomicrograph shows a cross-section of a welded area made on a low carbon steel with a Westinghouse general purpose flux coated electrode.

Structure is a fine aggregate of ferrite and pearlite. There is little indication of nitriding which at high magnification reveals the black needles that appear in ferrite grains.

Fig. 14B--This photomicrograph is of the same section as that of 14A, but at a much higher magnification. The structure is also an aggregate of ferrite and pearlite. The little round dark spots as shown in the white areas are non-metallic impurities.

These structures would reveal that the weld has good physical properties. (See specimen 14, Table III)

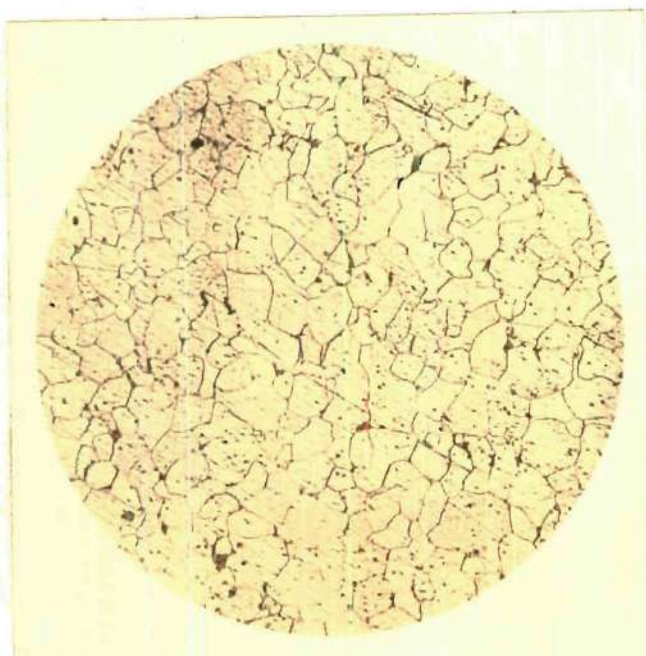


Fig. 15--200X Nitol Etch

Fig. 15--This photomicrograph shows a cross-section of the base metal near the bond of the deposited and original metal of test bar No. 15 as listed in Table No. III.

Structure is an aggregate of ferrite and pearlite. The effect of the welding heat was responsible for reduction of the crystal size of this steel. This structure relates good physical properties.

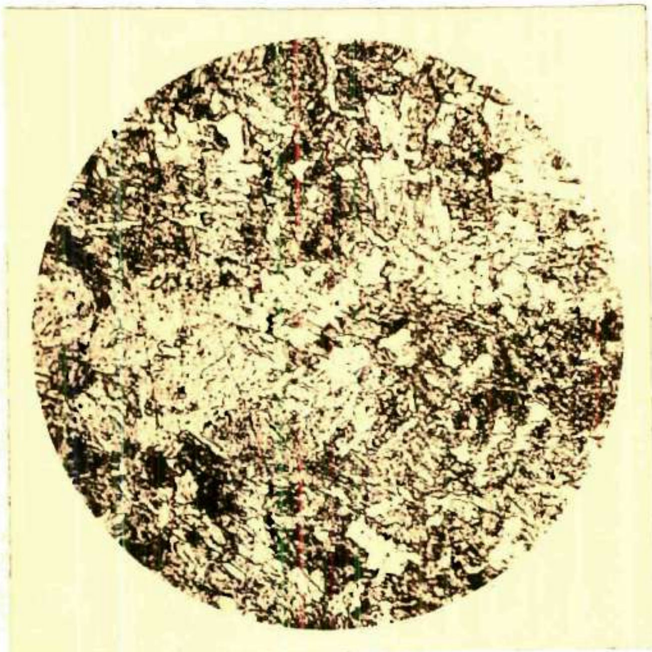


Fig. 16--200X Nitol Etch

Fig. 16--This photomicrograph was taken from a cross-section of the deposited metal on test bar No. 16 made with a bar Westinghouse flex arc electrode which was peened.

Structure is an aggregate of ferrite, FeN_4, and sorbito or granulated pearlite. This structure would indicate high tensile strength and lower ductility than that of test bar No. 15. (See specimen 15 and 16 in Table III)

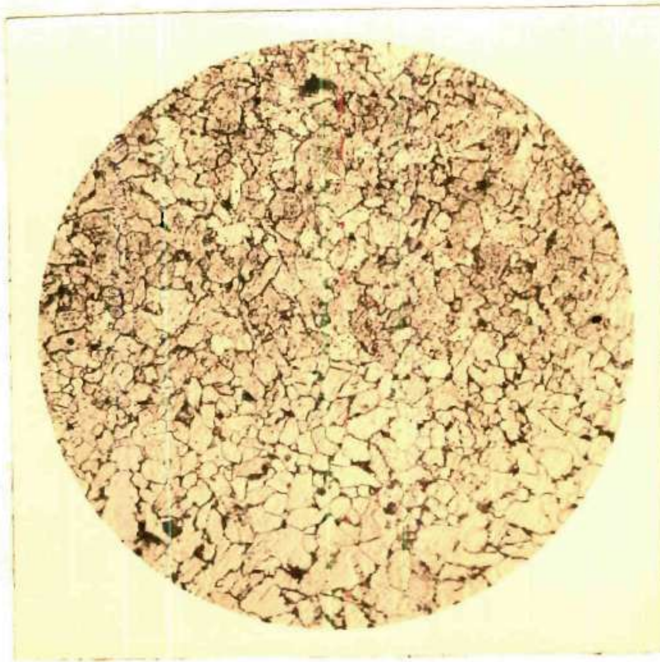


Fig. 17--150X Nitol Etch

Fig. 17--This photomicrograph is a cross-section of the deposited and base metal of test bar No. 17, peened. The upper section is the deposited metal which is a fine aggregate of ferrite and sorbito pearlite.

The lower section shows the base metal. Structure is a fine aggregate of ferrite and pearlite. Under high magnification, the white area in the welded section reveals that some nitriding took place, also some non-metallic inclusions were present. The dark areas in both sections show sorbitic or laminated pearlite. The welded junction is of very good quality showing perfect arrangement of the grains.

This structure reveals ideal physical properties. (See results of Specimen 17, Table III)

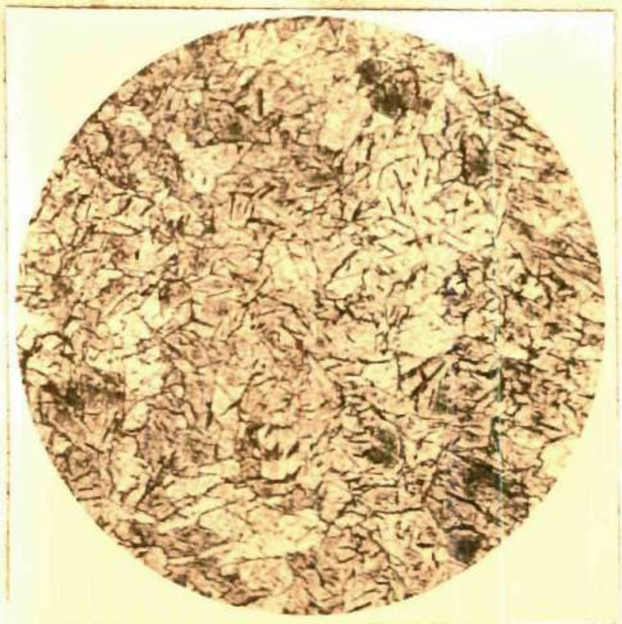


Fig. 18A--200X Nitol Etch

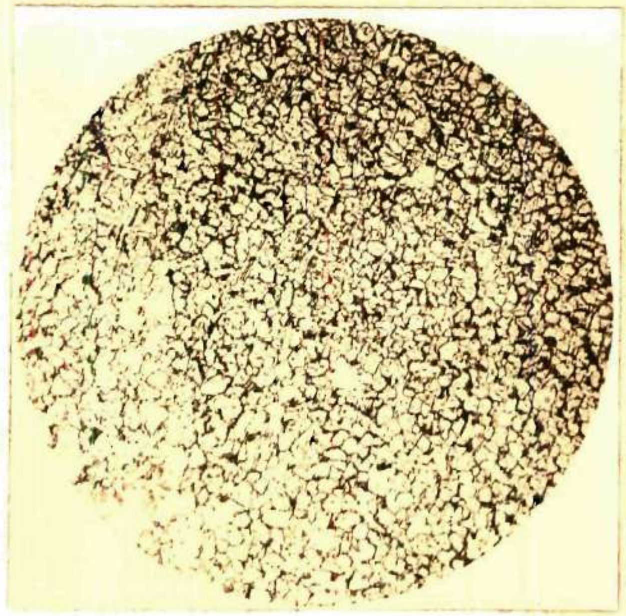


Fig. 18B--150X Nitol Etch

Fig. 18A--This photomicrograph is an outer cross-section of deposited metal of the Cresta-Murex electrode on a low carbon steel, non-peened.

Structure is a uniform aggregate of ferrite, nitride of iron, and sorbitic pearlite. In the outer layers of the welded area, nitriding took place in that nitride needles are present in ferrite grains.

Fig. 18B--This photomicrograph shows a cross-section of the welded junction or bond between base and deposited metal. This micro-photograph is of the same specimen as that of 18A.

Upper section is the welded section which is a fine structure of ferrite and sorbitic pearlite. In that nitriding took place in the outer layer of deposited metal as shown in 18A, there is no reason why nitrides should not be present in the inner layers and doubtless constitutes part of the dark pearlite-like areas which are composed of a eutectoid of Fe & FeN_4. The little dark particles are non-metallic inclusions. The lower section is the base metal which is an aggregate of ferrite and pearlite. These structures reveal good physical properties, but due to nitriding that took place, the ductility was slightly reduced as will be seen in Table III.

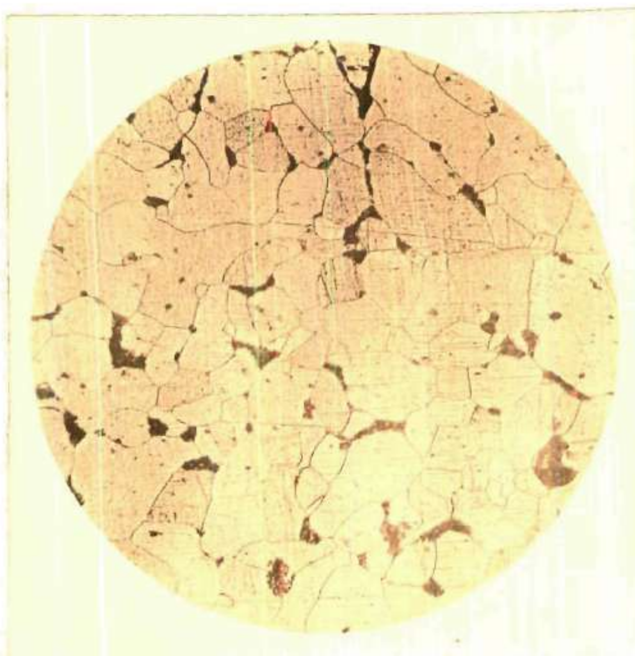


Fig. 19--150X Nitol Etch

Fig. 19--This photomicrograph shows the structure of the cross-section of test bar No. 22 made of original metal. Structure is ferrite (white areas) and pearlite (dark areas). The percentage of dark areas indicate that the steel is about 0.10--0.15 percent carbon. The structure indicates a very ductile material. (See Specimen No. 22 in Table III)

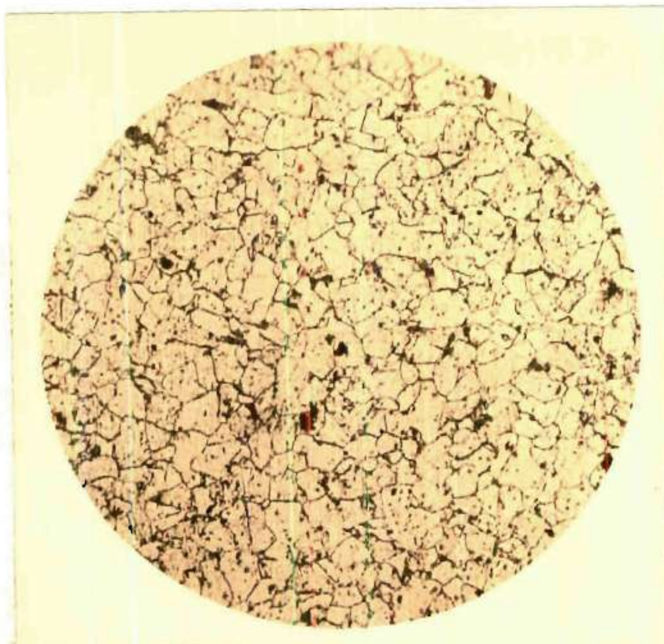
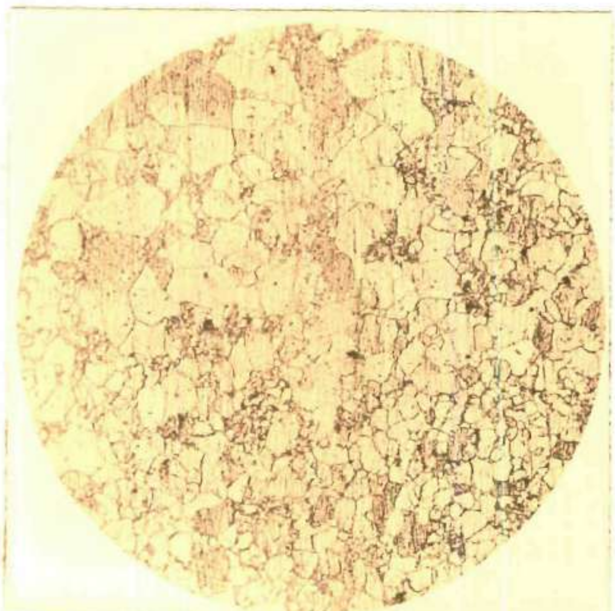


Fig. 20--200X Nitol Etch

Fig. 20--This photomicrograph shows the structure of the deposited metal at the bond on a low carbon steel. The weld was made with Lincoln Fleetweld electrodes on test Specimen No. 23, non-peened.

Structure is a uniform aggregate of ferrite and pearlite. The dark areas that have a tendency to follow the grain boundaries are pearlite. The dark spots that appear in ferrite (white areas) are non-metallic impurities.

This structure indicates a high tensile strength but due to uniformly distributed impurities the ductility is slightly decreased. (See Specimen 23, Table III)



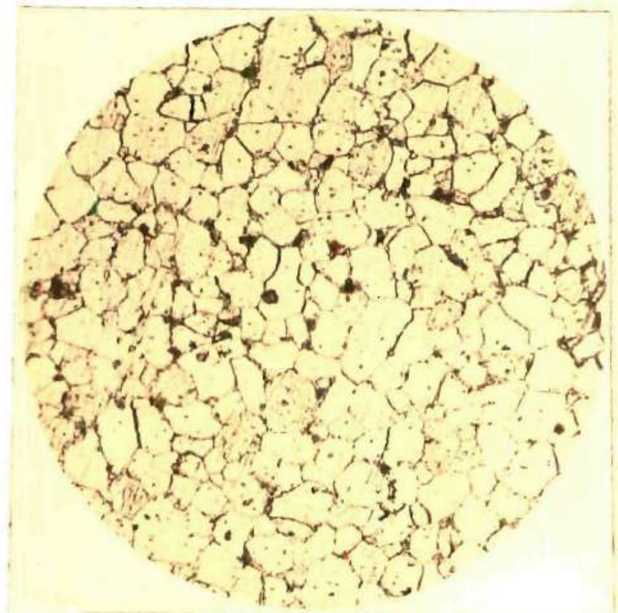


Fig. 21A--150X Nitol Etch

Fig. 21B--300X Nitol Etch

Fig. 21A.--This photomicrograph shows the cross-section of the base metal in test bar 24. Structure is a non-uniform aggregate of ferrite and pearlite. White areas are ferrite and dark areas are pearlite. The small grain clusters are due to bonding resulting from rolling at improper temperature.

Fig. 21B--This photomicrograph shows a cross-section of the deposited metal of Lincoln Fleetweld electrode on a low carbon steel.

Structure is a uniform aggregate of ferrite and pearlite. White areas are ferrite ans some presence of nitride of iron, and dark areas that follow the grain boundaries are pearlite. The little dark spots in the ferrite grains are non-metallic impurities that occurred during the welding.

While welding test bar No. 24, each deposited layer was peened and cleaned. Structure relates why physical properties were as shown in Table III.

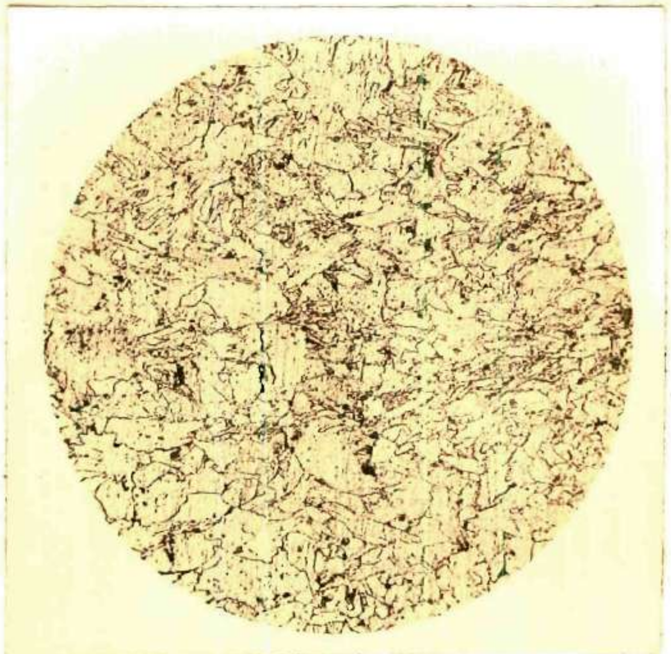


Fig. 22--150X Nitol etch

Fig. 22--This photomicrograph shows outside cross-section of welded area made with Lincoln Fleetweld electrodes on low carbon steel.

The structure is an aggregate of ferrite and pearlite, holding in solid solution some impurities such as iron nitrides and iron oxides. The nitrides are shown in the ferrite grains as black needles. Also in the form of a eutectoid of Fe & FeN_4 which is shown as a dark pearlitic substance. The iron oxides are present in the form of dark, round spots.

The distorted grain structure is due to two things:

(1) Peening below the (Ax) transformation point.

(2) Heat evolution, causing recrystallization.

The deformation resulting from cold working (Fig. 22) has caused an orientation of the ferrite and pearlite particles to be elongated in a non-uniform direction, but it will be noticed that the ferrite areas remain structureless, and indicates that it has the same crystalline orientation throughout.

The evolution of heat observed at the (Ax) temperature necessarily indicates a sudden change of internal energy which probably results from a relief of internal strains, this relief, in turn, causing recrystallization, hence the coincidence of the two phenomena. Bearing in mind that the more severe the cold working, the lower the temperature of recrystallization, it should be expected that after severe deformation of the (Ax) point will occur at a lower temperature. V. N. Krivobok[2] has found the above results to be true from his investigation on samples of hypo-eutectoid steels and Armco iron while cold worked and then heated, the evolution of heat being observed in the vicinity of 650 degrees C.

(2) Reference. Sauveur: Metallography and Heat Treating of Iron and Steel. Chapter XVII

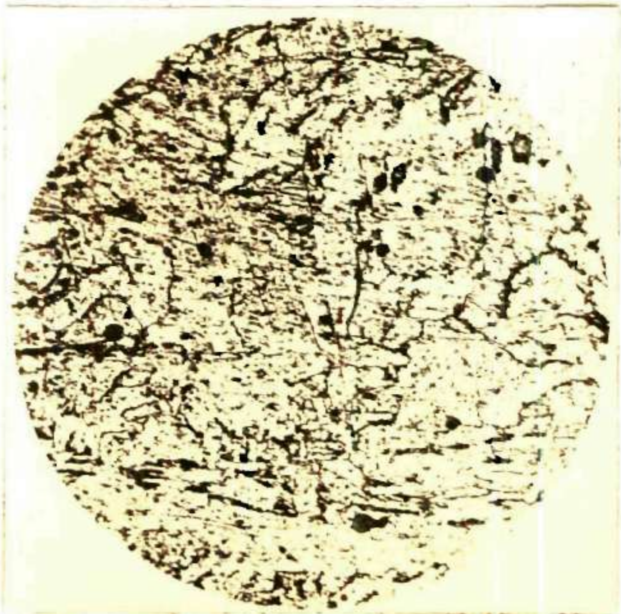


Fig. 23A--200X Nitol Etch

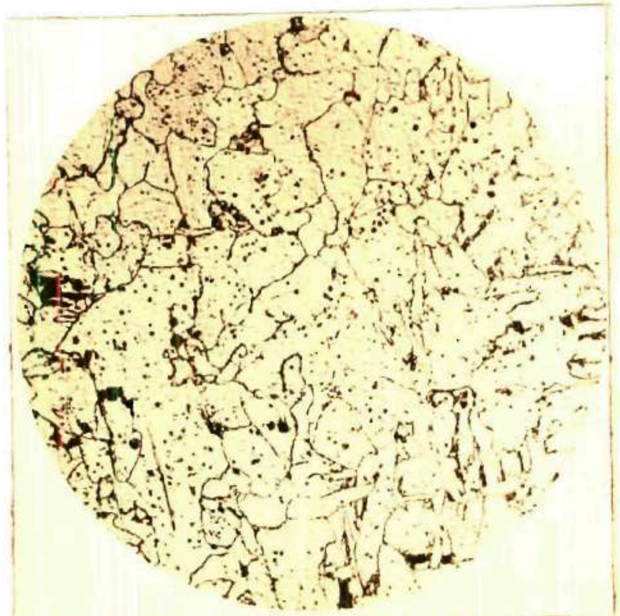


Fig. 23B--200X Nitol Etch

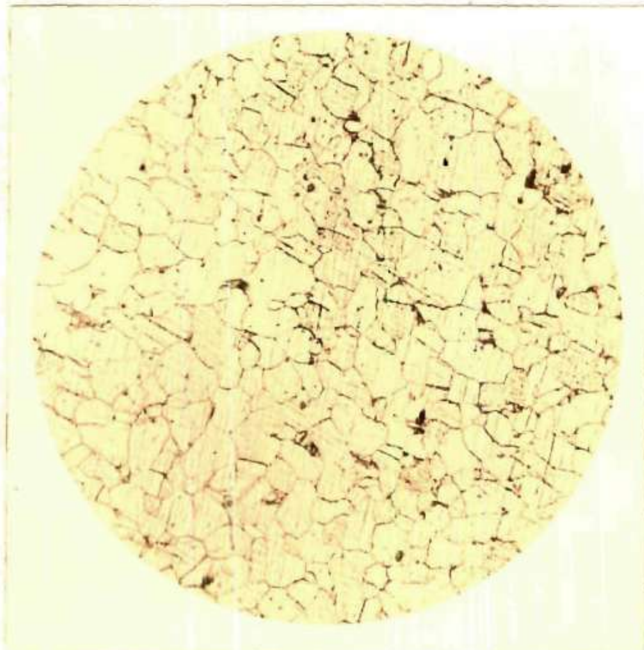


Fig. 23C--200X Nitol Etch

Fig. 23A--The photomicrograph shows a cross-section of outside layer of Fleetweld electrode deposited metal, non-peened.

Structure is an aggregate of ferrite and pearlite. The pearlite has a tendency to segregate at grain boundaries. The dark round spots are non-metallic inclusions. There is also evidence of nitriding.

The non-uniform distribution of the aggregate is due to the inherent method of deposition. That is, the metal from the cathode melts and the cathode globules thus formed fall to the anode puddle or crater. The freezing of this molten crater in the wake of the arc ionic bombardment of globules of metal constitute the welding process.

The generated heat-energy is suddenly released through radiation. When the weld is built up in layers as in arc-welding, the conduction of heat in the inner layers is retarded, giving it an annealing effect, but radiation of the outer layer is very rapid, which in turn sets up an internal strain during the recrystallization that takes place below the Ax point. This strain is responsible for the distorted grains as shown in the photograph.

Fig. 23B--This photomicrograph shows cross-section of the deposited metal next to the outer layers of the same as specimen 23A.

Structure is an aggregate of ferrite (white areas) and pearlite (dark areas) as may be seen following grain boundaries. The little round black spots as shown in the white areas are slag inclusions. There is also some evidence of nitriding.

This structure shows a distorted grain structure which is due to sudden evolution of heat and recrystallization that has taken place below the Ax point.

Fig. 23C--This photomicrograph shows cross-section of center layers in same specimen as stated above. The structure is a fine grain formation of ferrite (white areas) and the pearlite (dark areas) following the grain boundaries. This uniform structure is due to the annealing process received from the conducted heat from deposited metal.

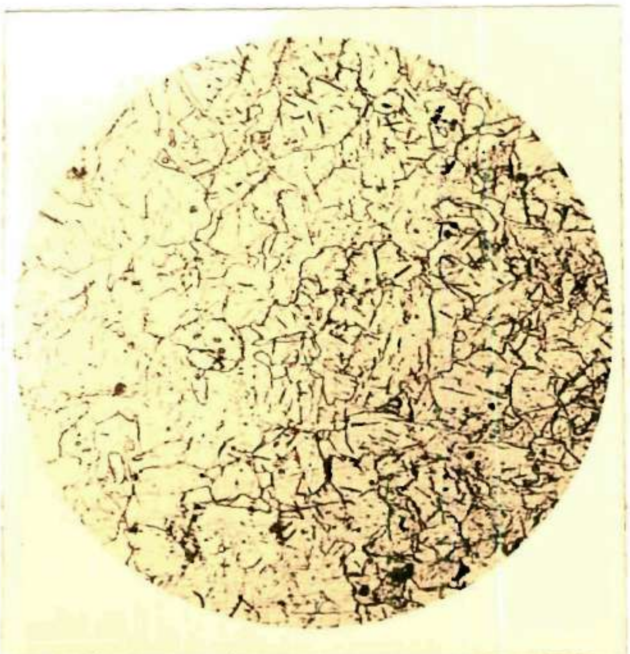


Fig. 24A--200X Nitol Etch

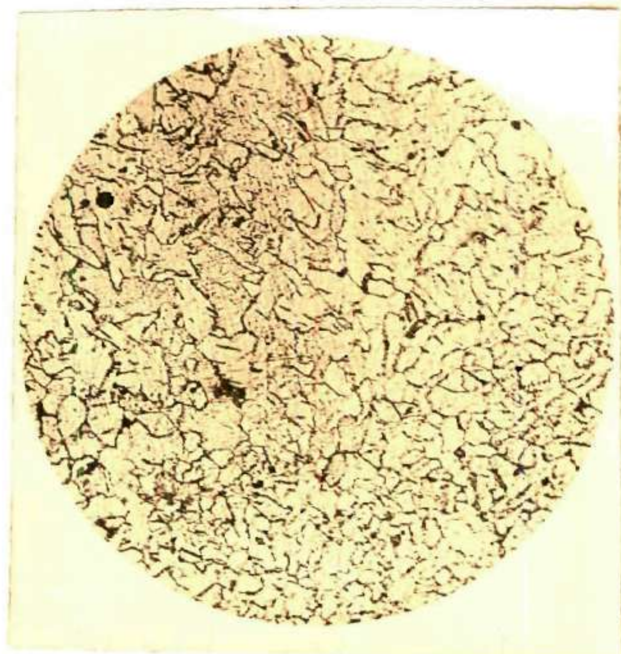


Fig. 24B--200X Nitol Etch

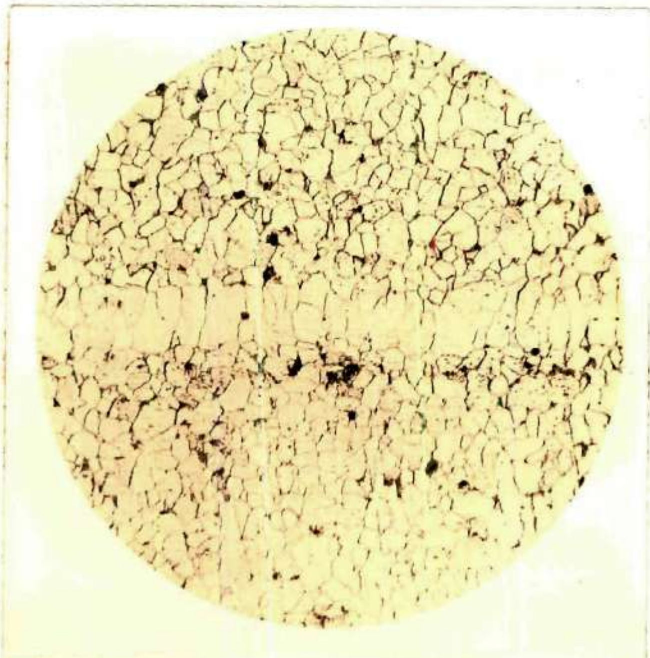


Fig. 24C--200X Nitol Etch

Fig. 24A--This photomicrograph shows a cross-section of weld made with Cresta Murex electrodes near the outside surface of peened weld. Structure is an aggregate of ferrite and traces of pearlite at grain boundaries. The little black needles as may be seen in the ferrite (white areas) are nitrides.

Fig. 24B--This photomicrograph shows a cross-section of the bond between the base and deposited metals of the same as that of Specimen 24A. The upper section is the deposited metal which is a fine grain structure of ferrite and pearlite. The dark pearlite-like areas are no doubt a eutectoid of Fe & FeN_4 in that nitriding took place in the outer section as shown in Fig. 24A.

The lower section is a fine aggregate of ferrite (white areas) and pearlite (dark areas).

Fig. 24C--This photomicrograph shows a cross-section of the base metal near the bond of weld. Its fine structure of ferrite (white areas) and pearlite (dark areas) are due to annealing treatment received from the heat conduction of the deposited metal causing recrystallization to take place. The large white bands of ferrite as shown in center of photograph are caused by recrystallization due to evolution of heat below the Ax point.

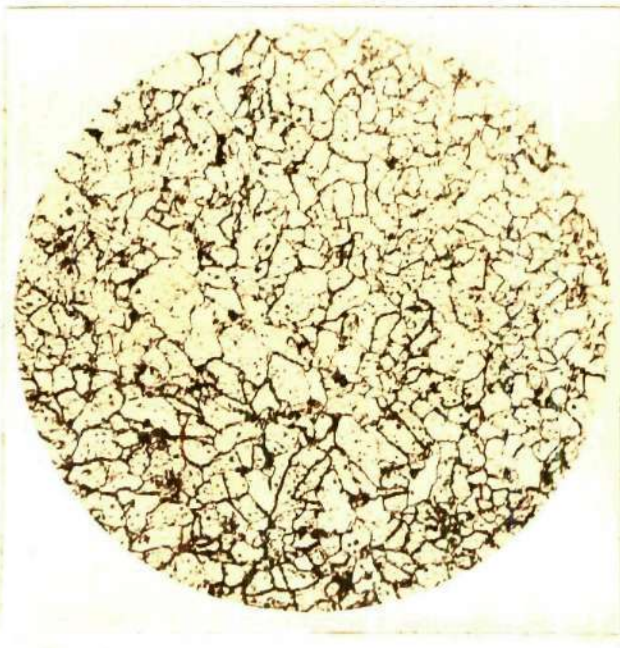


Fig. 25A--200X Nitol Etch

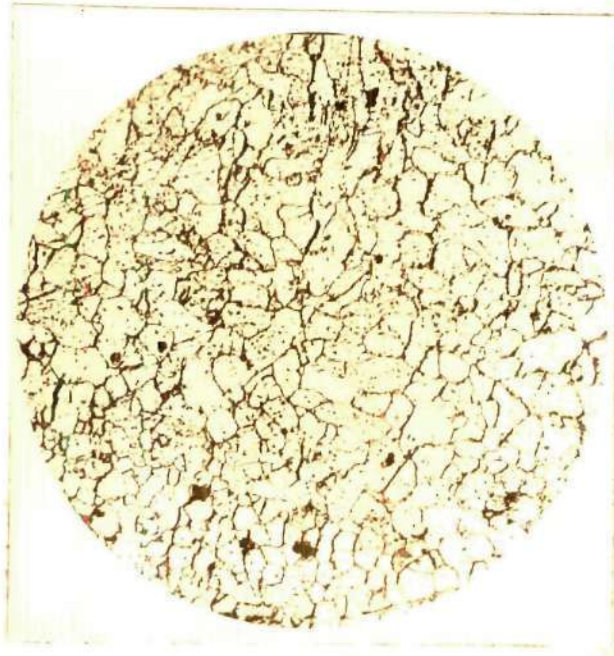


Fig. 25B--200X Nitol Etch

Fig. 25A--This photomicrograph shows a cross-section of weld made with Cresta Murex electrodes, non-peened.

Structure is a coarse grain aggregate of ferrite with traces of pearlite following the grain boundaries. This photograph was taken near the outer section of the weld.

Fig. 25B--This photomicrograph shows cross-section of deposited and base metal which is a coarse grain structure of ferrite and traces of pearlite. The lower section is the base metal which is a finer structure of ferrite and pearlite.

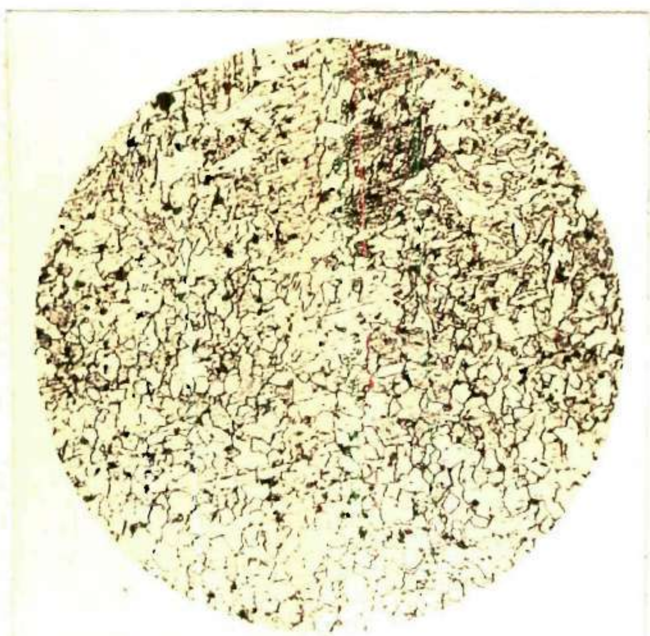


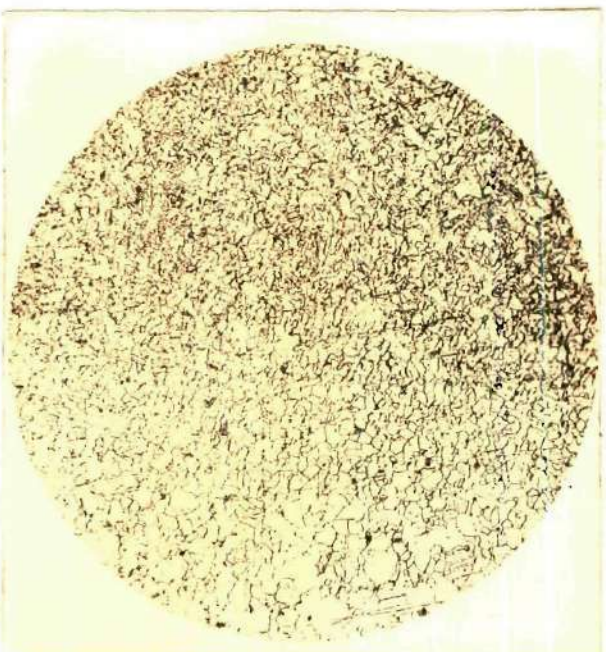
Fig. 26--200X Nitol Etch

Fig. 26--This photomicrograph shows a cross-section of a weld made with a bare electrode and peened. The upper section

shows the effect of peening and recrystallization due to evolution of heat as has been stated and explained in previous photomicrograph.

The lower section is a finer structure which was due to heat treatment received from the outside deposition.

The structure is an aggregate of ferrite grains (white) and traces of pearlite (dark) as shown at grain boundaries. The dark round spots are non-metallic inclusions, and the little dark needles as seen in the ferrite grains are nitrides.



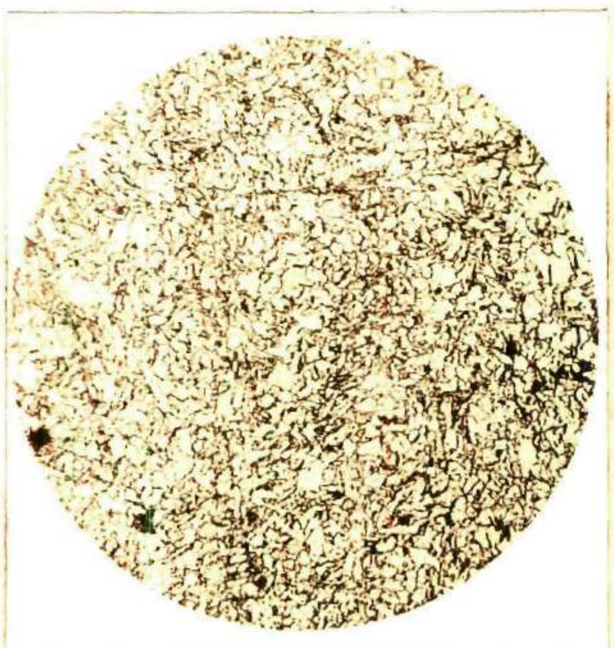


Fig. 27A--150X Nitol Etch

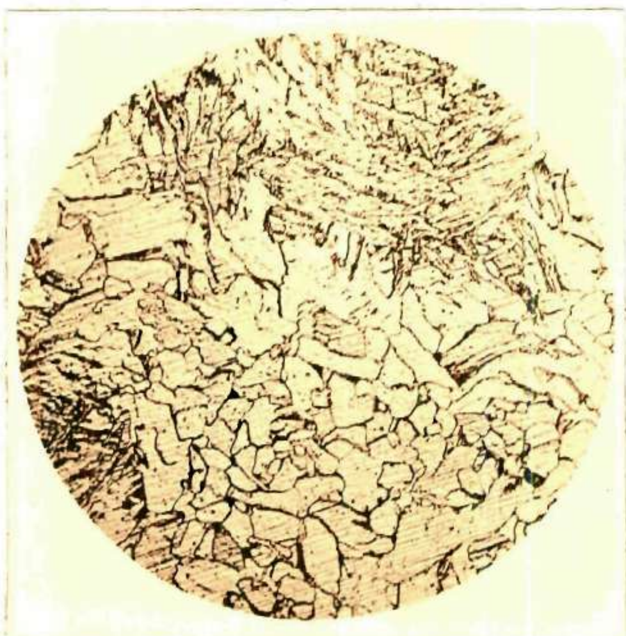
Fig. 27B--[illegible] Nitol Etch

Fig. 27A--This photomicrograph shows the bond between deposited and base metal of a weld made with bare electrode, non-peened.

The upper section is the deposited metal which is a fine aggregate of ferrite (white areas) with the presence of nitrides and sorbito pearlite (dark areas).

The lower section is the base metal which is a uniform structure of ferrite and pearlite.

Fig. 27B--This photomicrograph shows a section of the deposited metal like that of Specimen 27A. The structure is a fine aggregate of ferrite (white areas) and the presence of nitrides and sorbito pearlite (dark areas).



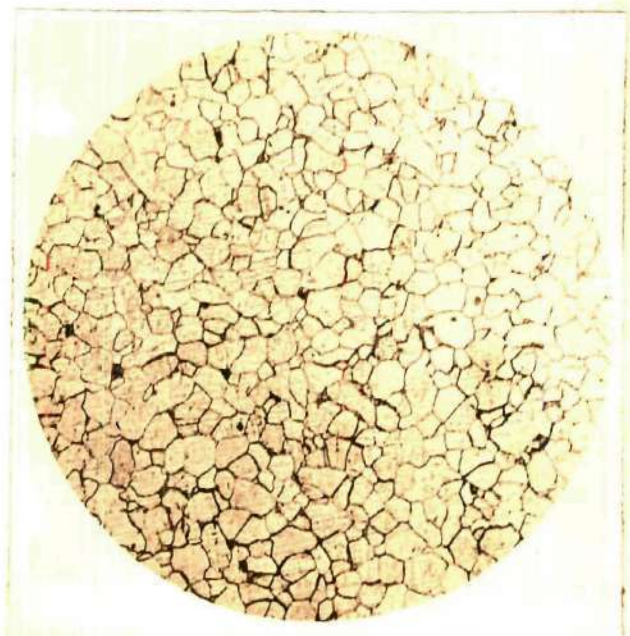


Fig. 28A--200X Nitol Etch

Fig. 28B--200X Nitol Etch

Fig. 28A--This photomicrograph shows the outside deposited metal on a weld made with a Westinghouse general purpose electrode, non-peened.

Structure is a coarse, distorted grain aggregate of ferrite (white areas) with traces of nitrides and traces of pearlite (dark areas) at grain boundaries. The black round particles are non-metallic inclusions. The distorted grain structure is due to the recrystallization of grain structure as previously explained in Fig. 23A.

Fig. 28B--This photomicrograph shows a cross-section of inner deposited layers of metal of same specimen as 28A.

The photograph shows a uniform structure of ferrite (white areas) and traces of pearlite (dark areas) at grain boundaries.

TABLE NO. I

Berry Strain Gage Readings

Spec. No.	Welding Procedure	Side	Point 1	Point 2	Point 3	Point 4	Ave.
1	Cross and Horizontal Weave, Non-Peened	A_o	-0	-32	-26	-27	-21.5
		A_h	42	79	72	73	61.5
							40.0
		A_c	20	52	48	55	43.7
							22.2
		B_o	-1	-8	-14	-5	7
		B_h	41	55	61	41	49.5
							42.5
		B_c	20	25	34	23	25.50
							19.50
2	Cross and Horizontal Weave, Non-Peened	A_o	-0	-4	-9	-21	8.5
		A_h	31	45	49	59	46
							37.5
		A_c	21	32	34	35	30.5
							22.0
		B_o	-11	-31	-30	-16	22
		B_h	41	70	74	58	60.75
							38.75
		B_c	30	51	50	35	41.50
							19.50
3	Cross and Horizontal Weave, Non-Peened	A_o	37	47	43	54	45.20
		A_h	77	89	82	94	85.50
							40.30
		A_c	57	64	61	72	63.50
							18.30
		B_o	24	0	20	26	17.5
		B_h	64	34	59	55	53.0
							35.5
		B_c	40	18	41	50	37.23
							20.25

TABLE NO. I (Cont'd)

Spec. No.	Welding Procedure	Side	Point 1	Point 2	Point 3	Point 4	Ave.
4	Vertical Layer Weave, Non-Peened	A_o	-46	-76	-78	-8	-52
		A_h	76	116	104	45	85.25 / 33.25
		A_c	67	103	88	29	71.75 / 19.75
		B_o	-56	-0	-54	-66	-44
		B_h	95	41	92	105	83.25 / 39.25
		B_c	76	22	72	88	62 / 18
5	Vertical Layer Weave, Non-Peened	A_o	-48	-48	-61	-0	-39.25
		A_h	90	91	102	40	81.25 / 42.00
		A_c	69	78	81	18	60 / 20.75
		B_o	-27	-32	-34	-33	-31.50
		B_h	65	70	73	69	69.25 / 37.75
		B_c	50	47	50	53	50 / 18.50
6	Cross and Horizontal Weave, Peened using 50-lb air press on hammer	A_o	-21	-0	-40	-45	-26.50
		A_h	44	25	64	66	49.75 / 23.25
		A_c	40	18	55	60	43.25 / 16.75
		B_o	-40	-24	-5	-45	-28.25
		B_h	58	54	32	65	52.25 / 24.00
		B_c	55	49	23	60	46.75 / 18.50

Average surface temperature while peening, Specimen 6: Side A 450° F; Side B 465° F. Temperature recorded before and after peening each layer.

TABLE NO. I (Cont'd)

Spec. No.	Welding Procedure	Side	Point 1	Point 2	Point 3	Point 4	Ave.
7	Cross and Horizontal	A_o	-40	-6	-96	-60	-50.5
	Weave,	A_h	60	29	116	79	71
	Peened						20.50
	Using 70-lb air	A_c	54	23	110	74	65.25
	Pressure						14.75
		B_o	-55	-45	-0	-42	35.5
		B_h	64	69	26	70	59.5
							24.0
		B_c	62	54	16	55	41.75
							6.25
8	Cross and Horizontal	A_o	-40	-35	-44	-88	51.75
	Weave,	A_h	60	50	59	100	64.75
	Peened, Us-ing 50-lb						13.00
	Air Pressure	A_c	48	47	50	93	59.50
							7.75
		B_o	-0	-20	-44	-41	-26.25
		B_h	25	48	70	70	53.25
							27.00
		B_c	13	32	53	54	38.00
							12.75

Average surface temperature while peening Specimens 7 and 8:

Sides A 450° F; Sides B 425° F.

TABLE NO. I (Cont'd)

Spec. No.	Welding Procedure	Side	Point 1	Point 2	Point 3	Point 4	Ave.
9	Vertical Layer Peened Using 70-lb air Pressure	A_o	-35	-45	-5	-85	-42.5
		A_h	57	60	31	112	65 / 22.5
		A_c	47	53	16	97	53.25 / 11.75
		B_o	-94	-94	-48	-48	-71
		B_h	113	113	68	73	91.75 / 20.75
		B_c	108	110	60	63	78.50 / 7.50

Average surface temperature while peening:

Side A, 425^{0}F; Sides B, 432^{0}F.

Spec. No.	Welding Procedure	Side	Point 1	Point 2	Point 3	Point 4	Ave.
10	Vertical Layer Weave Peened Using 70-lb air Pressure	A_o	-42	-50	-78	-91	65.25
		A_h	64	74	100	114	92.25 / 27
		A_c	54	64	90	100	77 / 11.75
		B_o	-54	-50	-13	-18	33.75
		B_h	80	74	34	46	58.50 / 24.75
		B_c	66	62	23	31	45.50 / 12.75

Average surface temperature while peening:

Side A, 400^{0}F; Side B, 425^{0}F.

All temperature readings were recorded before and after each layer was peened.

TABLE NO. I (Cont'd)

Spec. No.	Welding Procedure	Side	Point 1	Point 2	Point 3	Point 4	Ave.
11	Cross and Horizontal Weave, Non-Peened	A_o	-5	-75	-56	-55	-47.75
		A_h	31	99	85	84	74.50
							26.75
		A_c	20	87	73	73	63
							15.25
		B_o	-46	-46	-5	-46	-35.75
		B_h	70	70	35	46	55.25
							19.50
		B_c	57	.57	21	46	45.5
							9.75

Average surface temperature while peening:

Side A, 400°F; Side B, 450°F.

Spec. No.	Welding Procedure	Side	Point 1	Point 2	Point 3	Point 4	Ave.
12	Cross and Horizontal Weave Peened, Using 70-lb air Pressure	A_o	-71	-0	-70	-35	-56.50
		A_h	90	17	91	105	75.5
							19.00
		A_c	82	13	86	100	67.75
							11.25
		B_o	-14	-41	-56	-70	-45.25
		B_h	29	62	74	82	61.75
							16.50
		B_c	22	43	68	76	52.25
							7.00

Specimens No. 11 and 12 were made with air reduction sails No. 65 light-coated electrodes.

TABLE NO. I (Cont'd)

Spec. No.	Welding Procedure	Side	Point 1	Point 2	Point 3	Point 4	Ave.
13	Cross and Horizontal	A_o	-46	-23	-15	-15	24.75
	Weave Peened,	A_h	65	47	40	46	49.50 / 24.75
	Using 70-lb air Pressure	A_c	51	46	28	36	40 / 15.25
		B_o	-15	-0	-70	-70	38.75
		B_h	50	40	108	102	75.00 / 36.25
		B_c	30	18	86	83	54.25 / 16.50

Average surface temperature while peening:

Side A, 420°F; Side B, 430°F.

Spec. No.	Welding Procedure	Side	Point 1	Point 2	Point 3	Point 4	Ave.
14	Cross and Horizontal	A_o	-78	-76	-90	-26	-67.50
	Weave Non-Peened	A_h	119	118	135	70	110.00 / 42.50
		A_c	96	95	114	48	88 / 20.50
		B_o	-72	-43	-78	-28	-55.25
		B_h	108	80	116	75	94.50 / 39.25
		B_c	90	62	92	48	73.00 / 18.25

These welds were made with 5/32" Westinghouse heavily Flex-arc general purpose electrode, using 130 amperes and about 25 volts.

TABLE NO. I (Cont'd)

Spec. No.	Welding Procedure	Side	Point 1	Point 2	Point 3	Point 4	Ave.
15	Cross and Horizontal	A_o	-48	-62	-21	-50	-45.25
	Weave Non-Peened	A_h	77	96	48	66	72. 26.75
		A_c	66	83	35	50	58.50 13.25
		B_o	-40	-33	-45	-14	-35
		B_h	65	57	69	36	58 23
		B_c	50	62	60	25	49.25 14.25
16	Cross and Horizontal	A_o	-70	-56	-18	-56	-50
	Weave Peened Using	A_h	94	77	53	80	71 21
	70-lb air Pressure	A_c	80	66	34	65	61.25 11.25
		B_o	-50	-60	-36	-21	-41.75
		B_h	74	78	48	42	60.50 18.75
		B_c	58	65	48	31	50.25 8.75

Average surface temperature while peening Specimen 16:

Side A, 326^{0}F; Side B, 350^{0}F.

T A B L E N O. I (Cont'd)

Spec. No.	Welding Procedure	Side	Point 1	Point 2	Point 3	Point 4	Ave.
17	Cross and Horizontal Weave, Peened Using 70-lb air Pressure	A_o	-70	-63	-70	-35	-59.50
		A_h	94	84	94	60	83 18.50
		A_c	82	76	80	41	69.75 10.25
		B_o	-74	-24	-20	-57	-43.75
		B_h	98	51	46	83	69.50 26.00
		B_c	83	34	30	64	52.75 9.00

Average surface temperature at which peening was done:

Side A, 400°F; Side B, 425°F.

Temperature was recorded before and after peening each layer.

Spec. No.	Welding Procedure	Side	Point 1	Point 2	Point 3	Point 4	Ave.
18	Cross and Horizontal Weave, Non-Peened	A_o	-41	-66	-84	-87	-69.50
		A_h	90	110	125	130	113.50 44.00
		A_c	66	84	94	107	87.25 17.75
		B_o	-54	-12	-66	-64	-49
		B_h	95	44	94	98	82.75 33.75
		B_c	89	25	71	93	69.50 20.50

Specimens No. 17 and 18 were made with 3/16" Murex-Cresta coated electrodes.

T A B L E NO. I (Cont'd)

Spec. No.	Welding Procedure	Side	Point 1	Point 2	Point 3	Point 4	Ave.
19	Cross and Horizontal	A_o	-86	-65	-60	-57	-67
	Weave Peened,	A_h	115	93	86	85	94.50
	Using 70-lb air Pressure	A_c	90	79	71	71	77.75
							10.75
		B_o	-44	-46	-60	-15	-41.25
		B_h	71	72	81	41	66.25
							25.00
		B_c	58	60	69	27	53.50
							12.25

Average surface temperature while peening:

Side A, 390°F; Side B, 450°F.

Spec. No.	Welding Procedure	Side	Point 1	Point 2	Point 3	Point 4	Ave.
23	Cross and Horizontal	A_o	-0	-10	-15	-20	-11.25
	Weave Non-Peened	A_h	48	54	56	63	55.25
							44.00
		A_c	23	33	35	38	32.25
							21.00
		B_o	-5	-0	-0	-10	-3.75
		B_h	53	45	42	57	49.25
							45.50
		B_c	22	19	20	35	24.00
							21.75

Specimens No. 19 and 23 were welded with 5/32" Lincoln Fleetweld electrodes, using 130 amperes and about 25 volts.

TABLE NO. II

ACTUAL TEST BAR DATA AS TAKEN ON PART OF BARS

Spec. No.	Original Diameter In Inches	Final Diameter In Inches	Elastic Limits In Actual Load
1	.867	.79	18,000
2	.769	.70	18,000
3	.805	.74	14,500
4	.847	.80	18,900
5	.842	.802	19,200
6	.841	.755	18,800
7	.84	.75	18,600
8	.81	.70	18,500
9	.794	.71	19,000
10	.724	.61	15,790
11	.813	.707	18,800
12	.853	.75	19,380
13	.82	.61	23,990
14	.755	.56	19,680
15	.748	.66	14,990
16	.81	.72	19,000

TABLE NO. II (Cont'd)

Maximum Strength Actual Load	Original Length In Inches	Final Length In Inches	Type of Electrode Used	Spec. No.
29,640	.56	.65	Airco 41 B E	1
22,000	.575	.67	NP "	2
24,510	.64	.72	"	3
24,100	.70	.77	"	4
25,650	.80	.84	"	5
29,650	.80	.90	Airco 41 B E	6
28,650	.68	.78	P "	7
27,500	.84	.98	"	8
27,900	.69	.81	"	9
22,000	.79	.92	"	10
28,000	.80	.96	Airco 65 L.C.E. Non-Peened	11
29,990	.85	1.00	Airco 65 L.C.E. Peened	12
39,370	.87	1.10	W.G.P.E. Peened	13
29,640	.73	.94	W.G.P.E. Non-P	14
22,700	.90	1.01	W.B.F.E. Non-P	15
27,600	.80	.90	W.B.F.E. Peened	16

TABLE NO. II (Cont'd)

Spec. No.	Original Diameter In Inches	Final Diameter In Inches	Elastic Limits In Actual Load
17	.747	.51	22,100
18	.80	.602	20,500
19	.925	.80	29,610
20	.81	.728	17,000
21	.99	.90	28,000
22	.913	.823	26,960
23	.92	.70	29,360
24	.97	.71	32,500
25	.919	.69	28,640
26	.101	.90	30,050
27	.895	.461	18,450
28	.896	.485	18,500

T A B L E N O. II (Concluded)

Spec. No.	Maximum Strength Actual Load	Original Length In Inches	Final Length In Inches	Type of Electrodes Used
17	32,650	.75	.965	M.C.E. P
18	34,990	.50	.28	M.C.E. N.P.
19	42,780	.90	1.08	L.F.E. P
20	22,000	.72	.78	Airco 41 B.E. N-P
21	40,000	.88	1.06	"
22	32,500	.66	.78	"
23	46,350	1.04	1.295	L.F.E. N-P
24	48,170	.96	1.24	L.F.E. P
25	46,100	1.05	1.315	M.C.E. N-P
26	42,010	.88	1.03	Airco 41 B.E. P
27	31,150	7"	9.68	Base Metal
28	31,600	8"	10.5	Base Metal

Symbols:

Airco 41 B.E.--No. 41 bare electrode, Air Reduction Sales Company.

Airco 65 L.C.E.--No. 65 light-coated electrode, Air Reduction Sales Company.

Murex C.E--Cresta (Heavy-Coated) electrode, American Murex Corporation.

W.G.P.E.--General purpose (heavy-coated) electrode, Westinghouse Electric and Manufacturing Company.

W.B.F.E.--Bare Flex arc electrode, Westinghouse Electric and Manufacturing Company.
L.F.E.--Fleetweld (heavy-coated) electrode, Lincoln Electric Company.

P--Peened.
N.P.--Non-Peened.

TABLE NO. III

PHYSICAL TEST OF WELDED BARS

Spec. No.	Tensile Strength #Sq. In.	Elastic Limit #Sq. In.	Per Cent Reduction In Area
1	51,500	31,200	15.5
2	49,000	36,000	15.2
3	49,150	28,200	14
4	43,600	34,500	10
5	45,500	34,600	10
6	52,900	33,700	20.3
7	51,500	33,800	20.4
8	52,900	36,300	23.5
9	54,000	38,000	22
10	56,600	37,600	21.9
11	55,850	38,000	23.5
12	54,150	34,600	22.6
13	74,400	44,500	45.3
14	57,500	44,800	43.2
15	52,800	32,600	20
16	53,000	36,500	21

TABLE NO. III (Con'd)

Spec. No.	Per Cent Elongation	Rockwell Hardness B Scale	Type Peened	Electrodes Non-Peened
1	13.8 in .56"	72		5/32" Airco 41 B.E.
2	14.2 in .57"	72.5		"
3	11.2 in .72"	72		"
4	10 in .70"	69		"
5	5 in .80"	75.5		"
6	12.5 in .80"	70.5	5/32" Airco 41 B.E.	
7	14.7 in .68"	67.8	"	
8	16.7 in .90"	67.8	"	
9	15.9 in .59"	74	"	
10	15.5 in .79"	66.2	"	
11	17.8 in .83"	70.6	"	
12	20 in 1.00"	67.5	Airco 65 L.C.E.	
13	33 in .87"	68.5	5/32" W.G.P.E.	
14	35.8 in .73"	71		5/32" W.G.P.E.
15	14.5 in .74"	67.8	1/8" W.F.B.E.	
16	12.5 in .80"	60		1/8" W.F.B.E.

T A B L E   N O. III (Cont'd)

Spec. No.	Tensile Strength #Sq. In.	Elastic Limit #Sq. In.	Per Cent Reduction In Area
17	74,200	41,000	46.5
18	69,800	40,000	40
19	58,200	36,350	25,4
20	44,300	32,700	19.6
21	54,500	35,600	19.5
22	49,000	31,000	19.4
23	69,500	43,800	41.5
24	76,400	44,100	47.6
25	70,000	43,600	29.2
26	53,850	38,500	19.4
27	49,600	29,500	74.5
28	49,000	29,600	71.5

T A B L E N O. III (Cont'd)

Spec. No.	Per Cent Elongation	Rockwell Hardness B Scale	Type Peened-	Electrodes Non-Peened
17	32.6 in .75"	70.6	5/32" M.C.E.	
18	29 in .65"	72		5/32" M.C.E.
19	20 in .90"	65.5	5/32" Airco 41 B.E.	
20	8.3 in .72"	67.5		5/32" Airco 41 B.E.
21	20.5 in .88"	63.5	5/32" Airco 41 B.E.	
22	18.1 in .66"	67		
23	28.5 in 1.04"	62		5/32" L.F.E.
24	32.2 in .96"	60	5/32" L.F.E.	
25	29.2 in 1.05"	60.5		5/32" M.C.E.
26	17 in 1.05"	64	5/32" Airco 41B.E.	
27	38 in 7"	49	Base Metal	
28	31.6 in 8"	49	Base Metal	

TABLE NO. IV

Spec. No.	Types of Electrodes	Welding Procedure	Air Pressure #Sq. In on Hammer	Average Strain Gage Readings: Sides A & B Hot	Average Strain Gage Readings: Sides A & B Cole	$e = \frac{\text{Gage Reading X .0002}}{2}$: Sides A & B Hot	$e = \frac{\text{Gage Reading X .0002}}{2}$: Sides A & B Cold
1	5/32" Airco 41 B. E.	Cross and Horizontal Weave, Non-Peened		41.25	20.85	.00412	.00208
2	"			26.12	20.85	.00381	.00285
3	"	"		37.90	19.27	.00379	.00192
4	"	Vertical Layer Weave Non-Peened		35.22	18.87	.00352	.00186
5	"			39.87	18.62	.00398	.00186
6	"	Cross and Horizontal Weave Peened	50	23.62	17.62	.00236	.00176
7	"		70	22.25	10.50	.00222	.00105
8	"	"	50	20.00	10.25	.0020	.00102
9	"	Vert. Layer Peened	70	21.62	9.62	.00216	.000962
10	"	"	70	25.87	12.25	.00258	.00122
11	5/32" Airco 35 L.C.E.	Cross and Horizontal N.P.		23.12	12.50	.00231	.00125
12	"	Cross and Horiz. P.	70	17.76	9.12	.00177	.00091
13	5/32" W.G.P.E.	Cross and Horiz. P.	70	30.50	15.87	.00305	.00158
14	"	Cross and Horiz. N.P.		40.87	19.57	.00408	.00197
15	1/8" A.S.F.E.	Cross and Horiz. N.P.		24.87	14.00	.002487	.0014
16	"	Cross and Horiz. P.	70	19.87	10.00	.00198	.0010

TABLE NO. IV (Cont'd)

Spec. No.	Type of Electrodes	Welding Procedure	Air Pressure # Sq. In. On Hammer	Average Strain Gage Readings Sides A & B Hot	Average Strain Gage Readings Sides A & B Cold	$e = \frac{\text{Gage Reading X .0002}}{2}$ Sides A & B Hot	$e = \frac{\text{Gage Reading X .0002}}{2}$ Sides A & B Cold
17	5/32" W.G.E.	Cross and Horiz. Weave P.	70	22.25	9.62	.00222	.00962
18	"	Cross and Horiz. N.P.		38.87	19.12	.00388	.00191
19	5/32" L.F.E.	Cross and Horiz. Weave P.	70	21.25	11.50	.00212	.00115
20	"	Cross and Horiz. Weave N.P.		28.87	12.25	.00288	.00122
23	5/32" Airco 41 B.E.	Cross and Horiz Weave N.P.		44.50	21.43	.00445	.002143

135 amperes, 18-20 volts were used on all 5/32" Airco 41 bare electrodes.

130 amperes, 25 volts were used on all 5/32" Westinghouse Flexarc general electrodes.

130 amperes, 25 volts were used on all 5/32" Lincoln Fleetweld electrodes.

130 amperes, 18-20 volts were used on all 1/8" Westinghouse Flexarc electrodes.

TABLE NO. V

WORK DONE IN DEFORMATING THE CENTER BARS OF THE SPECIMENS WHILE HOT AND COLD

Spec. No.	Sides A&B Hot	Sides A&B Cold	Work Ft. Lb. Elastic Deformation Hot	Work Ft. Lb. Elastic Deformation Cold	Work Ft. Lb. Plastic Deformation Hot	Work Ft. Lb. Plastic Deformation Cold	Total Work Ft. Lb. Deformation Hot	Total Work Ft. Lb. Deformation Cold	Pressure #Sq. In. On Air Hammer
1	.00412	.00208	20.30	20.30	126.20	43.80	146.50	64.10	
2	.00381	.00235	"	"	111.00	75.10	131.30	95.40	
3	.00379	.00192	"	"	108.30	37.20	128.60	57.50	
4	.00352	.00188	"	"	101.90	35.30	122.20	55.50	
5	.00398	.00186	"	"	120.50	34.90	140.80	55.20	
6	.00236	.00176	"	"	55.25	30.80	75.55	51.10	50
7	.00222	.00105	"	"	50.80	2.16	71.10	22.16	70
8	.0020	.00102	"	"	40.50	.80	60.80	21.11	50
9	.00216	.000962	"	"	47.10	-2.30	67.40	18.00	70
10	.00256	.00122	"	"	64.06	9.06	84.30	29.36	70
11	.00231	.00125	"	"	53.20	10.16	73.50	30.46	
12	.00177	.00091	"	"	31.30	-3.65	51.60	6.76	70
13	.00305	.00158	"	"	83.20	23.60	103.50	43.90	70
14	.00408	.00197	"	"	104.60	38.50	124.90	58.80	
15	.00248	.0014	"	"	58.60	16.20	78.90	36.50	
16	.00198	0010	"	"	40.00	0	60.30	20.30	70
17	.00222	.000962	"	"	42.60	-10.60	62.90	18.76	70
18	.00388	.00191	"	"	116.80	37	137.[illegible]	57.30	
19	.00212	.00115	"	"	68.60	6.21	88.[illegible]	26.51	70
20	.00288	.00122	"	"	77.40	9.06	97.[illegible]	29.36	
23	.0044	.00214	"	"	116.00	46.10	136.[illegible]	76.40	

Specimen Number	Min. Work Ft. Lb. Deformation Cold	Max. Work Ft. Lb. Deformation Cold	Ave. Work Ft. Lb. Deformation Cold
1-2-3-18-23			37.30
15		58.80	
23	46.10		
6-7-8-16			27.86
6		51.50	
16	20.30		
9-10			23.68
9	18.00		
		29.36	
4-5			55.50
4		55.50	
5	55.50		
11-12			
11		30.46	
12	16.65		
13-14			
14		58.80	
13	43.90		
17-18			
17	18.56		
18		57.30	
19-20			
19	26.51		
20		29.36	

METHOD OF CALCULATING WORK DONE BY EXPANSION AND CONTRACTION

In making a study of the stress set up in a rigid type of welded joint as shown in Fig. 9A, assume that the strain is transmitted to the center bar in a uniform distribution. Considering this being true, calculations were made to determine the total work done in deforming the center bar by dividing the work in two parts--work done during elastic deformation and work done during plastic deformation.

The work done per unit length of bar in elastic deformation is equal to the work required to stress the center bar of the specimen to yield point (30,000 lbs. per sq. in.) as in equation (1).

$$We = \frac{S^2 A}{24\ E} \text{ Ft. Lb.}$$

Where L = Length of center bar.

S = Yield pt. stress (30,000 lbs per sq. in.)

A = Cross-section area center bar in square inches.

E = Modulus of elasticity on the material(30,000 lbs. per sq. in.) Therefore the work done on the center is:

$$We = \frac{S^2 AL}{24\ E} \text{ Ft. Lb } 16 \quad (1)$$

The work done per unit length on center bar in plastic deformation is equal to the force on the bar times the difference between the measured elongation and the elongation to produce a stress equal to the yield point of the material as in equation (2):

$$W_p = \frac{SAL}{12\,E}\left(e - \frac{S}{E}\right) \text{ Ft. Lb.}$$

Where e is the unit elongation with the gage. The work done on the entire center bar length L is therefore:

$$W_p = \frac{SAL}{12\,E}\,(E_e - S) \qquad (2)$$

The total work done on the center bar by expansion and contraction is equal to the sum of the elastic work plus the plastic work, as in equation (3):

$$W = W_e + W_p \qquad (3)$$

$$W = \frac{S^2AL}{24\,E} + \frac{SAL}{12\,E}\,(E_e - S) \quad (4)$$

$$W = \frac{SAL}{24\,E}\,(2E_e - S) \qquad (5)$$

'It is the best to use formula (4) because it will give the work done in elastic and plastic deformation separately.

Example:

S = 30,000 lb. Sq. In.

A = (1.625) (1.25) 2.03 Sq. In.

L = 8"

E = 30,000,000 lb. sq. in.

e = .00393 while hot

e = .00201 while cold

Average strain gage readings on Sides A and B while hot on side A_h, 39.23 and while cold on side A_c, 20.83; while hot on side B_h, 38.91 and while cold on side B_c, 19.41.

These averages of reading were taken on non-peened bars using cross and horizontal weave procedure.

Total average of $A_h + B_h = 41.25$.

Total average of $A_c + B_c = 20.85$.

$$E = \frac{\text{Gage reading X .0002}}{2} = \frac{20.85 \text{ X } .0002}{2} = .002085$$

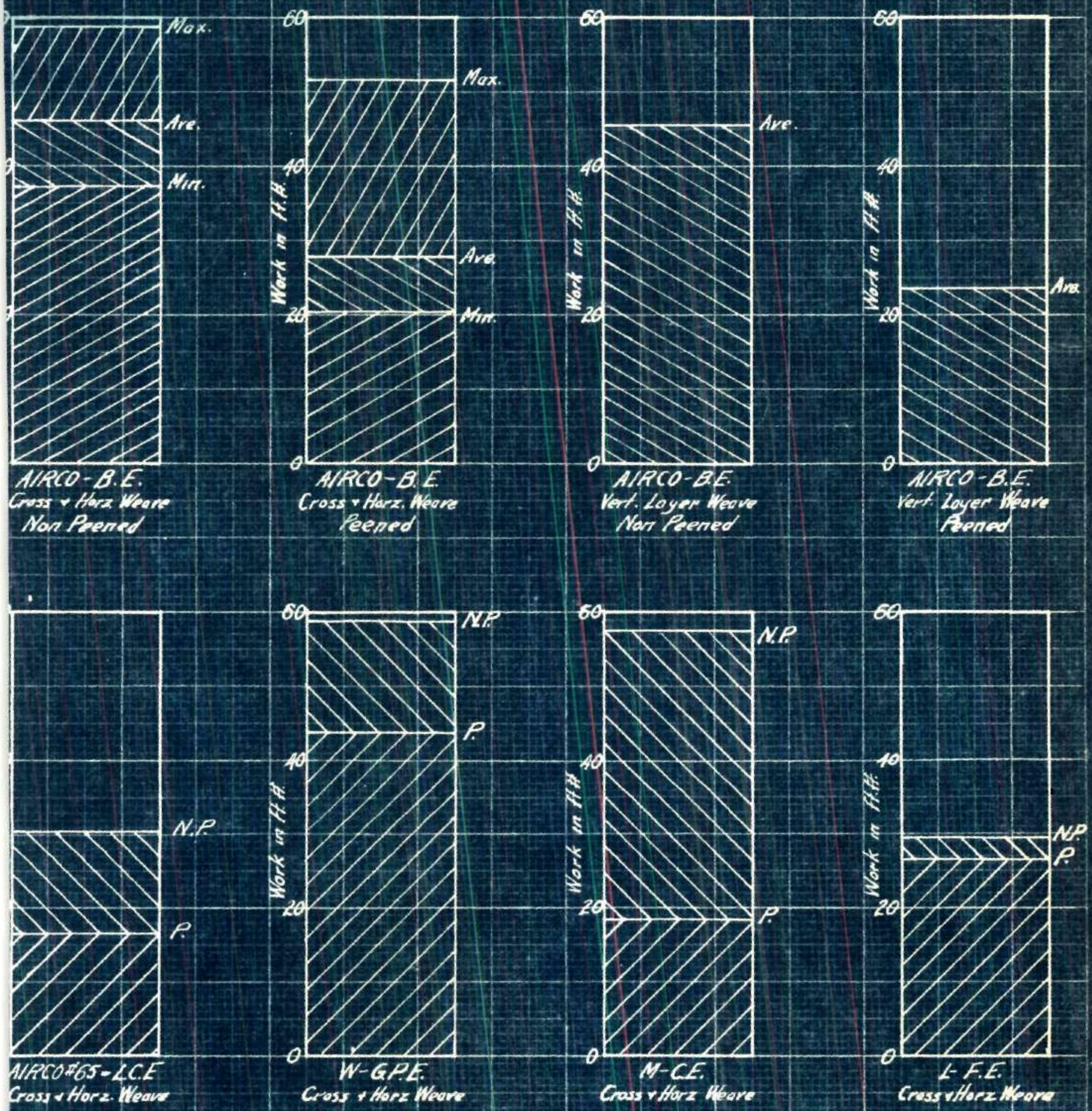
$$W = \frac{(30,000)^2(2.03)\ (8)}{24\ (30,000,000)} + \frac{(30,000)\ (2.03)\ (8)}{12\ (30,000,000)}$$

$$\left\{ (30,000,000) \quad (.00208)-30,000 \right\}$$

Therefore:

$W = 20.30 + 43.80 = 64.10$ Ft. Lb. of work done in elastic and plastic deformation.

Curves Showing Relation Between Peened and Non-Peened Welds.



RCO-B.E. — Air Reduction Sales Co. Bare Electrode #41.
RCO-#65-L.C.E. — Air Reduction Sales Co. Light Coated Electrode.
P.E. — Westinghouse Electric + Mfg. Co. Heavy Coated General Purpose Electrode.
C.E — Murex Cresta Heavy Coated Electrode.
F.E. — Lincoln Electric Co. Fleetweld Heavy Coated Electrode.
P. — Non Peened.
— Peened.

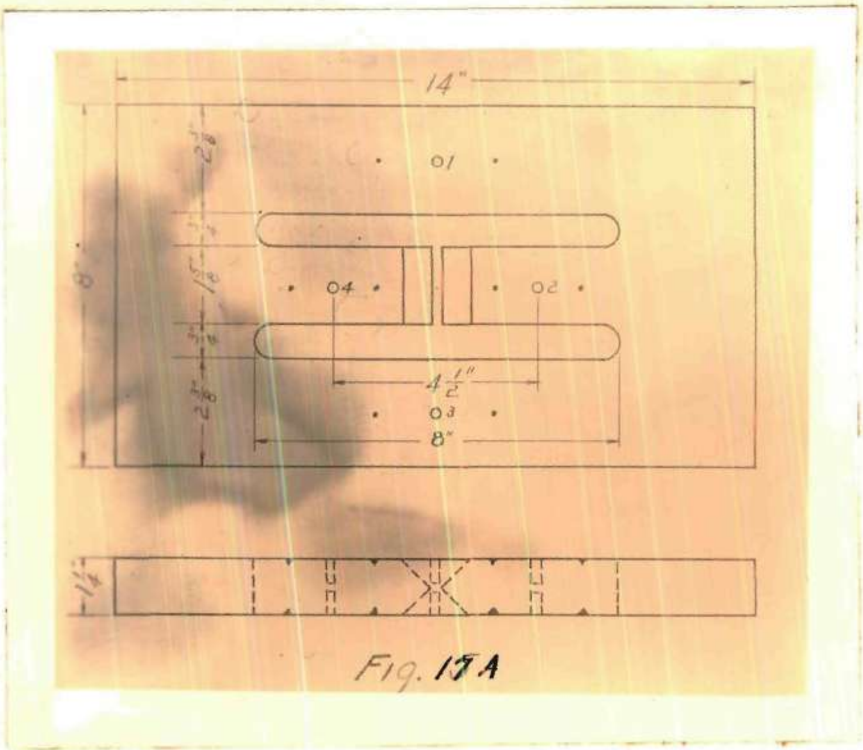


Fig. 17A

For a check of data obtained from test on the 1 1/4" X 6" X 14" plates as shown in Tables IV and V, four other plates were prepared as shown in Fig. 17A. The gage holes as shown in center and side bars were drilled with a No. 56 drill and reamed with a special reamer. The 1/4" holes between the gage holes were drilled 1/2" deep and filled half full of mercury. Then the hot junctions of chromel alumel thermocouples were submerged in the mercury and connected through a special switch to the Leeds & Northrup Petentiometer as shown in Fig. 17B.

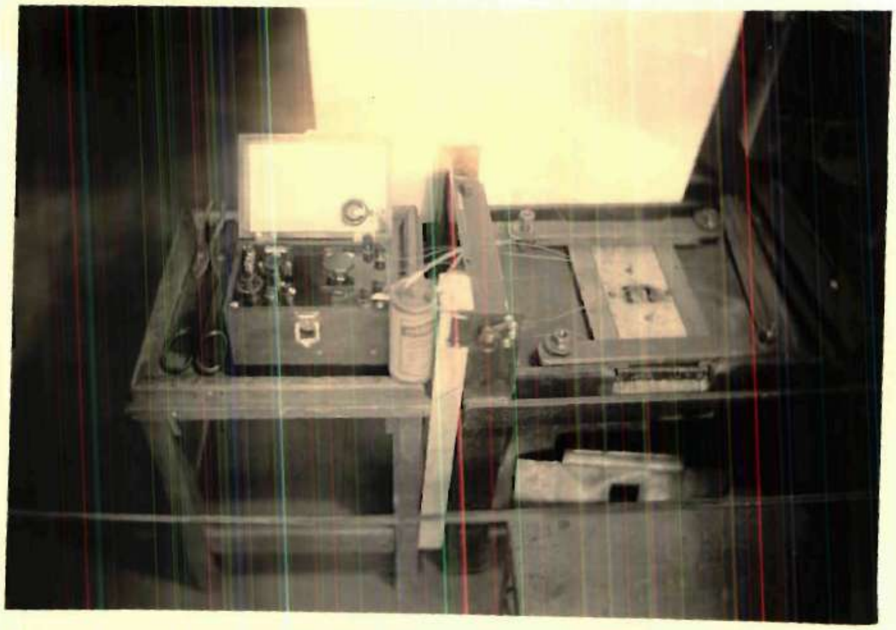


Fig. 17B

The mercury and special switch made it possible to obtain temperatures at these points with a fair degree of accuracy while welding. Strains were taken with a Berry strain gage using a 2" gage length as was used in the other test. These gage readings and temperature readings were taken on both sides of the plates.

Two of these welds were made with bare electrodes, one of which every other deposited layer of metal was peened while welding. The other two were welded with coated electrodes using reverse polarity, one being peened as stated above.

When welds were completed they were allowed to cool to room temperature and strain gage readings taken. Then the center bar was cut through the center of the weld and gage readings taken again. Results are shown in Table VI.

TABLE NO. VI

Standard bar gage reading: 206 before welding, 204 after welding

Spec. No.	Welding Procedure		Side A 1	Side A 2	Side A 3	Side A 4	Side B 1	Side B 2	Side B 3	Side B 4	Average 1&3	Average 2&4
5	Cross and Horizontal	Before Welding	173	210	173	163	223	202	233	204		
	Weave, Non-Peened	After Welding	166	259	167	185	215	234	223	227		
		Dif.	-7	+49	-6	+22	-8	+32	-10	+23	-7.75	+31.5
		Center Bar Cut	170	229	170	166	220	210	227	205		
	Welded With	Dif.	-3	+19	+3	+3	+3	+8	-4	+1	-1	+7.75
	5/32" Airco	Temp. 2nd. Layer	80°C	183°C	72°C	190°C	103°C	180°C	93°C	168°C		
	Bare Elec.	Temp. 4th Layer	103	204	77	210	124	243	128	227		
		Temp. 6th Layer	130	240	135	250	132	243	137	235		
6	Cross and Horizontal	Before Welding	177	200	201	180	214	201	211	189		
	Weave, Non-Peened	After Welding	167	238	193	207	206	237	202	218		
	Welded With	Dif.	-10	+38	-8	+27	-8	+36	-9	+29	-8.75	+32.5
	5/32" Fleetweld	Center Bar Cut	175	205	202	183	218	210	207	192		
	Electrode	Dif.	-2	+5	+1	+3	+4	+9	-4	3	-.25	+5
		Temp. 2nd Layer	67°C	162°C	67°C	172°C	79°C	173°C	85°C	181°C		
		Temp. 4th Layer	129	219	130	225	113	225	99	218		
		Temp. 6th Layer	143	250	145	255	105	235	103	235	105°C	212°C

TABLE NO. VI (Cont'd)

Spec. No.	Welding Procedure		Side A 1	Side A 2	Side A 3	Side A 4	Side B 1	Side B 2	Side B 3	Side B 4	Average 1&3	Average 2&4
7	Cross and Horizontal	Before Welding	190	180	170	132	176	166	190	162		
	Weave, Peened	After Welding	186	211	166	143	175	196	184	191		
	Welded With	Dif.	-4	+30	-4	+11	-1	+30	-4	+29	-3.25	+25
	5/32" Fleetweld	Center Bar Cut	188	187	170	134	176	170	187	168		
	Elects.	Dif.	-2	+7	0	+2	0	+4	-3	+6	-0.25	+4.75
8	Cross and Horizontal	Before Welding	229	219	153	295	230	157	198	219		
	Weave, Peened	After Welding	215	252	149	320	227	188	192	241		
	Welded With	Dif.	-4	+33	-4	+25	-3	+31	-6	+22	-4.25	+25.75
	5/32" Airco	Center Bar Cut	228	224	153	296	228	161	200	209		
	Bare Elects.	Dif.	-1	+5	0	+1	-2	+4	+2	10	-.25	+5

Stress calculations on Specimens 5, 6, 7, & 8

Spec. No. 5

Stress on center bar after welding 31.5 X 3,000=94,500 # Sq. In.

Stress on center bar after cut 7.75 X 3,000=22,250

Stress relieved on center bar after cut 23.75 X 3,000=68,250

Stress on outside bar after welding 4 X 7.75 X 3,000=93,000

Spec. No. 6

Stress on center bar welded 32.5 X 3,000=97,000 # Sq. In.

Stress on center bar after cut 5 X 3,000= 15,000

Stress released on center bar cut 23.50 X 3,000=70,500

Stress on outside bar after welding 4 X 8.75 X 3,000=99,000

Spec. No. 7

Stress on center bar welded 25 X 3,000 = 75,000

Stress on center bar cut 4.75 X 3,000 = 14,250

Stress released on center bar cut 20.25 X 3,000 = 60,750

Stress on outside bars after welding 4 X 3.25 X 3,000 = 39,000

Spec. No. 8

Stress on center bar welded 25.75 X 3,000 = 77,250

Stress on center bar after cut 5 X 3,000 = 15,000

Stress released after cut 20.75 X 3,000 = 62,250

Stress on outside bar after weld 4 X 4.75 X 3,000 = 57,000

Strain per one division on Berry gage using 2" gage length is equal to $\frac{.0002}{2}$ X 30,000,000 3,000

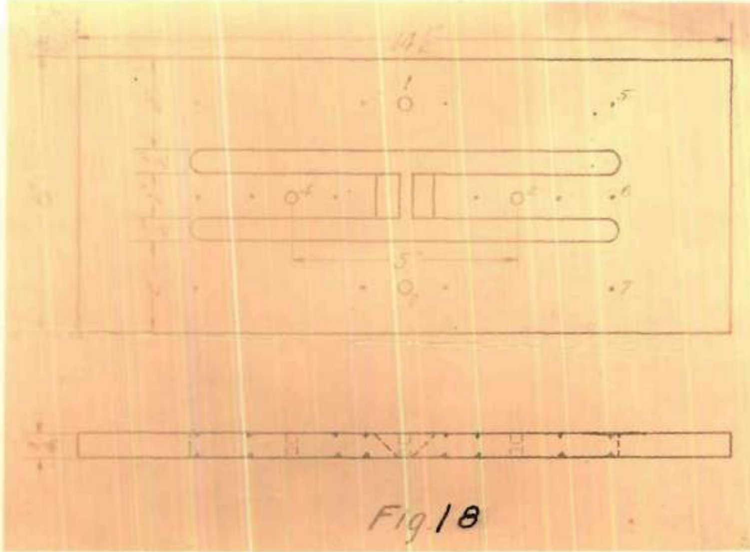


Fig. 18

In order to obtain information as to whether the residual stresses caused by welding are the same in thin plates as in thick plates, the above 3/4" X 8" X 14" 1/4" plate was selected and prepared as shown in Fig. 18. The same procedure of welding and peening as was done on the thicker plate was carried out, with the exception of welding and recording temperatures at points 1,2,3, and 4 being done only on one side. Strain gage readings were taken at points 1,2,3,4, and C on both sides with a Berry strain gage using two-inch gage length. In addition to these strain readings a ten-inch Whittemore strain gage reading was taken at points 5,6, and 7 on both sides of the plate.

Four bars were prepared as stated above, two of which the welds on center bars were made in 60-degree "V" double bevel joint with a 1/4" opening at the bottom. One of the welds in each case was peened as was done in the thicker plates.

After the welds were made and allowed to cool down to room temperature, the gage readings were taken and center bars cut through the center of the welds and the strain gage reading again recorded.

The No. 1 weld cracked after cooling, therefore, the results were discarded. The results of the other bars are recorded as shown in Table VII.

TABLE NO. VII

Spec. No.	Welding Procedure		Strain Gage Points 1	2	3	4	C	5	6	7	Average 1&3	2&4
		Standard bar strain gage reading: Berry, 205, Whittemore, 560 (45 V 1/4 opening before welding)										
2	Cross and Horiz. Weave N. P.	Before Welding Side A	207	170	183	206	176	527	570	587		
		After Welding Side A	203	189	176	227	3	492	449	556		
		Dif.	-4	+19	-7	+21	-173	-35	-121	-31		
		Before Welding Side B		197		216	176	563	787	575		
		After Welding Side B		220		242	1	554	677	546		
		Dif.		+23		+26	-175	-29	-110	-29	-5.5	+22.2

Average of strains at points: C=174, 5,= -32, 6, = -116 7= -30

	Weld Cut Side A	204	173	179	212	97	532	542	588		
	Dif.	-3	+3	-4	+6	-79	+5	-28	+1		
	Weld Cut Side B		202		221	92	565	766	577		
	Dif.		+5		+5	-84	+2	-21	+2	-15	+4.75

Average of strains of points: C= -81, 5= 3.5, 6= -24.5, 7= 1.5

T A B L E N O. VII (Concluded)

Average Whittmore readings after welding:

Average points 5&7 = 31 Ratio center bars to side bars 1 : 4.

Average point 6 116 ∴ 4 X 31 = 124 compared to 116 on No. 6 center bar.

Average reading on center bar equals = 24 ∴ total strain released 116-24 92.

Stress on outside bars before cut 124 X 300 = 37,200 #Sq. In.

Stress on center bar before cut 116 X 300 = 33,800 #Sq. In.

Stress on center bar released by cut 92 X 300 = 27,600 #Sq. In.

Stress on center bar left after cut 24 X 300 = 7,200 #Sq. In.

Stress on outside bars before cut 62 X 300 = 18,600 #Sq. In.

Ave. of Berry gage points 1 & 3 after welding 5.5 X 3,000 = 15,500 #Sq. In.

Ave. of Berry gage points 2 & 4 after welding 22.2 X 3,000 = 66,600 #Sq. In.

Ave. of Berry gage points 1 & 3 after cut 3.5 X 3,000 = 10,500 #Sq. In.

Ave. of Berry gage points 2 & 4 after cut 4.7 X 3,000 = 14,100 #Sq. In.

Total strain released by cutting center bar 22.2-4.7 = 17.7 X 6,000 = 52,500 #Sq. In.

TABLE NO. VII (Cont'd)

Spec. No.	Welding Procedure		Strain Gage Points 1	2	3	4	C	5	6	7	Average 1&3	2&4
	Standard Bar Strain Gage Reading: Berry, 206; Whittemore, 550 (60 V 1/4 opening before opening before welding)											
3	Cross and Horiz. Weave Peened	Before Welding Side A	210	206	204	203	219	569	552	561		
		Welded Side A	203	229	200	222	49	537	421	529		
		Dif.	-7	+23	-4	+19	-170	-32	-131	-32		
		Before Welding Side B		209		219	231	973	537	556		
		After Welding Side B		235		236	42	945	421	532		
		Dif.		+26		+17	-189	-28	-115	-24	-5.5	+21.2
		Average Strain At Points					179.5	-30	-123	-28		
		Side A Cut Weld	208	212	202	205	153	570	513	561		
		Dif.	-2	+6	-2	+2	-66	+1	-39	0		
		Side B Cut Weld		213		220	136	974	505	555		
		Dif.		+4		+1	-95	1	-32	+1	0	+3.5
		Average Strain At Points					81	2	-35.5	-.50		
		Temp. 2nd Layer	71°C	173°C	71°C	181°C						
		Temp. 3rd Layer	96	202	80	212						
		Temp. 4th Layer	118	250	117	261					92.1°C	213°C

TABLE NO. VII (Cont'd)

Stress calculations taken from data obtained with a Whittemore strain gage:

Stress on center bar after welding 123 X 300 = 36,900 #/Sq. In.

Stress on center bar after cut 36 X 300 = 10,800 #/Sq. In.

Stress released on center bar after cut 87 X 300 = 26,100 #/Sq. In.

Stress on outside bars 4 X 29 X 300 = 34,800 #/Sq. In.

Stress calculation taken from data obtained with a Berry gage strain gage:

Stress on center bar after weld 21.5 X 3,000 = 63,500 #/Sq. In.

Stress on center bar after cut 3.50 X 3,000 = 9,250 #/Sq. In.

Stress released on center bar cut 18.00 X 3,000= 54,000 #/Sq. In.

Stress on outside bars after welding 21.0 X 3,000 = 63,000 #/Sq. In.

Stress on outside bars after cut -0.

Stress across weld 189 X 3,000 = 56,700 #/Sq. In.

TABLE NO. VII (Cont'd)

Spec. No.	Welding Procedure		Strain Gage Points 1	2	3	4	C	5	6	7	Average 1&3	1&4
	Standard bar readings: Berry gage, 205; Whittemore gage, 560 (60 V 1/4 opening before welding)											
4	Cross and Horiz. Peened	Before Welding Side A.	300	36	61	204	227	586	577	598		
		After Welding Side A	295	52	56	224	84	567	454	556		
		Dif.	-5	+16	-5	+20	-143	-21	-117	-36		
		Before Welding Side B		204		176	196	407	576	543		
		After Welding Side B		230		192	17	374	463	508		
		Dif.		+ 26		+16	-189	-27	-107	-29	-5	+ 19.5
		Average Strains					166	-24	-112	-32.5		
		Side A Cut Weld	299	37	55	208	172	589	543	594		
		Dif.	-1	+ 1	-6	+ 4	-55	+6	-28	+ 2		
		Side B Cut Weld		208		174	109	403	550	543		
		Dif.		+ 4		-2	-87	+2	-20	+ 6	-3.5	+3.5
		Average Strains					- 71	+4	-24	+ 4		

TABLE NO. VII (Cont'd)

Stress calculation taken from data obtained with a Whittemore gage:

Stress on center bar after welding 112 X 300 = 33,600 #/Sq. In.

Stress on center bar after cut 28 X 300 = 7,400 #/Sq. In.

Stress released on center bar after cut 112-28 84 X 300 = 25,200 #/Sq. In.

Stress outside bars 4 X 28.75 X 300 = 34,500 #/Sq. In.

Stress calculation taken from data obtained with a Berry strain gage:

Stress on center bar after welding 19.5 X 3,000 = 58,500 #/Sq. In.

Stress on center bar after cut 3.5 X 3,000 = 10,500 #/Sq. In.

Stress released on center bar after cut 16 X 3,000 = 48,000 #/Sq. In.

Stress on outside bar 20 X 3,000 = 60,000 #/Sq. In.

Stress across Weld 189 X 3,000 = 56,700 #/Sq. In.

Stress across weld after cut 71 X 3,000 = 21,300 #/Sq. In.

TABLE NO. VIII

Calculation Showing Locked-up Stresses in Rigid Frames Caused by Expansion and Contraction.

The strain gage reading taken before and after welding center bar in frames (or plates) as shown in Fig. 18 furnished necessary data for computing the residual stresses resulting from the shrinkage of deposited metal.

$S = Ee$

S = Stress in lb/sq. in.

E = Modulus of elasticity.

e = Measured unit elongation in inches.

T A B L E N O. VIII (Cont'd)

Spec. No.	e Center Bar	S Center Bar	e Out-Side Bar	S Out-Side Bar	Peened	Non-Peened	Thickness of Plates in Inches
1	.00208	62,400				"	1 1/4"
2	.00285	75,500				"	"
3	.00192	57,600				"	"
4	.00188	56,400				"	"
5	.00186	55,800				"	"
6	.00176	52,800			"		"
7	.00005	31,500			"		"
8	.00102	30,600			"		"
9	.000962	27,960			"		"
10	.00122	36,600			"		"
11	.00125	37,500				"	"
12	.0009	27,300			"		"
13	.00158	47,400			"		"
14	.00197	59,100				"	"
15	.0014	42,000				"	"
16	.0010	30,000			"		"
17	.000962	28,860			"		"
18	.00191	47,300				"	"
19	.00115	34,500			"		"
20	.00122	36,600				"	"
23	.00214	64,200				"	"

TABLE NO. VIII (Cont'd)

Spec. No.	e Center Bar	S Center Bar	e Out-Side Bar	S Out-Side Bar	Peened	Non-Peened	Thickness of Plate In Inches
	The following specimens were run for a check on previous data obtained;						
5	.00315	94,500	.00308	92,400		"	1 1/4
6	.00325	96,500	.0033	99,000		"	"
7	.0025	61,500	.00128	38,400	"		"
8	.00257	76,000	.00168	49,400	"		"
	The following specimens were run for a comparison of data on 1 1/4" to 1/2" plate:						
2	.00222	66,600	.0022	66,000		"	"
3	.00212	63,600	.0022	66,000	"		"
4	.00195	58,500	.0020	60,000	"		"

T A B L E N O. VIII (Cont'd)

Spec. No.	e Center Bar Cut	S Center Bar Cut	e Outside Bar After Center Bar Was Cut	S Outside Bar After Center Bar Was Cut	S Stress Released On Center Bar After Cut
The following specimens were run for a check on previous data obtained:					
5	.000775	22,350	.00020	6,000	72,250
6	.0005	15,000	.0001	3,000	81,500
7	.000475	13,250	.0001	3,000	48,000
8	.0005	15,000	.0001	3,000	61,000
The following specimens were run for comparison of data on 1 1/4" to 1/2" plate:					
2	.000475	13,250	.000	0	53,350
3	.00035	10,500	.000	0	53,500
4	.0003	9,000	.000	0	49,500

High stresses, caused by expansion and contraction of the deposited metal in all test specimens previously run, have brought about further investigation as to why these stresses are so high.

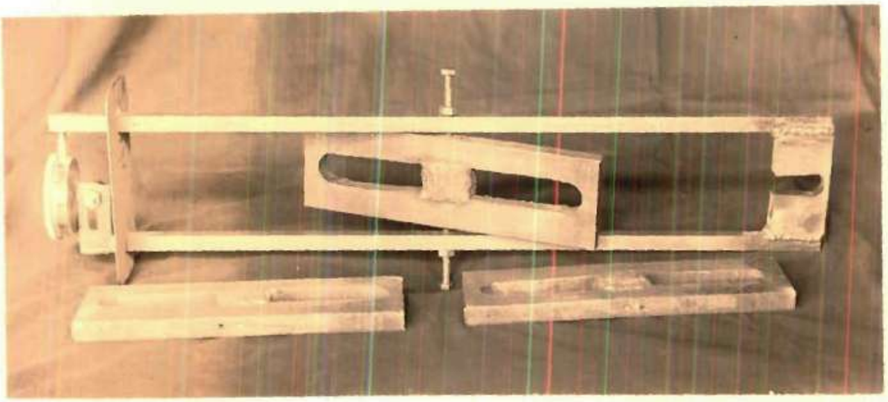


Fig. 19

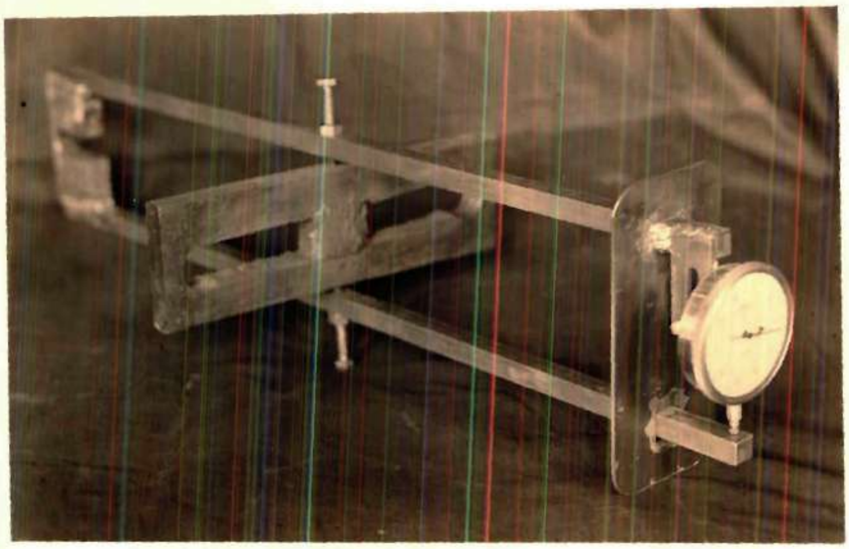


Fig. 20

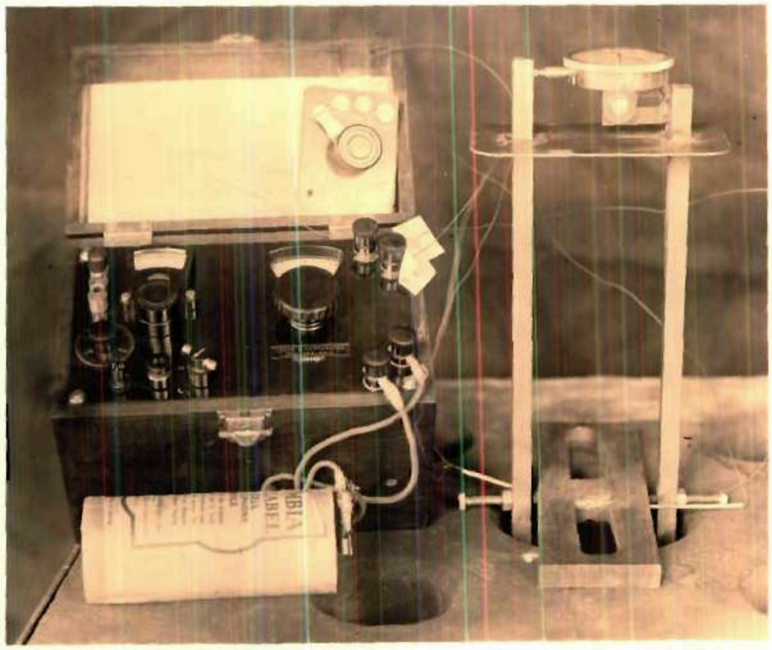


Fig. 21

The above photograph shows a complete set-up of the Leeds and Northrup petentiometer and shrinkage gage.

Some of the test specimens were prepared as shown in the above photographs with both ends fixed; some were prepared with only one end fixed.

The results obtained thus far are shown in Table IX. The measurements indicate that the shrinkage in butt welds varies from .025" to .074". How the dimensions of the welds and conditions under which they were made affected the shrinkage has not yet been determined.

Curves have been plotted to show the effect of expansion and contraction of the welded joint while metal was being deposited and cooled to room temperature.

It will be noticed from the curves (Page 103) that the strain dropped as the temperature approached the transformation point (A_c) of the steel which was about 800 C. At this point the weld was completed and had reached a uniform maximum temperature. The character of material obtained at this point is austenitic which is changing into pearlite at about 700° C (the Av inversion) and is greatly affected by the rate of cooling past the LSK or eutectoid line. Since this rate of cooling was slow, it is reasonable to believe that the structure would change back to an aggregate of ferrite and pearlite. While doing so residual strains and stresses would rapidly increase to a maximum at room temperature.

With this in mind a special shrinkage gage was designed and built as shown in Figs. 19 and 20 to determine the actual shrinkage of deposited metal. These specimens were prepared on different thickness of plates with a double bevel joint in the center of steel plates as shown in Fig. 19 and 20. On the sides of the plates 1/8" holes were drilled into the scarfed sides of the beveled joint in which to place the thermocouples so that the hot junction would be as near the deposited metal as possible. A special drill was used to make an insert in the sides of the plates for the blunt point adjustment screws to set for zero dial reading on the Ames gage. A Leeds & Northrup potentimeter with chromel-alumel thermocouples connected through a special switch were used to determine the temperatures while welding.

The complete set-up for obtaining the data is shown in Fig. 21. With this equipment it was possible to make direct measurements of shrinkage (or contraction) and temperature of deposited metal in butt welded joints while welding.

Procedure of recording data:

After the set-up was made as shown in Fig. 19, the zero reading of the Ames gage and room temperature were recorded. At the beginning of the welding, temperatures and gage reading were again recorded and thereafter, at equal intervals until welds were completed and cooled to room temperature.

TABLE NO. IX

DATA TAKEN ON SHRINKAGE OF DEPOSITED METAL, SPECIMEN NO. I
(Room temperature: 74° F or 23° C)

Temperature 1	2	Average	Gage Reading	Shrinkage In Inches
23	23	23	174	.0087
389	437	413	475	.0237
601	649	625	500	.025
701	723	712	482	.0241
790	817	805	485	.0242
695	667	681	495	.0247
469	463	466	600	.0300
422	413	418	690	.0345
375	371	373	755	.0377
323	341	332	790	.0395
307	305	306	830	.0415
275	283	279	864	.0432
255	259	257	888	.0444
231	233	232	912	.0456
209	209	209	941	.0470
183	183	183	966	.0483
159	159	159	993	.0496
135	135	135	1016	.0508
112	112	112	1044	.0522
88	88	88	1065	.0532
65	65	65	1082	.0541
41	41	41	1106	.0553
27	27	27	1117	.0558

DATA TAKEN ON SHRINKAGE OF DEPOSITED METAL, SPECIMEN NO. II
(Room temperature, 72°F or 22°C)

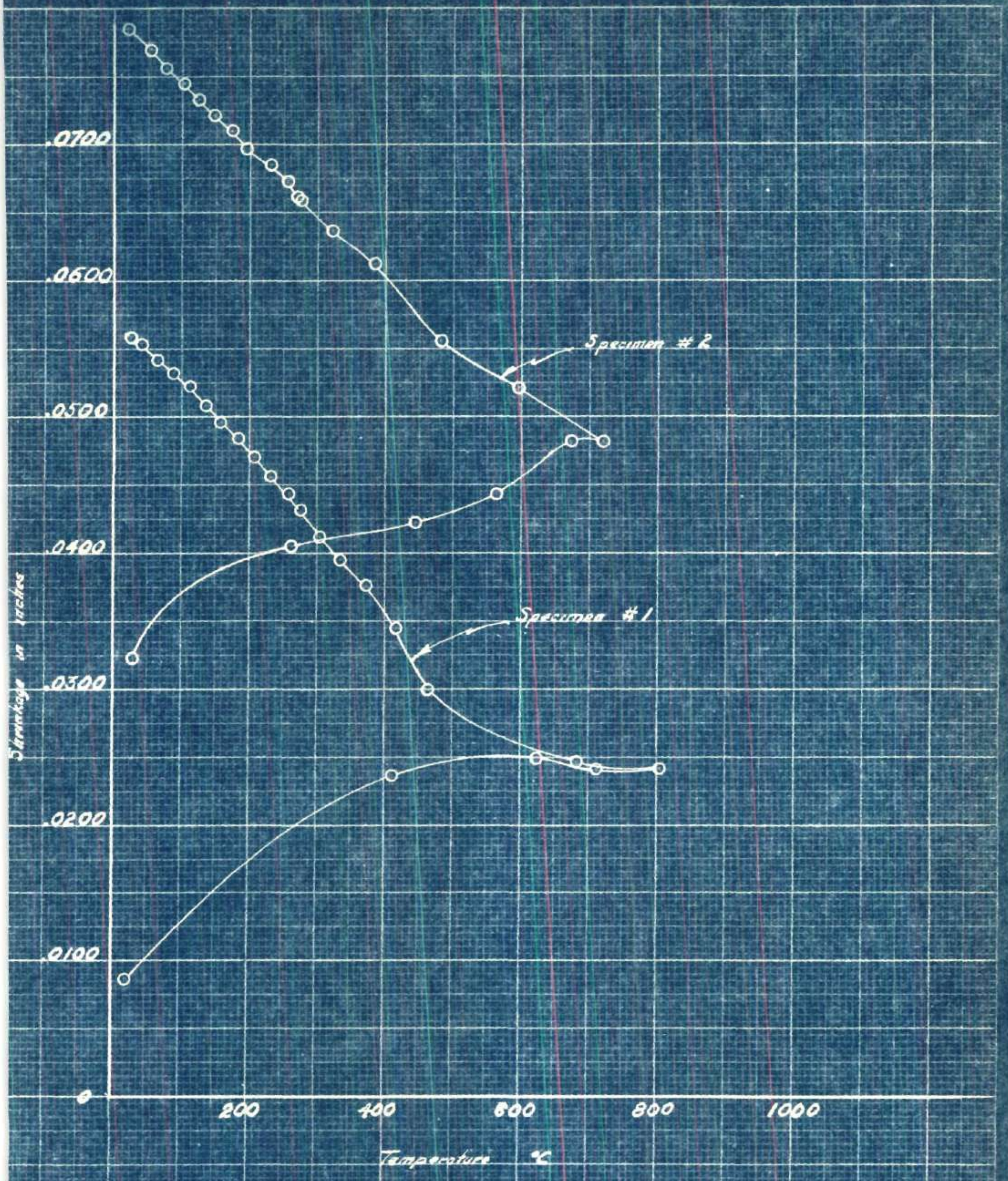
Temperature	Gage Reading	Shrinkage In Inches
33	646	.0323
264	810	.0405
446	845	.0422
564	888	.0444
672	964	.0482
720	972	.0481
596	1045	.0522
482	1113	.0556
384	1225	.0612
321	1275	.0637
276	1321	.0660
270	1322	.0661
255	1346	.0673
230	1370	.0685
196	1394	.0697
172	1418	.0709
148	1442	.0721
124	1466	.0733
102	1490	.0745
78	1514	.0757
52	1538	.0769
22	1570	.0785

TABLE NO. X

THE FOLLOWING DATA IS RESULTS ON SHRINKAGE TEST RUN ON SPECIMENS 1-21
(A .001 Ames gage was used to obtain data)

Spec. No.	Plate Thickness In Inches	Length of Fillet In Inches	Plate Opening For Fillets In Inches: Top	Plate Opening For Fillets In Inches: Bottom	Shrinkage Total Dial Readings	Actual Shrinkage In Inches
1	1/4	1 1/2	7/16	3/32	775	.03875
2	"	1 7/16	13/32	1/16	785	.03925
3	"	1 1/2	5/8	3/32	620	.0310
4	"	1 1/2	7/16	3/32	520	.0260
5	1/2	1 1/2	1 1/4	1/4	940	.0475
6	"	1 1/2	1 1/16	9/32	1060	.053
7	"	2 3/8	1 1/16	3/8	1480	.074
8	"	1 7/16	7/8	5/16	880	.044
9	"	1 3/4	1	3/16	710	.0355
10	"	2 1/8	1 1/32	1/4	1260	.063
11	"	2 1/16	1 1/16	3/8	1350	.0675
12	"	1 5/16	29/32	1/4	823	.04115
13	"	1 7/16	27/32	3/16	967	.04835
14	3/4	1 5/8	1 1/16	1/8	570	.0285
15	"	1 3/8	1 1/16	1/8	520	.0260
16	"	1 1/2	1 1/8	7/32	585	.02925
17	"	1 1/2	1 1/16	7/32	502	.0251
18	5/8	1 3/4	1	3/8	943	.05715
19	"	1 3/4	1	3/8	940	.047
20	"	1 3/4	1	3/8	941	.04705
21	1 1/4	1 3/4	1 1/4	3/16	877	.04385

The special-built shrinkage gage has a 2:1 ratio legs. Therefore all dial readings must be divided by 2. The gage reads direct in .001".



Curves Showing Expansion and Contraction of Deposited Metal in a Butt Weld

DISCUSSION OF RESULTS

Examination of the summary of test data in Table VIII and IX reveals the fact that there was a rather wide variation in the reading of the strain gage on the different specimens, and that some of the specimens were subjected to warping.

It is possible that the variation in gage reading could be due to the technique of welding and the method of deposition.

It is very easy to understand why manual operation of the electrode would enter into the variation of gage reading when one considers that the operator must master the proper manipulation of the electrode so as to maintain a constant voltage and flow of current to prevent excessive heating at certain points. This could only be done by absolutely controling the arc length which means the feed and speed of travel of the electrodes must be automatically operated.

Where peening of the weld is done it is possible that certain portions of the welds could have been peened more than others. This would affect the distribution of stresses causing a variation of gage reading. Although being able to control the effective blow by the use of a special peening machine, as has been previously explained, it is reasonable to believe this has been cut to a minimum.

The inherent method of welding means the deposition of small globules of metal which form on the end of the cathode and fall into the anode puddle of crater, which in turn forms the thin layer of deposited metal. This process of deposition causes an uneven distribution of stresses because the progressive layers of this deposition cause progressive heating and cooling which naturally would cause a non-uniform stress distribution. This also would cause variation in gage reading. By taking the strain gage reading as has been done in the first and second run, and taking the average of all readings on each individual bar in test plates, one should gain a fair degree of accuracy of strains set up in the bars.

Even though there should have been a considerable variation in strain reading due to inaccuracy of the method used in obtaining the reading, it would not have greatly affected the amount of stress set up by expansion and contraction caused by the cooling deposited metal. When the test data were worked up it was found that the stresses in the majority of center bars of specimens ran above the elastic limit of the base metal. Then a second series of test specimens were run to check the results and find out if different thicknesses of plates would affect the results. These data repeated the same condition in each case. Then a further investigation was brought about to determine if it were possible for deposited metal to shrink (or contract) enough in a butt weld to cause such stresses. Investigation proved that shrinkage was much higher than expected. In studying the strain temperature curves it can readily be seen that practically all work done in deforming the center bars, causing residual stresses, were due to shrinkage, and very Little from expansion. This can be easily understood from the study of the effect of steel cooling from the molten condition passing through the A G S E area in the iron carbon equilibrium diagram which is composed of a solid solution finely dispersed carbon in gamma iron, known as austenite. Then on further slow cooling, the steel crossed the broken line G S E on side G S. At this point the alpha ferrite separates out and forms a mixture of alpha and gamma iron. Then on further cooling, this mixture passes through another transition point at the (L S K) eutectoid line, which means that the solution has changed to an aggregate of alpha ferrite and cementite. During the passage of the metal through this transition point, there has been a complete change in the crystallization of metal during which the crystals in reforming new bodies set up a tremendous amount of stress in the center bar of the plate, caused by the contraction of the individual crystals.

It is true that in this investigation it was the writer's intension to try to reduce the stresses by peening the deposited metal. In doing so, several different pressures were used and peening was controlled the same in each case to determine what pressures were more effective. It was found that peening is somewhat effective in relieving residual stresses and improving physical properties. The effect of pressures were about the same from about 40 to 75 pounds.

The effect of peening is shown by a block curve as may be seen on page 79.

In making a study of the structures by microscopic examinations of the sections cut from the test specimens, it was proved that peening improved the qualities of welds by elimiating some of the impurities such as oxides, etc., also helping to from a uniform structure by forming a closer and more perfect bond between crystals. The study also shows that strain had been set up in the outside deposited layers because the crystals had been distorted. This, in itself, accounts for the amount of stresses that were set up in the center bars of the test specimens.

CONCLUSIONS

The study of the summary of all test data obtained has revealed the fact that peening of welds with the idea of relieving stresses alone is a serious mistake, for very little benefit has been accomplished from peening. It has a vital effect on improving the structures and causing all physical properties of the metal to be improved. With the combination of the two, peening is very beneficial in welding fabrications.

In the writer's opinion stresses in the bars that were obtained by the use of strain gages is more or less a skin effect, and not uniform through the entire sections. The reason for making this statement is due to the distorted crystals in the outside deposited layers of metal which is clearly shown by microscopic examination of the weld deposits. Further investigation will be carried out, endeavoring to prove this theory.

If it were possible for the percentage of shrinkage of the deposited metal to be reduced, the problem of high stresses would be solved. With this in view, a thorough investigation should be made to find some method of alloying the electrode metal to aid in the reduction of shrinkage.

It is the writer's purpose to make it definitely clear that the high stresses that were obtained in this investigation do not occur except in very rigid type of structures.

Ordinarily the stresses do not go beyond the elastic limit in commercially fabricated structures.