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THE STRENGTH OF OXYACETYLENE WELDS IN STEEL

BY

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ENGINEERING EXPERIMENT STATION

BULLETIN NO. 45 SEPTEMBER 1910

THE STRENGTH OF OXYACETYLENE WELDS IN STEEL

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*Since the manuscript for this bulletin was submitted, Mr. Whittemore has accepted appointment as Engineer of Tests of the U. S. Ordnance Department at Watertown Arsenal.

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I. Introduction.

1. *Preliminary.*—Among the recent developments which give promise of wide-spread use in the field of metal working, is that of the oxyacetylene blowpipe. Due to the high temperature of the flame produced by this instrument, results are obtained which heretofore have been impossible. The most important use of the oxyacetylene flame is the welding of two pieces of metal by fusion without the necessity of adding either flux or soldering or brazing material. This process is known as autogenous welding.

This process has already become important commercially. It seems probable that when its effectiveness and availability have become known, it will be quite generally used, both by large and small metal working shops. In this connection the following facts may be noted:

(1) The combination of oxygen with acetylene produces one of the highest temperatures known,—the highest due to combustion and about equal to that obtained in the electric furnace.

(2) Methods of producing calcium carbide in the electric furnace, and methods, recently perfected, of producing oxygen by the distillation of liquid air, and by other means, have reduced the cost of these gases to the point where they are commercially available.

(3) The oxyacetylene blowpipe, formerly liable to dangerous explosions, has been perfected until entire safety is claimed.

(4) The necessary apparatus, when conditions demand extreme simplicity, consists only of a small tank of compressed oxygen and another of acetylene dissolved in acetone, both connected to the blowpipe by rubber hose. It is easily portable and can be used in almost any place or position.

(5) Skill in operating the blowpipe is readily acquired by an ordinary workman.

The general applicability of this process to welding depends upon two things: first, the strength and other physical properties of the welds; and second, the cost of the work. Of these, the first is the more important. An extensive search for data upon the matter of strength showed that very little had been published, merely a few general statements and still fewer definite ones. Most of the latter, however, appeared to be of doubtful accuracy. References to articles on this subject are given in the bibliography.

The process has been used successfully for the following work:

(1) Welding tanks and sheet metal work of all descriptions.

(2) Welding frame joints for automobiles, making a rigid structure all in one piece.

(3) Adding metal where needed, usually in small quantities; for example, eliminating defects in castings, particularly in steel castings, such as blowholes, etc., or adding metal to a piece which has been machined under size.

(4) Repairing boilers by either welding cracks, patches, etc., or adding metal where "grooving" or "pitting" has occurred.

(5) Bonding of electric traction rails by fusing the copper bond to the rails.

(6) Repairs of all kinds, made necessary by breakage. For example, a cast-iron punch press frame, broken at the throat, has been welded so that practically it is as useful as ever.

While the oxyacetylene blowpipe method of welding may be applied successfully to a very wide range of work in emergencies, such as "break-down repairs", etc., the cost of the necessary gases for welding thick pieces is so high that this method will never entirely displace coke, gas, or electric welding outfits for manufacturing conditions. Its field is especially *repair work*, *field work*, and manufacturing operations on *pieces of small cross-sectional area*, say, plates not exceeding ¼ in. in thickness.

2. *Scope of Tests.*—The experiments recorded in this bulletin were undertaken with the aim of adding to the information regarding the strength and other physical properties of oxyacetylene welds in steel, inasmuch as steel is the most important metal used in commercial construction. The number of tests was made large enough, it is hoped, to make the results representative of the results which may be obtained under favorable commercial conditions. Although circumstances limited the work to a small range in the thickness of the steel plates, an attempt was made to determine the effect of other variables, such as thoroughness of fusion, forging and heat treatment, and flame regulation, which might have an effect on the welds.

Little attention was paid to the matter of cost of welding the test pieces, as data of cost are of doubtful value unless obtained under commercial conditions. Several of the references listed under VI. Bibliography discuss this matter quite fully, and the firms supplying oxyacetylene welding apparatus are willing to undertake work for prospective customers and thus determine experimentally the time and materials required. In any case, there should be no excuse for operating a blowpipe for any length of time under commercial conditions without estimating the cost, but to obtain data on the strength of the welds requires apparatus and time not usually available, so that there is likely to be much doubt on the latter subject even where the process has been in use for long periods of time.

Incidentally, an investigation was made of the effect of flame regulation upon the strength of the weld and upon the proportions of oxygen and acetylene in the blowpipe flame. The record of experience in blowpipe manipulation and skill in welding as the work progressed, together with other information obtained, will, it is thought, be of service to users of the oxyacetylene blowpipe.

3. *Acknowledgment.*—The apparatus used was a part of the equipment of the Laboratory of Applied Mechanics of the University of Illinois, and the work was carried on in the Laboratory as an investigation for the Engineering Experiment Station. All the work of welding and testing was done by the writer.

In making the chemical analyses of the gas samples, valuable assistance was rendered by R. H. Jesse, Jr., Ph. D., of the Chemistry Department, University of Illinois, to whom much of the credit for this part of the work is due.

4. *Historical.*—The oxyacetylene blowpipe is an outgrowth of the blowpipes in common use which are supplied with coal gas and air. Attempts to increase the temperature of the flame led to the use of combustible gases having higher thermal values per unit of volume, and to the use of pure oxygen. In this way, a given number of heat units, produced by the combustion, were confined to the smallest possible volume of gas. The use of pure oxygen eliminated the nitrogen present in the air which served only to dilute the gases and to lower their temperature in a corresponding degree. The result of these changes was to bring

into use the oxyhydric blowpipe, which is extensively used in Germany for the autogenous welding of steel and for other work.

Acetylene, as a substitute for hydrogen, offered theoretic advantages, as its thermal value is 1846 British thermal units per cubic foot. This amount is over six times the thermal value of hydrogen, which is 293.5 British thermal units. Attempts to use acetylene, however, resulted in serious explosions. The first successful oxyacetylene blowpipe was devised by E. Fouché, a French investigator, who experimentally determined the rate of propagation of an explosion in tubes of varying cross-section, when they were filled with an explosive mixture containing acetylene. He then perfected a blowpipe in which the acetylene is supplied through small tubes at a rate greater than that of the propagation of the explosion back toward the acetylene reservoir. While this precaution would, apparently, be unnecessary if the tubes contained only pure acetylene, there is always some danger that, on account of imperfect operation, the oxygen which is under higher pressure than the acetylene will be forced into the acetylene passages or even into the reservoir itself.

In order that use may be made of the acetylene gas under the pressure at which it is usually generated (about 20 in. of water or less) the Fouché blowpipe uses the oxygen under pressure to draw the acetylene into the blowpipe on the injector principle. This avoids the necessity for an expensive compressor for the latter gas.

Fouché invented his blowpipe probably about 1902 or 1903, but the process was not introduced into this country until 1904, when the Fore River Shipbuilding Co., of Quincy, Mass., installed oxyacetylene blowpipes for welding light sheets of metal which had formerly been riveted.

Several blowpipes have since been designed to use both gases under pressure, and they are said to have the following advantage over the Fouché blowpipe. Both gases, being under pressure, maintain quite accurately their relative proportions when once properly adjusted. In the injector blowpipes, on the contrary, changes in temperature of the blowpipe and the copper tip forming the outlet cause some variation in the size of this opening and consequently variations in the relative proportions of the gases.

II. WELDING APPARATUS AND METHODS.

5. *Apparatus.*—The Fouché blowpipe was selected for these experiments because it is probably the best known and most widely used. While there may be differences among various oxyacetylene blowpipes in regard to convenience of operation, there can be very little difference in the efficiency of joints welded by these various blowpipes.

A welding equipment was secured from the American firm controlling the Fouché patents. It consisted of a Fouché blowpipe, a hydraulic back-pressure valve, a tank of compressed oxygen, an oxygen pressure regulator, a pair of blue glasses and a rubber hose.

In order to avoid the trouble and expense of an acetylene generator for this work, tanked acetylene was secured from The Commercial Acetylene Company, 80 Broadway, New York, from their plant at Joliet, Illinois. For commercial work of any magnitude, acetylene would usually be generated, as the cost would then be about one-third that of tanked gas. Tanked acetylene offered advantages for experimental work, among which were the probability of a more uniform quality of gas than would have been obtained from a generator, and also the possibility that the gas was more nearly pure. This company furnished a tank of acetylene, a high pressure gauge, and an acetylene pressure regulator.

6. *The General Arrangement of Apparatus as Used.*—The apparatus was arranged as shown in Fig. 1, the parts being as follows: A, work bench, covered with fire brick; B, blowpipe; C, oxygen pressure regulator; D, oxygen tank; E, hydraulic back pressure valve; F, acetylene pressure regulator; G, water U–tube for pressure of acetylene as supplied to blowpipe; H, gauge for acetylene tank pressure; I, acetylene tank.

The arrangement of the oxygen connections and of the acetylene connections is shown in Fig. 1. The acetylene supply is connected to the back pressure valve E. The hose J–K conveys the gas from the back pressure valve to the blowpipe. The oxygen tank is shown with its pressure regulator, C, the gas passing to the blowpipe through the hose L–M.

7. *Oxygen Supply.*—The oxygen tank had a capacity of 100 cu. ft., when charged to 120 lb. per sq. in., and weighed, empty,

132 lb. The oxygen was about 95% pure, nitrogen being the principal impurity.

In order to maintain a constant pressure suitable for use in the blowpipe, a regulator was attached to the oxygen tank. This is shown in Fig. 1. The pressure gauge, N, measures the tank pressure and allows computations to be made, at any time, of the amount of oxygen remaining in the cylinder. The thumb screw P adjusts the pressure of the gas as delivered to the blowpipe, which is measured by the pressure gauge O.

8. *Acetylene Supply.*—The acetylene tank had a capacity of 225 cu. ft., when charged to 150 lb. per sq. in. pressure. The tank was 12 in. in diameter by 36 in. long and weighed 120 lb. These tanks are packed with asbestos disks before the ends are closed. The asbestos is then saturated with acetone (a species of wood alcohol,) which at 10 atmospheres, or 150 lb. per sq. in. pressure, absorbs ten times its own volume of the gas at a normal temperature, thus increasing the storage capacity of the tank tenfold. Absolute safety for this method of storage is claimed by the manufacturers from whose catalog the above information regarding the tank was obtained. Analyses made by the firm supplying the acetylene indicate that the gas used was about 99.6% pure.

The acetylene tank I with its valve Q is connected by a pipe to the constant pressure regulator F. The pressure gauge H measures the pressure in the acetylene tank; with the pressure known, the amount of gas contained at any time may be computed.

This regulator was not provided with means for adjustment, but a pressure in the outlet pipe of about 12 in. of water was maintained. A U-tube filled with water and connected into this outlet pipe, (G, Fig. 1), allowed this pressure to be measured. It varied somewhat, depending partly upon the amount of water in the back pressure valve.

9. *Hydraulic Back Pressure Valve.*—A section through this valve is shown in Fig. 2. Water is supplied through D and G, and brought to the proper level, E, by opening the cock F, and draining any excess, after which F is closed. The acetylene enters through the cock B and bubbles up through the water, then passes to the blowpipe through cock C. If, for any reason whatever, the direction of flow is reversed, the water level at E

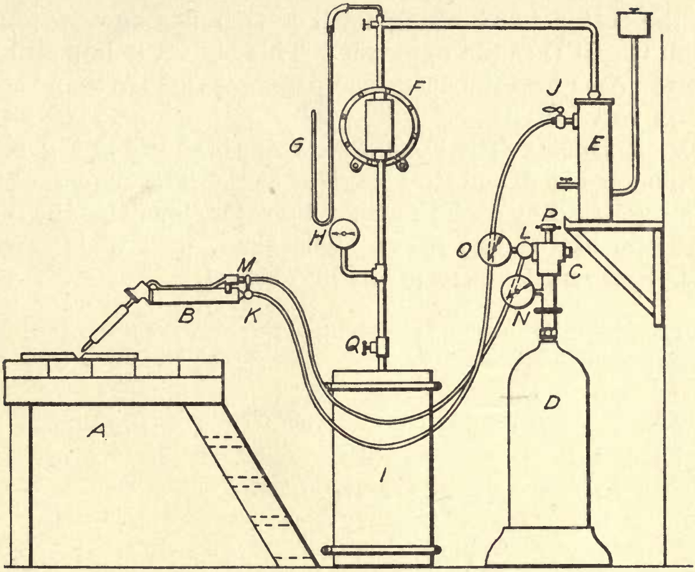


FIG. 1. GENERAL ARRANGEMENT OF OXYACETYLENE WELDING APPARATUS.

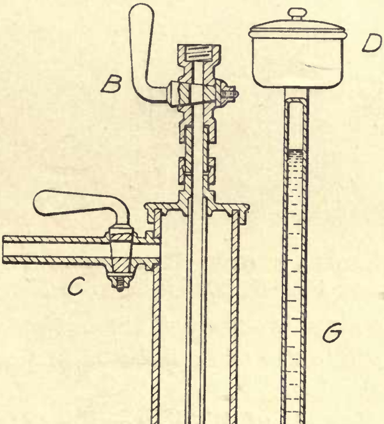


FIG. 2. BACK PRESSURE VALVE FOR ACETYLENE.

falls, the water in G rising until a free passage is provided through G and D to the outer air. This makes it impossible for oxygen to pass into the acetylene passages further than the back pressure valve.

10. *Blowpipe.*—The Fouché blowpipe is shown in Fig. 3. The oxygen enters at A and the acetylene at B. The amount of acetylene is regulated by cock C, which, therefore, controls the relative proportions of the two gases. The sizes, with their capacities and gas consumption, are given in Table 1.

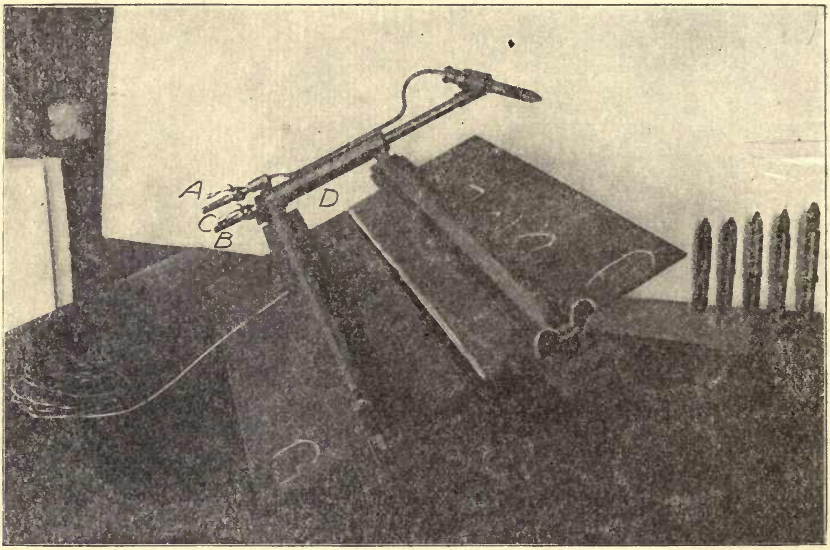
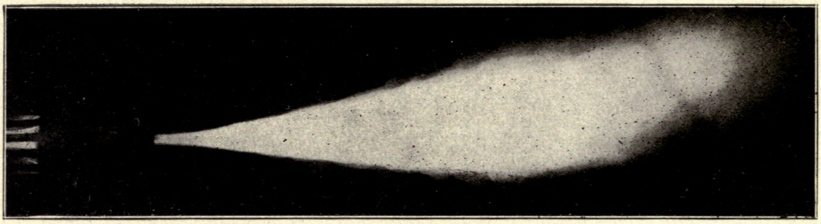


FIG. 3. FOUCHE BLOWPIPE WITH REMOVABLE TIPS AND TEST STRIP READY FOR WELDING—SECOND METHOD.

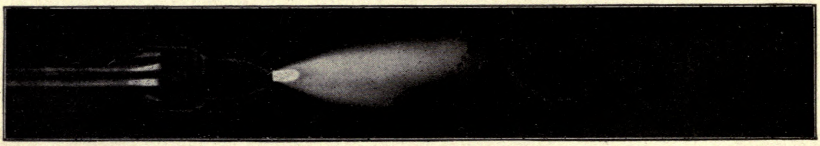
Each of the above sizes is intended for use only on plates of the thickness stated. The use of an unsuitable size of blowpipe will result in loss in economy.

11. *General Methods of Welding.*—There are two methods of making autogenous welds. The first, suitable for thin plates, requires that the edges be brought into perfect contact. They are then fused together without the addition of any material. The second, used for thick plates, consists in fusing into a groove formed by the beveled plate edges, material similar to that in the plate. The thickness generally given as the dividing line between



(a) Acetylene Flame in Air.

(b) Excess-acetylene Flame (Double Cone).



(c) Normal or Correct Oxyacetylene Flame.

(d) Excess-oxygen Flame (Short Cone).

Fig. 4. Variations in the Flame of the Blowpipe.

the two methods is ¼ in. The No. 7 blowpipe was selected on this account, as with it both methods of welding could be investigated. This size also allowed the use of specimens having fairly large cross-sectional areas without the unduly great cost of operation of the larger sizes.

TABLE 1.

SIZES AND CAPACITIES OF FOUCHE BLOWPIPE.

Blowpipe No.	Approximate Thickness of Sheet or Plate, inches	Approximate Consumption, cu. ft. per hour	
		Oxygen	Acetylene
2	$\frac{1}{32}$	2	1½
3	$\frac{3}{64}$	4	2½
4	$\frac{3}{32}$	6	3¾
5	⅛	10	6
6	$\frac{3}{16}$	16	10
7	¼	25	15
8	⅜	36	22
10	½	45	28
12	⅝	65	40
15	¾	100	60

NOTE: For copper plates, larger blowpipes are required than for steel plates of corresponding gauge.

12. *Regulation of the Blowpipe.*—Given the gases supplied under constant pressure, the proper proportioning of the two is obtained by adjustment of the cock C, Fig. 3.

The operator is governed in the regulation solely by the appearance of the blowpipe flame. Slight variations in the proportions caused relatively large variations in the appearance of the flame. This is well shown in Fig. 4, reproduced from photographs of the flame itself. The combustion of acetylene alone (see (a)) gives an intensely white flame of large volume with a heavy formation of soot at its outer end. When oxygen is added, the flame shortens (see (b)) and the combustion is more nearly complete, as is indicated by the nonformation of soot. There is then one small cone close to the tip of the blowpipe which is intensely white. This is surrounded by another white cone which in the cut partially masks the inner cone. Both are perfectly visible to the eye, particularly when observed through blue glasses. Beyond these two white cones is a nearly colorless flame of large volume.

Proper regulation is obtained by reducing the amount of acetylene until only one white cone is visible, as shown at (c), with a colorless flame as before. This single white cone is with the No. 7 blowpipe about $\frac{1}{8}$ in. in diameter and $\frac{5}{16}$ in. long, and has a rounded end. If the acetylene is reduced still further, the cone shortens as shown at (d). Proper regulation is effected when the flame is seen as a single cone of dimensions as large as possible. This is the operator's chief guide. As it is difficult to determine by inspection when this cone has shortened, especially after work has been in progress several minutes, it is convenient to increase the supply of acetylene until two cones appear, then decrease it until the second cone disappears.

References No. 1 and 2 under VI. Bibliography give descriptions of the various flame characteristics and a discussion of the chemistry of the combustion.

III. Test of Welds.

13. *General Plan of Tests.*—As these experiments were undertaken to ascertain the strength of welds as made by a workman of moderate experience, a large number of specimens were prepared for tensile tests. While the statement is often made that the strength of the weld is affected by conditions which are practically beyond commercial control, such as the purity of the gases and the material to be welded, and also, possibly, the construction of the blowpipe, these factors were all disregarded, as they were probably constant in this work and more especially as they duplicated accurately the conditions which exist in commercial work. The skill and care of the operator, without a doubt, are chief factors in controlling the quality of the welds. The effect is especially noticeable when the operator is utterly without experience, as was the case when this work was started. Attention was therefore concentrated on the proper blowpipe manipulation, and the number of test pieces was made great enough to provide considerable practice, which, it was hoped, would show an increase in the strength of the welds as skill was acquired.

The general plan of preparing and testing specimens for tests of strength of welded joint may be seen from Fig. 5. A plate of steel was cut into strips A, B, C, etc., and from the ends of each strip test pieces were cut which were tested in tension to give the strength of the plate material. The remainder of the strip was then cut in two lengthwise. These cuts are shown in Fig. 5 (a), by broken lines lengthwise of the strip. The two parts were then welded together and the welded strip cut across the weld into specimens as shown by the cross-wise lines in Fig. 5. Each strip was about 2 ft. long by 1 ft. wide. In the first series of tests the strips were so arranged that some specimens were cut in the direction of rolling and others perpendicular to the direction of rolling. The specimens were then tested in tension.

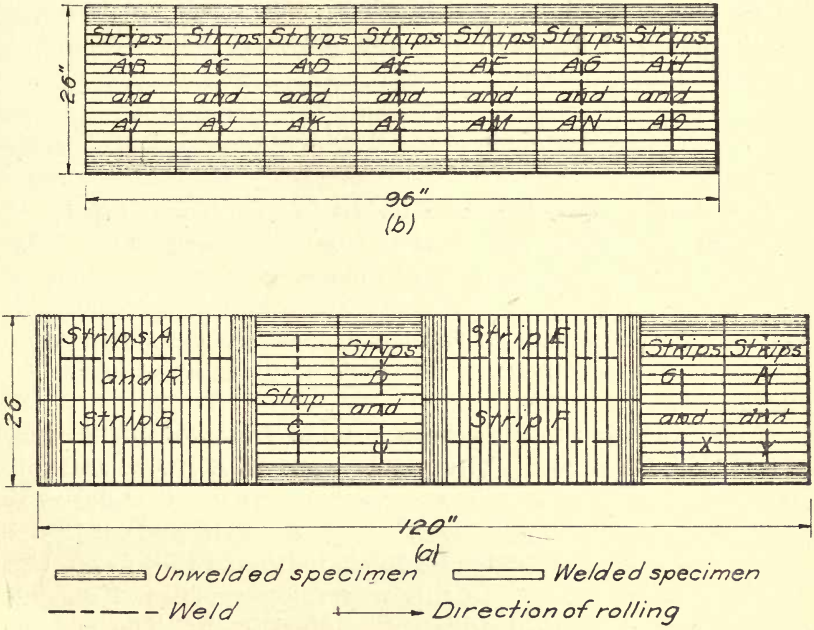


FIG. 5. LOCATION OF STRIPS AND TEST SPECIMENS IN STEEL PLATES.

14. *Preliminary Tests.*—Some welding practice was obtained by welding pieces of band iron 0.135 x 1.344 in.; about 50 such welds were made and tested. The actual blowpipe time required, as computed from the amount of oxygen used, was 2.16 hours.

This band iron, unwelded, had an average ultimate strength of 62 300 lb. per sq. in. and a yield point of 46 400 lb. per sq. in. with an elongation in 4 in. of about 20%. When welded the values for all these properties were lower than in the unwelded material. The loss was about 5.7% in the yield point, 30% in the ultimate strength, and 88% in the elongation. The results of these preliminary tests are not considered of sufficient importance to be recorded here.

This work was excellent considering that the operator had no previous experience and no instruction except that contained in the printed directions accompanying the apparatus. It should also be remembered that the blowpipe was much too large for this thickness of metal so that the material was undoubtedly over-heated.

A. FIRST SERIES OF TESTS.

15. *Specimens.*— The main object in this series of tests was to provide practice in the use of the blowpipe, and to bring out, if possible, the variables affecting the strength of the welds. In general, the efficiency of the welds was found to be low, and a constant effort was made to find the cause of the low strength and its relation to the appearance of black or dark blue spots in the fracture.

Four flange steel plates were secured from Joseph T. Ryerson and Son, Chicago. The plates were 26 × 120 in. and ¼ in. thick. The method of preparing specimens was that described under 13. General Plan of Tests. A whole strip was cut into 16 specimens about 1½ in. wide and 13 in. long, and these were tested in tension to failure. In this way the properties of the weld at every portion of its length were determined. The material would have been injured had the metal been sheared, so the cuts were made on the planer or shaper with a cut-off or parting tool. As this proved to be a tedious job, after the first few strips a power hacksaw was used and proved satisfactory.

For filling, very soft open hearth steel wire No. 14 (0.079 in. in diameter, actual measurement) was used. This was also purchased from Joseph T. Ryerson and Son. The physical properties of this wire, as determined by tension tests, were as follows:

Ultimate strength, lb. per sq. in.,	64 400
Yield point, (about) lb. per sq. in.,	37 500
Elongation in 10 in., per cent,	15
Reduction of area, per cent,	74

No analyses of gas or material were made for this series of tests.

16. *Method of Testing.*—The testing was done in a 100 000-lb. Riehle testing machine having an autographic attachment. The dimensions of the specimens were first carefully taken. A thread micrometer with contact surfaces about $\frac{1}{32}$ in. in diameter was used for obtaining the thickness. Great care was necessary in this measurement, because of the roughness of the surface of the weld when it remained as it came from the blowpipe. The surface of the specimen was divided in such cases into strips $\frac{1}{4}$ in. wide, and the micrometer readings for thickness were taken at the center of each strip and averaged for the thickness of the specimen.

A 6-in. gauge length was laid off each specimen and marked with a center punch. The shortness of the specimens made an 8-in. gauge length impracticable. When placed in the machine, the clamps for the autographic apparatus were secured to the specimen at the punch marks and a record made as the test progressed. From this the yield point and ultimate strength of the specimen were determined with sufficient accuracy for this work. A copy of a number of such records is shown in Fig. 6. The elongations were measured with a steel scale from the specimen after rupture, not from the graphical record.

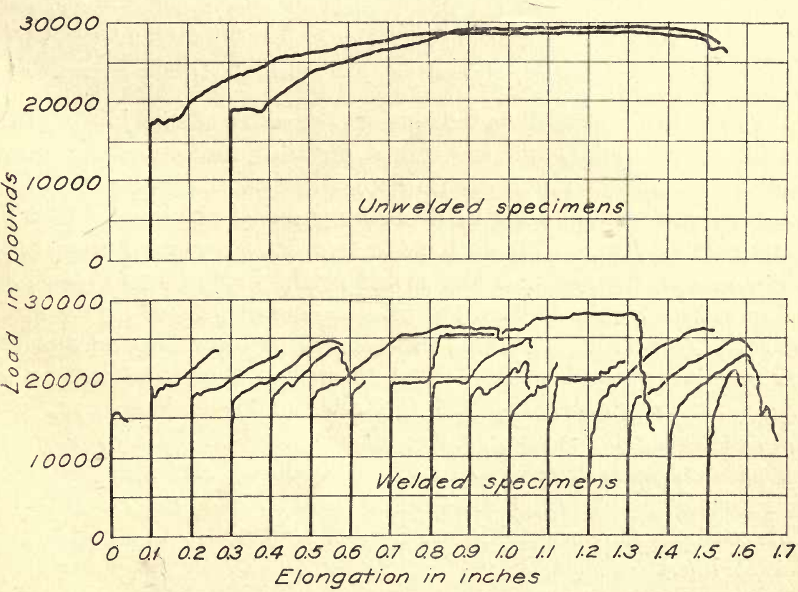


FIG. 6. AUTOGRAPHIC TENSION-TEST DIAGRAMS OF WELDED AND UNWELDED SPECIMENS.

The stresses at yield point and ultimate strength were computed by dividing the load from the graphical record by the actual original area at the place where the rupture occurred, usually at the weld.

The efficiency of the weld was determined by dividing the ultimate unit-stress (when rupture occurred at the weld) by the average ultimate unit-stress of the unwelded specimens, for the same section of the plate. Thus:

$$\frac{\text{Ultimate stress in weld}}{\text{Ultimate stress of unwelded material}} = \text{Efficiency of weld.}$$

This efficiency is then the ratio of the strength of the weld to the strength of the material, and measures, in some degree, the value of the welding process.

17. *Manipulation and Preparation.*—In this, as in the preliminary work, an attempt was made to follow all instructions given in the manufacturer's circular as closely as possible.

These may be summarized as follows:

Commence welding at nearest point and work away from the operator. (See 26. Improvements in Methods of Welding.)

Attend carefully to the regulation of the flame.

The apex of the small flame cone should be in contact with the metal to be welded. (See 26.)

The blowpipe should be held at a constant distance from the work and advanced slowly and regularly with a slight oscillating or circular motion.

When adding metal to the weld, care must be taken not to let the full force of the flame play on the rod or wire unless it is in contact with the pieces being welded which will prevent its being overheated.

Material being added must come in contact only with metal which is fused, otherwise welding does not occur.

The blowpipe was directed against the sides of the joints until the fusion occurred, and the slight circular motion of the flame caused the molten metal to flow together at the bottom. The blowpipe was advanced, still describing small circles, as fast as this weld was formed for an inch or two, then a return was made to the starting place and the metal again brought to a state of fusion. The wire was then fed into the small pool of liquid steel until the blast from the flame threatened to blow it over against comparatively cool steel. The blowpipe was then swung in larger circles which extended the area under fusion somewhat, while allowing the center of the pool to harden. These pools of molten steel were from ½ to 1 in. in diameter. Another pool was then formed just beyond the first so that their edges overlapped. (This method was changed later. See 26. Improvements in Methods of Welding.)

The plates for this series were clamped as shown in Fig. 7, to hold them in their proper relative positions and with their surfaces in the same planes. The thumb-nuts were not tightened sufficiently to prevent the plates from drawing together as the welding proceeded. Unless otherwise stated, the plates were beveled as shown in Fig. 8 (a), and clamped with the edges at one end of the joint in contact, and at the other end ½ in. apart to allow for "creeping". Welding was started at the closed end of the joint. The single strands of soft steel wire, No. 14, were used for filling.

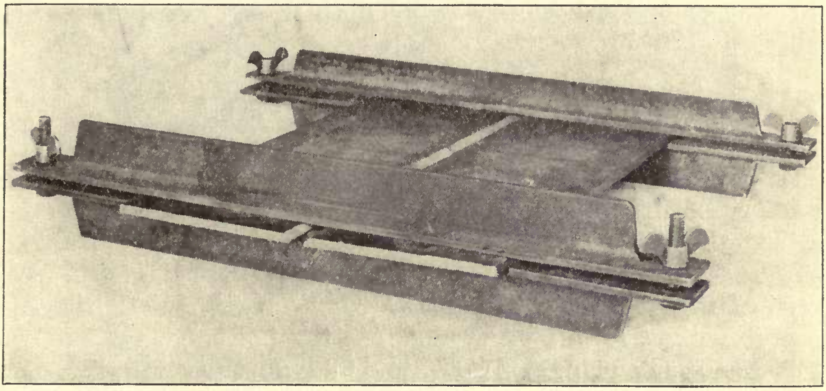


Fig. 7. Strip Clamped Ready for Welding.

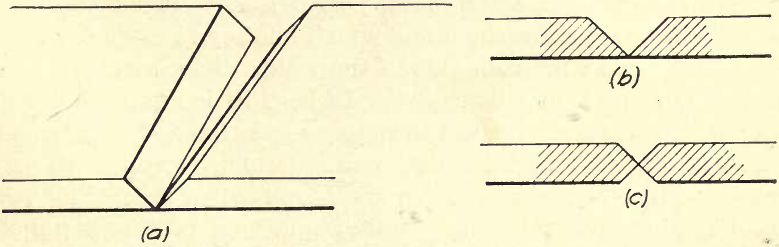


Fig. 8. Plates Beveled for Welding.

In adding the wire, difficulty was found in preventing the playing of the full flame on the wire when the blowpipe was given a circular motion; so at times, it was held nearly stationary and the steel wire pushed, as rapidly as it melted, into the pool just beside the flame. Working in this way, it took some time to build up the required thickness of metal at the weld. If depressions appeared after cooling occurred, the surface was again fused and more wire added until, as far as could be determined by inspection, no portion of the welded surface was below the adjacent surfaces of the plates. This series of operations was repeated until the weld was completed.

At times, in welding together the bottom of the groove before adding wire, the metal became too hot and dropped away, leaving an opening which the strong blast of the flame quickly enlarged. In such cases it became necessary to fuse the edges by passing the flame over the opening rapidly, while adding wire as rapidly as it fused, leaving a short length in the opening. When enough metal had been added to prevent the flame from passing through the opening, the whole mass was thoroughly fused together, forming a weld across the bottom of the groove. Wire was then added, as before, to build up the thin place, care being taken not to direct the flame against it too continuously.

The general appearance of such a joint is well shown in Fig. 9 and 10, taken from strip E after welding. Fig. 9 shows the upper side from which the work was done, and Fig. 10 the bottom where the edges were practically in contact before welding commenced. In Fig. 9 the pools forming the weld are shown. They are covered with black oxide formed by the oxygen of the air on the white hot metal left by the advancing blowpipe. The concave centers appear somewhat spongy on the surface but a file shows the bright, clean metal just below. The lighter portions of the plate show the metal which has been heated to redness but not to fusion on each side of the weld. The work proceeded from left to right in this case. In Fig. 10 is again shown the metal which has been heated to redness and also the excrescences of wire and molten metal which passed through gaps in the thin edges. This occurred at about three places in this weld. While not apparent in the photograph, this bottom sagged of its own weight while hot, aided, of course, by the blast from the blowpipe, so that the line of the weld was raised somewhat above the adjacent surfaces thus tending to thicken the metal at the weld. Probably this never exceeded $\frac{1}{16}$ in.

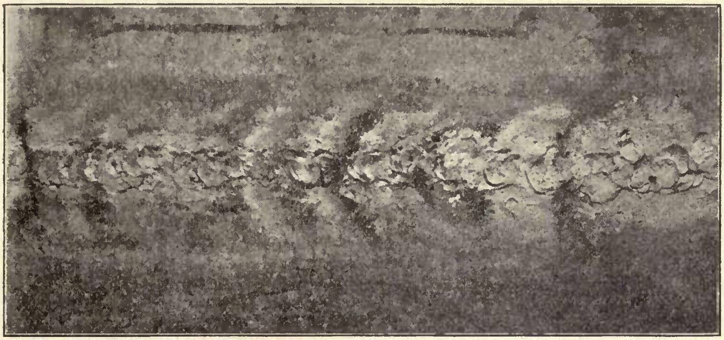


FIG. 9. UPPER SIDE OF WELD MADE BY "POOL" WELDING.

FIG. 10. UNDER SIDE OF WELD MADE BY "POOL" WELDING.

18. *Strip A.*—In the first strip tested, the general methods of welding, cutting, and testing specimens described in the preceding paragraphs were followed. One of the clamps was removed after the welding had progressed about half the length of the joint. After cooling it was found that the plates had been drawn up at their outer edges on account of the cooling of the comparatively large body of molten metal near the upper surface, so that they formed a shallow trough or V. While the section was almost flat where the welding started, on account of its having cooled while held by the clamp, at the other end of the weld where the clamp had been removed, the sides were fully an inch above the joint.

While the welding had been in progress, the edges had been drawn together just ahead of the blowpipe by the cooling of the joint just back of it. The amount allowed for this "creep" ($\frac{1}{2}$ in.) was hardly sufficient, as the thin edges appeared to crowd, thus tending to overlap. The strip was cut into specimens and these were tested without being straightened, although severe bending stresses were undoubtedly imposed on the material on the concave side of the specimen, thus tending to lower the strength of the weld. The data for these specimens are given in Table 2. The appearance of the metal in the welds after rupture is shown in Fig. 11. In most cases the silky fracture of the unwelded specimens is altered to crystalline in the welds, probably on account of the rapid cooling from a liquid state without rolling or other working of the metal. At intervals dark spongy spots, black or blue in color, occur in the weld. When questioned regarding them, the blowpipe manufacturer claimed that any discoloration must be due to burnt metal caused by an excess of oxygen in the welding flame.

The average efficiency of these specimens was 69.3%, the highest, 90.7% and the lowest 47.7%. A gradual decrease was noted as the welding of the strip progressed, due, very probably, to the fact that specimens were not straight when tested, although the data are insufficient to verify this.

For specimens having an ultimate strength below that of the yield point of the material, the weld fails before the material in the remainder of the specimen is stressed to the yield point. Although the material in the weld is probably somewhat brittle, it is so small in amount that little or no elongation would be observed on a 6-in. gauge length even if it were as ductile as the remainder of the specimen.

When the strength of the weld is above the yield point of the material, then the material throughout the length of the specimen elongates until the rupture occurs. This rise in the elongation was very noticeable for specimens 6 to 9, inclusive, for strip A.

The length of the welded portion is so small in comparison with the length of the specimen that the yield point at the weld could not be determined with accuracy, and hence the yield point of the welded specimen is not considered especially significant.

19. *Strip B.*—The preparation and manipulation used for strip A were followed as closely as possible for strip B, except that the allowance for "creep" was $\frac{5}{8}$ in. instead of $\frac{1}{2}$ in. This was found to be too much, as the plates did not draw together sufficiently to close the bottom of the groove, and consequently the flame melted through at frequent intervals.

When the weld was about half completed, work was stopped to lengthen the thread on one of the thumb bolts. This allowed the plates to cool and they warped and twisted badly. The unwelded edges of the groove overlapped about $\frac{1}{2}$ in. at the further end of the section so that satisfactory completion of the weld was impossible. The specimens were cut from the good weld and tested as before. The data are given in Table 2.

The average efficiency was 68%, the highest 79% and the lowest 56.3%.

20. *Strip C.*—This strip was welded in the same way as the two previous strips. The allowance for "creep" was $\frac{1}{2}$ in. and the section was practically flat when cold. The rough surfaces of the welds were ground practically smooth on an emery wheel before measuring the thickness. The width was divided into three strips, each about $\frac{1}{2}$ in. wide, and the thickness was measured at the middle of each as before. All welds in this strip and in all strips later tested, unless otherwise stated, were ground smooth, as by so doing the area of the weld could be more accurately determined. The emery wheel was of a medium coarse grade and used dry but the specimens were cooled frequently in water and some care was taken not to heat them enough to cause much "bluing" of the steel surface, as an annealing effect upon welds might result. See Table 2 for data.

The average efficiency was 74.3%, the highest 90.5% and the lowest 52.7%.

21. *Strip D.*—This strip was welded as usual except that an attempt was made to determine the effect of variations in the flame regulation, which were intentionally made excessive. The allowance for "creep" was $\frac{9}{16}$ in.

Specimens No. 5 to 8, inclusive, were welded with the regulation as perfect as possible, while for 9 to 12, inclusive, there was a decided excess of acetylene, and for 13 to 15, inclusive, a decided excess of oxygen. In the second lot, the second cone of the flame, Fig. 4b, was, as nearly as could be judged by the eye, 150% of the length of the first cone, both being measured from the blowpipe tip. In the third lot, the first cone, Fig. 4 (d) was shortened to little more than 50% of its length when properly regulated. Fig. 4 (c) shows the flame properly regulated. See Table 2 for data.

The average efficiency was 64.5%, the highest 79% and the lowest 52.7%.

22. *Strip E.*—As the effect of varying the regulation of the blowpipe with the previous section did not appear to have a marked influence upon the strength of the weld, it was decided after some consideration that possibly the single strands of No. 14 wire which had been used for filling up to this time, might become overheated in the blowpipe flame and thus be the cause of the burnt spots and the low strength. In order to try a larger cross-section of filler rod, four strands of wire were twisted tightly together for this section. This gave a large surface exposed to the action of the flame so that melting occurred rapidly, but at the same time gave a larger body of metal to absorb the heat and fill the groove rapidly. See Table 2 for data. Specimen No. 12 broke 2 in. from the weld.

The average efficiency was 69.2%, the highest 80.5% and the lowest 54.6%.

23. *Strip F.*—The allowance for "creep" was ½ in. Four-strand filling was again used. As in previous work, the blowpipe tip became heated from the weld, as the tip of the flame was kept approximately in contact with the surface of the metal. A gradual increase in the amount of acetylene for proper regulation was found necessary, due to this increase in temperature. Several times the acetylene cock was open wide so that further regulation was impossible. When this occurred, the blowpipe was cooled in water which restored the original conditions as regards regulation. Upon the whole, the flame regulation for this section was quite poor.

The surface of the welds was purposely not ground, in order to avoid any annealing effect due to the heating caused by the dry emery wheel. See Table 2 for data. The low percentage of elongation for the unwelded specimens is due to the fact that they all broke outside the gauge length.

The average efficiency was 66.8%, the highest 74.9% and the lowest 55%.

24. *Strip U.*—As the welds with beveled edges did not increase noticeably in efficiency, a butt weld was tried. This strip had square edges which were practically in contact along the seam before welding. This may be expressed by saying that the edges of the plates were beveled at 90° instead of 45°, as in previous strips. No filling material or wire was added.

The plates were clamped as usual with no allowance for "creep," as it was supposed that the square edges would prevent any tendency to overlap due to the contraction of the metal in the weld. This, however, proved to be an error. After the weld was finished and the plates cooled, they were found to be badly warped. When three corners were on a plane surface, the fourth was about one inch above it. They had also crowded together so that while the weld started with the surfaces of the plates flush, after about two-thirds of the weld had been completed they were offset $\frac{1}{8}$ in. and at the end offset $\frac{1}{16}$ in. The end was, of course confined closely by the clamp there. Evidently allowance should have been made for creep.

The welding was performed by causing fusion of the metal on one side only of the seam and causing the metal to flow together by the blast of the flame as it was swung back and forth. The metal was melted as deep as seemed possible and left rough with no attempt to add metal or grind the weld.

The flame was well regulated throughout, as it was frequently adjusted and never became hot enough to require cooling. After the weld was about half complete, the regulation remained practically constant until the work was finished. With the beveled seam the blowpipe tip becomes highly heated, due to the reflection from both sides of the groove. With the butt weld the blowpipe was further from the metal, generally, and maintained its regulation after reaching an approximately constant temperature. See Table 2 for data and Fig. 11 for appearance of fracture. Fig. 11 shows very clearly that the welds extended only a little way below the surface of the plates. The metal which has been melted shows a coarse crystalline fracture. Below that is a band of white metal which probably became pasty in welding but did not fuse thoroughly. This metal appears to unite to a slight extent but the weld there is weaker than through the molten metal. Below this, again, is a band of dark metal which was unaffected by the flame but was heated enough to oxidize on the surface wherever exposed to the air. The ragged appearance of this band, as in specimen 6, was due to a slight tearing of the metal surface by the dull cutting-off tool. Whereever this dark band appears on only one of the two pieces for each specimen, as in 13 and 14, it shows the amount of offset as explained above.

The average efficiency was 54%, the highest 74% and the lowest 35.1%. Considering the small areas actually fused and welded, this seemed quite remarkable.

25. *Strip Y.*—The allowance for creep was $\frac{1}{16}$ in. The plates were squared and the other conditions were the same as in strip U. They were welded from both sides without the addition of filling material.

The blowpipe was well regulated, particularly as the acetylene was readjusted to make sure of proper regulation after completing about 2 in. of weld. See Table 2 for data and Fig. 11 for appearance of fracture. As in the previous strip the band of white, noncrystalline metal through the middle of the fractures probably shows metal which was not melted.

A great increase is shown in the strength of the welds as work proceeded, but this may partly be accounted for by possible errors in measuring the thickness of the weld. The rough surfaces of the weld made accurate readings of the thickness impossible. As there was a tendency to measure the least thickness near the desired point, the average thickness and consequently the area are probably too low, thus causing the calculated stresses to be high proportionally.

The average efficiency was 82.4%, the highest 118% and the lowest 43.5%.

26. *Improvements in Methods of Welding.*—An engineer for the blowpipe manufacturers, Fred W. Wolf, Jr., was present when some of the specimens from the last three strips were tested. He discussed methods of welding and demonstrated the use of the blowpipe. Some days later, further instruction was obtained from an experienced welder employed by the same company.

While the manipulation used in making the welds up to this time was satisfactory, there were some ways in which the work could be more easily performed. It appeared likely that the adoption of such changes would also result in increased efficiency of the welds. These points may be briefly summarized as follows: Some workmen have found it preferable to work toward the operator rather than away from him, as was done in these welds. In working away from the operator, almost necessarily the blowpipe flame is directed toward the unwelded portion of the plates, making, perhaps, an angle of 60° with the completed weld. The blast from the flame tends to force melted metal from the end of the weld over upon colder metal with which it does not unite and to make it difficult to build up the filling material to the required thickness.

If, instead, the work progresses toward the operator, the blowpipe being held as described above, except that the blowpipe head makes an angle of about 120° with the finished portion of the weld, the flame strikes the sloping surface of the molten metal at the end of the weld more nearly perpendicularly and has less tendency to displace this metal.

Instead of welding in the bottom of the groove for a short distance, then forming a pool of molten metal of the required depth above it, it seems preferable to add constantly very small portions of the filling wire to the advancing surface of melted metal in the groove. If the work is done toward the operator, this procedure is comparatively easy. The sides and bottom of the groove become melted by the time the weld reaches them and the filling wire can be added uniformly to the comparatively small area of molten metal forming the end of the weld. This area advances, gradually, parallel to itself at all times, which was not the case when pools were formed.

To assist in keeping the molten metal in place, the plates may be inclined upward in the direction in which the weld is advancing. A rise of about an inch to the foot is sufficient.

Instead of keeping the tip of the flame constantly in contact with the molten metal it is advisable to increase the distance. If removed too far, the metal will not melt rapidly, and satisfactory work is impossible, so that experience shows that it is desirable to bring the flame in contact with the metal when working on cool metal, then gradually to withdraw the flame as long as satisfactory progress is being made.

Trial showed that the modified methods of carrying on the work aided considerably in *making* the welds, at least, and they were used in subsequent work. Often, after welding had started, and the metal became well heated, the flame could be removed from the work so that the distance from the tip of the flame to the metal was about equal to the length of the first cone. This apparently had no effect upon the progress of the work from the standpoint of rapidity of fusion, and did have two advantages. On account of the increased distance from the hot metal, the blowpipe did not become so highly heated, and after a short time maintained such a temperature by radiation, etc., that practically constant flame regulation was preserved. Frequent cooling of the blowpipe in water was therefore unnecessary; consequently, there were fewer interruptions to the work.

The greater distance from the metal also decreased considerably the number of "back fires", or small harmless explosions within the blowpipe. This will be evident when it is explained that the acetylene and oxygen unite to form an explosive mixture within the head of the blowpipe, but, as a rule, burn only upon issuing from the tip of the blowpipe. If the gases within the mixing chamber were stationary, the flame would be transmitted backward at a definite rate through the tip of the blowpipe and would cause an explosion or "back fire" in the mixing chamber of the blowpipe. The gases then continue to burn within the mixing chamber if oxygen and acetylene are supplied. Usually, however, the velocity of the gases out through the blowpipe tip is greater than that of the propagation of the explosion back into the mixing chamber, so that the gases burn quietly outside the tip. A "back fire" is caused by reducing the velocity of discharge through the tip, usually by obstructing the opening, as when the blowpipe is passed too close to the weld or other object. Increasing the distance of the blowpipe from the weld makes it much easier to avoid "back fires" from this cause.

Previously, when a "back fire" occurred, the acetylene was shut off, a procedure which in a few seconds extinguished the flame within the mixing chamber and allowed the blowpipe to be relighted. By observing an experienced operator, it was found that all that was necessary to extinguish a "back fire" was to close the tip completely for an instant, by brushing the tip across the clothing, then to relight the blowpipe by directing it upon the hot metal in the weld. This procedure reduced the interruption caused by a "back fire" to a second or so, at most, during which the metal scarcely cooled at all, while previously it often became very dark red, requiring some time to bring it again to the welding temperature. This cooling probably had a detrimental effect upon the strength of the welds.

27. *Strip G.*—In the tensile tests of specimens from strip G and in subsequent tests, instead of making an autographic diagram for the test of each specimen, the reading for ultimate strength was taken directly from the beam of the testing machine as usual, which effected a saving of time. The yield point for the welded specimens was not observed, as it appeared to depend entirely upon the yield point of the material outside the weld and to have no bearing upon the efficiency of the welds. Photographs of the specimens were also omitted as being unnecessary at this point in the work.

The allowance for creep in strip G was 0.4 in. The plates were beveled at 45° and four-strand No. 14 wire for filling used as for previous strips. A portion of these plates was used in demonstrating the rapidity of the modified methods of welding and was removed before making this weld. The surface of the weld was ground to obtain an approximately smooth surface. See Table 2 for data.

The average efficiency was 69.6 %, the highest 75.3% and the lowest 61.2%.

28. *Strip H.*—The allowance for creep was 0.45 in. The plates were beveled and ground after welding as for the previous strip. Instead, however, of using No. 14 wire for filling, a sample of $\frac{1}{8}$-in. soft iron wire supplied by the blowpipe manufacturers was used. See Table 2 for data. Apparently this $\frac{1}{8}$-in. wire did not make as strong a weld as the No. 14 used for the previous strip, but there were probably other conditions which affected the results.

The average efficiency was 50.6 %, the highest 58.9% and the lowest 41%.

29. *Strip R.*—The allowance for creep was 0.8 in., and three strands of No. 14 wire used for filling. Otherwise the conditions were the same as for the preceding strips. After welding the plates for about 12 in., it was found that the plates were separated by a gap which it was difficult to bridge with the filling material. Work was then stopped, and only the welded portion tested. See

Table 2 for data.

The average efficiency was 76.7 %, the highest 86.9% and the lowest 68.5%.

30. *Strip X.*—The allowance for creep was ½ in., otherwise conditions were the same as for the preceding strip. See Table 2 for data.

The average efficiency was 73.9 %, the highest 85.5% and the lowest 56.6 %.

TABLE 2.

RESULTS OF STRENGTH TESTS OF WELDS —FIRST SERIES.

Strip	Efficiency per cent			Rate of Welding ft. per hr.
	Av.	Max.	Min.	
A	69.3	90.7	47.7	1.47
B	68.0	79.0	56.3	....
C	74.3	90.5	52.7	....
D	64.5	79.0	52.7	1.00
E	69.2	80.5	54.6	....
F	66.9	74.9	55.0	2.80
U	54.0	74.0	35.1	....
Y	82.4	118.0	43.5	2.84
G	69.6	75.3	61.2	4.17
H	50.6	58.9	41.0	0.80
R	76.7	86.9	68.5	1.50
X	73.9	85.5	56.6	2.50

31. *Summary for First Series.—Grinding the Weld Surface.*—The necessity for removing the rough surface of the weld became very apparent when specimens from strip Y seemed to give over 100 % efficiency. A comparison of the range in efficiency for each section shows that upon the average ground specimens showed less variation than the unground. The unground strips are A, B, F, U, and Y, and their average range in efficiency, found by subtracting the lowest efficiency from the highest, is 39.8%. The ground sections are C, D, E, G, H, R, and X, and their average range is 22.2 %, only 56 % of range of the unground.

As explained for strip Y, when the weld was rough as left by the blowpipe, the constant tendency was to measure the least thickness near the point where a reading was to be taken. This, without doubt, frequently gave a sectional area less than the actual, and a consequently higher efficiency on the average for the unground specimens. The grinding introduced another factor into the problem whose influence upon the welds was unknown. If means were provided for milling the surfaces smooth, the temperature would probably never rise enough to cause any annealing effect. As care was taken in grinding to cool the specimen frequently, there is only a slight chance for annealing in these specimens.

32. *Consumption of Oxygen and Acetylene.*—The pressure gauges attached to both acetylene and oxygen tanks enabled the amount of gas consumed for each section to be computed. Readings of these gauges were taken during the welding of many strips. The amounts of acetylene and oxygen consumed were determined and compared with the average value for a No. 7 blowpipe given in the catalog of the blowpipe manufacturers. The measured average consumption of oxygen was 20.6 cu. ft. per hr. while 25 cu. ft. is given as the consumption in the catalog. The acetylene consumption was 22.7 cu. ft. per hr. and the catalog value is 15 cu. ft. The rather wide difference between the measured value and the catalog values and more especially the erratic fluctuations in the oxygen rate measured by gauge readings lead to the conclusion that while the pressure gauges are sufficiently accurate to determine the volume of gas contained in the tanks at any time, they are not sufficiently accurate (or sensitive) to determine the gas used for time intervals, say, of one hour. More accurate measurements were made in later tests. This subject is discussed in IV. Tests of Gases and Flame Regulation. The ratio of acetylene to total gas volume was also determined from the gauge readings and an average of 56.3 % found, which is much higher than the ratio of 37 % usually given, (1 volume of acetylene to 1.7 volume of oxygen). The ratio of the gas rates in the catalog is almost the same as this latter value, being 38.5 %. The wide fluctuations in the measured value of this ratio indicate that the tank gauge readings are wholly unreliable for determining this ratio or computing the quantity of gas used. Other means were therefore employed later.

33. *The Welding Rate.*—The rate of welding, of course, varies considerably with the skill of the workman and the conditions under which the work is done. The rates for the several strips are plotted in Fig. 12, and as might be expected, show an increase in speed as experience was gained.

In no case was the catalog value of 5 ft. per hr. reached, but it appears reasonable that an average, experienced workman could maintain that speed for several hours if not for the whole working

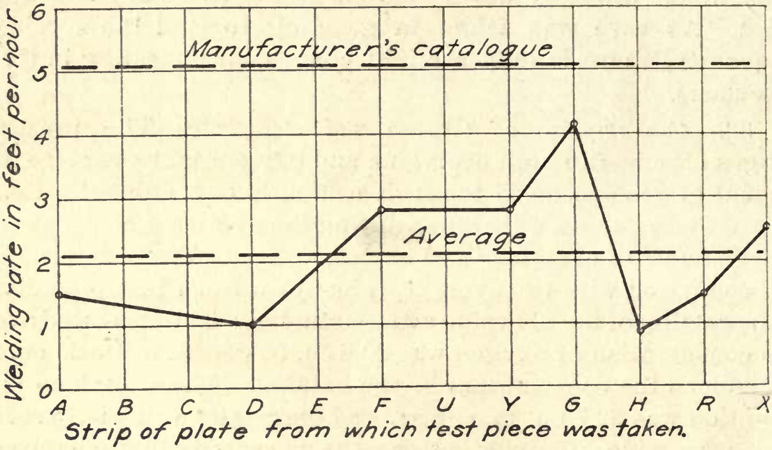
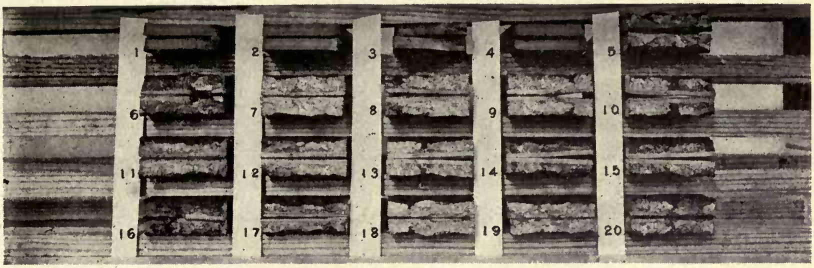


FIG. 12. RATE OF WELDING—FIRST SERIES.

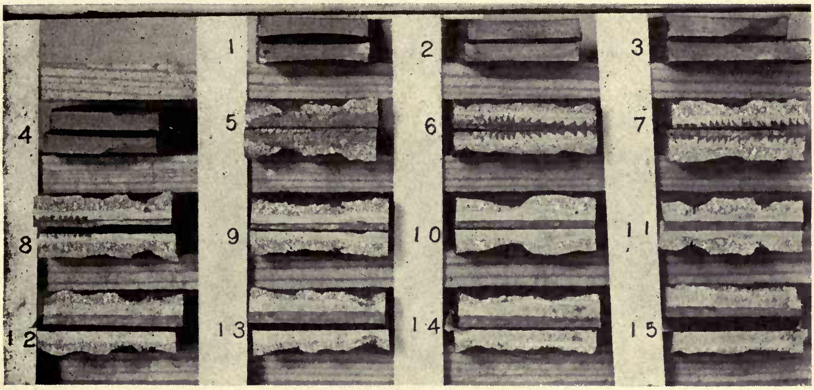
day. It should be noted that considerable instruction was received after strip Y was welded and that the method of working was changed considerably at that time. If the rate for strip G is excepted (possibly in error) the remaining strips, H, R, and X, show a return to about the original welding rate of one foot per hour with a much more rapid rise in the rate than was the case with the first strips. With continued practice, the catalog rate of 5 ft. per hr. would probably be reached.

It will also be noticed that the rate for strip Y, which was a butt weld, fused from both sides, is about the same as for strip F which was a beveled weld with wire filling. In both cases fusion occurred throughout the weld so that one method appears to permit about the same welding rate as the other.

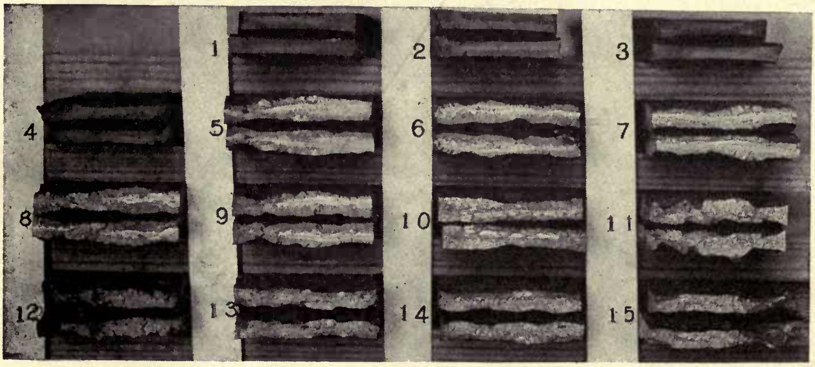
While too great reliance should not be placed upon these welding rates, either as to their accuracy or the ability of another workman to equal them, they do show that a moderate rate of welding, say, 2 to 3 ft. per hr. with $\frac{1}{4}$-in. steel plates, can be obtained with comparatively little practice. The total length of weld in these 12 specimens was about 24 ft. which at the average rate of welding of 2 ft. per hr. could be completed in 12 hours of blowpipe work. This tends to confirm the statement that some commercial shops train inexperienced men in two or three days to reasonable proficiency with the blowpipe and employ them upon their own work afterwards.



STRIP A.



STRIP U.



STRIP Y.

FIG. 11. FRACTURED SURFACES OF TEST SPECIMENS, (SPECIMENS NO. 1, 2, 3, AND 4 ARE UNWELDED).

34. *Allowance for Creep.*—The values are shown in Table 3 for the allowance for creep in per cent of the length of the weld.

TABLE 3.

ALLOWANCE FOR CREEP OF WELDED JOINTS

Section	Approximate Length of Weld, inches	Allowance for Creep, inches	Per cent	Remarks
A	27	½	1.8	Rathersmall
B	27	⅝	2.3	Too much
C	20	½	2.5	
D	20	$\frac{9}{16}$	2.8	
E				
F	27	½	1.8	
U	20	None		Too small
Y	20	$\frac{5}{16}$	1.6	
G	20	0.4	2.0	
H	20	0.45	2.3	
R	27	0.8	3.0	Too much
X	20	½	2.5	

The average of those allowances which appeared to be satisfactory is 2.2 %; not much less than the 2.5 % recommended by the blowpipe manufacturers. If the allowance is too small, the thin edges of the plates crowd together more or less with no bad results, but if the edges fail to meet or nearly so, it is almost impossible to weld at a satisfactory rate.

35. *Properties of the Steel Plates.*—Of the strips welded, A, B, E, F, and R, were cut into specimens perpendicular to the direction of rolling, and strips C, D, U, Y, G, H, and X, were cut into specimens parallel to that direction. The material, as shown by averaging the tests of the unwelded specimens from each strip, had the properties shown in Table 4.

TABLE 4.

PROPERTIES OF STEEL PLATE—FIRST SERIES

	No. of Specimens	Yield Point lb. per sq. in	Ultimate lb. per sq. in.	Elongation in 6-inch gauge length per cent
Perpendicular to rolling	20	40 800	65 500	19.0*
Parallel to rolling	28	39 900	63 000	23.8*
Average		40 350	64 250	21.4

*These values include 12 specimens perpendicular to rolling and 16 specimens parallel to rolling.

No elongation was recorded for the remaining specimens of each group.

36. *Efficiency of Welds.*—The average efficiency of the welds for the strips perpendicular to rolling is 70 %, which compares favorably with that for the sections parallel to rolling, 67 %.

On account of the many variables in this series of tests, it may safely be concluded that this slight difference in efficiency is entirely accidental and that the direction of rolling, so far as these tests permit an opinion to be formed, has no influence upon the efficiency of the welds.

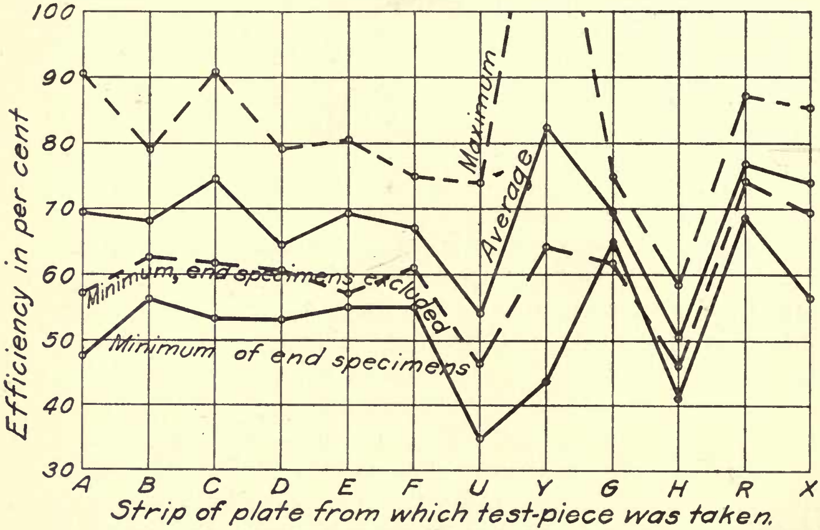


FIG. 13. EFFICIENCY OF WELDS—FIRST SERIES.

The efficiencies for each strip are plotted in Fig. 13, the maximum, minimum, and average being shown. To distinguish between end specimens and those from the body of the weld, the lowest efficiency of the end specimens and the lowest efficiency of inside specimens are shown separately. While the strength at the ends of the weld is markedly lower, this is not due entirely to the method of welding. In some specimens the width of the end specimens, at the weld, could not be accurately measured because one edge was not machined, and again, little effort was made when welding to obtain maximum strength at the ends.

Fig. 14 is a diagram showing the strength of the individual specimens of a representative strip.

A comparison of the strips shows that of the twelve strips, only in one (strip G) did the lowest efficiency occur at an inside specimen. Of the remainder, the minimum occurred at the beginning in three only (strips D, E, and H), while in the other eight it occurred at the end specimen, where work was stopped. In three of these (strips U, R, and X) the next lowest efficiency occurred at the beginning, while in the others it occurred at an inside specimen. Apparently any error in measuring the area of end specimens would act impartially either to raise or lower the efficiency so that this marked showing for low efficiencies at the beginning and end of the welds must be taken as evidence that such a tendency exists. While this appears reasonable at the beginning, where starting to weld with cold metal, it is not easily explained for the ends.

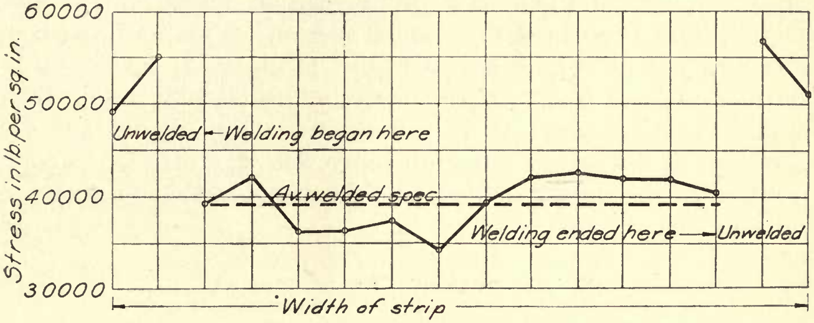


FIG. 14. STRENGTH OF INDIVIDUAL SPECIMENS AS STRIP AB.

Inspection of Fig. 13 shows that there is little change in the average efficiency from A to F inclusive, but a marked decrease in the variation from the average is apparent, probably showing better workmanship and increased skill on the part of the operator.

Strips U and Y, it must be remembered, are butt welds, the first fused on one side only and the second on both sides. As previously explained, fusion of the metal in strip U did not take place for its entire thickness, which accounts for its low efficiency. The very high efficiency of strip Y, in which thorough fusion occurred, may be explained, possibly, by the fact that as the blowpipe flame was confined almost entirely to the surface of the weld the metal did not suffer the deterioration which occurred in the beveled welds in fusing in wire for filler. Possibly, also, the low efficiency of strip H can be explained on the same basis by noting the very slow rate of welding employed, less than one foot per hour.

Strips G to X, inclusive, were welded after instruction and the adoption of modified welding methods. As a result the efficiencies rose, say, from 70 % to 75 %.

The variation from the average efficiency, in these last strips, is small enough to show, with the somewhat increased average, that the newer method of working was an improvement over the old, but it seemed that some precaution might have been neglected which would increase the efficiencies considerably. Inspection of the fracture of specimens welded by the modified method showed a decrease in the amount of black or blue discoloration of the metal, although there was still more than could be wished. Possibly the effect of this discoloration is shown in the low efficiencies.

B. SECOND SERIES OF TESTS.

37. *Blowpipe.*—The work of the second series was a continuation of that of the first under somewhat altered conditions. An effort was made to determine the variables affecting the efficiency of the welds, with some success for the last few strips of the series.

In place of the blowpipe used in the first series a recent form of the Fouché blowpipe was obtained which was provided with a number of interchangeable heads, in this case corresponding to the heads of blowpipes No. 3, 4, 5, 6, 7, and 8. The size best suited to the work could be quickly fitted to the blowpipe body, the result being an apparatus somewhat lighter than the design previously used but one operated in the same way. The general appearance of this blowpipe is shown in Fig. 3, (p. 12), the heads for it standing in a row at the right.

38. *Filling Wire, and Its Effect on Welds.*—Special wire, recommended by the blowpipe manufacturers, was obtained from John A. Roebling's Sons Company, 171 Lake Street, Chicago. This was designated by them as $\frac{1}{8}$-in. diameter, liquor finished, bright, annealed, genuine Norway iron wire. Tension tests of several samples gave the following results:

Ultimate strength	50 000 lb. per sq. in.
Yield point, about	31 000 lb. per sq. in.
Elongation in 10 in., per cent,	20
Reduction of area, per cent,	67

After being cut into lengths of about 6 ft., this wire was coiled, as shown in Fig. 3, so as to be readily held in the hand. Each coil was about sufficient for welding one strip of $\frac{1}{8}$-in. steel, 20 in. long. This wire melted readily and in general worked satisfactorily. The most noticeable difference between it and the No. 14 steel wire used up to this time was the absence of mill scale. If bent, the steel wire showed a coating of scale, or oxide, which flaked off. The iron wire, however, had been pickled or otherwise treated to give a clean metallic surface. When melted by the blowpipe, the steel wire showed a surface of moderate incandescence covered by irregular spots which were much brighter. While the general color appeared bright red through blue goggles, the spots seemed white hot. The red mass appeared quite firm, flowing reluctantly under the pressure of the blast from the blowpipe. The white material, on the other hand, seemed quite fluid and formed constantly changing figures on the red surface. Under the continued action of the blowpipe, it tended to gather into small globules. The impression formed as one watched it was that this material gradually decreased in amount under the blowpipe, but possibly its disappearance was due to its being driven on to comparatively cool metal where it was less visible. It seems probable that the red material was filler, fused without change, and the white hot material a film of oxide over it, as the behavior of each agreed with our general knowledge of these substances, especially that pure iron is melted with difficulty while the oxide melts at a much lower temperature. Possibly the oxide, if it is such, is reduced to metallic iron by the blowpipe. This would account for the disappearance of the oxide.

The steel wire, after each addition of material to the weld, showed half or two-thirds of the red area covered by the white, while the iron wire showed much less, possibly a quarter as much. In either case, some care was taken to continue the action of the blowpipe until the oxide had almost or entirely disappeared before adding more filler. Perhaps this was unnecessary, as the metal added may work down under the oxide; if, however, this does not occur, inclosing oxide in the weld must, necessarily, reduce its strength and efficiency. Possibly, dark spots in the weld after rupture are inclosed oxide.

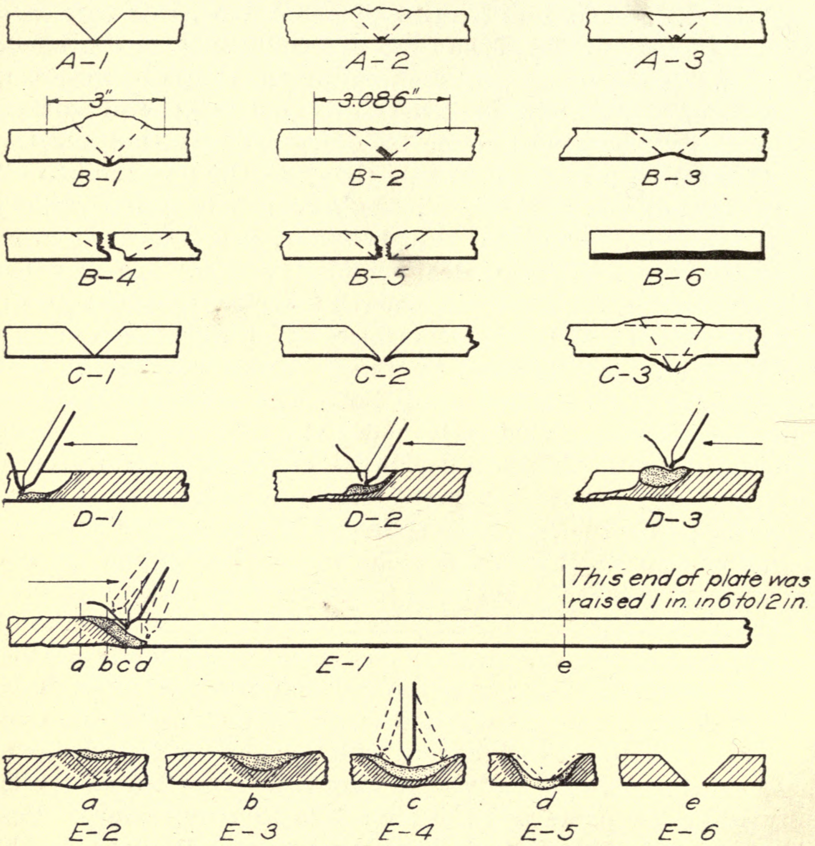


FIG. 15. PROGRESS OF WELDING—SECOND SERIES.

39. *Material and Preparation of Specimens.*—Instead of the ¼-in. plates used for the first series, similar sheets from the same firm were obtained which were ⅛-in. in thickness. Plates of this thickness seem better suited for practice welding and experimenting than either thicker or thinner ones. Each plate was divided into strips, as shown in Fig. 5 (b), so that all specimens lay with their longest dimension parallel to the direction of rolling. The strips were cut as for the first series, except that a sharp power shear was used instead of the cutting-off tool.

All strips were beveled at 45° as shown at A-1, Fig. 15. This was done on a dry emery wheel as the amount of metal to be removed was not large. Each section was clamped, as usual, and welded by fusing in a $\frac{1}{8}$-in. iron wire, using the No. 5 head fitted to the blowpipe.

The pressure under which oxygen was supplied to the blowpipe was 12 lb. per sq. in. The acetylene pressure averaged 11.8 in. of water and varied from 11.5 to 12.75 in. As slight variations in these pressures probably had little or no effect on the flame regulation or the welds, they need little consideration.

A cross-section through the weld is shown at A-2, Fig. 15. As is the case with all the sketches in Fig. 15, an attempt is made to show the general features of the weld under discussion, not to represent them accurately to scale, which would be difficult if not impossible. Many are exaggerations, more or less crude, of the phenomena they are intended to illustrate.

All specimens were cut from the strips with the power hack saw, as before, and the surface of the weld ground, as shown at A-3, top and bottom, on a dry emery wheel, to give a reasonably smooth surface. In many cases the thickness through the center of the weld was slightly less than that of the plate.

40. *Manipulation.*—For all of the strips of the second series the welding process used for the last of the first series was employed, the pool system of welding used at first (described on page 18) having been discarded. The difficulties involved in the pool system and in working away from the operator can better be understood by reference to D, Fig. 15. In the diagram, comparatively cool metal (black hot) is represented by coarse cross hatching, or is left unshaded; metal heated to redness, by close cross hatching, and molten metal is represented by a dotted surface. The arrows indicate the direction in which the weld is progressing. In the pool method the bottom of the groove was first welded for a short distance (See D-1) by melting down the sides of the groove (see E-5) and adding some filler. The thickness was then increased by a pool (See D-2) to the required thickness of the plates (see D-3). Working in this way it was somewhat difficult to prevent the filler cooling on metal imperfectly fused.

The method used for the welding of the second series is shown in Fig. 15. A longitudinal section along the weld is shown at E-1, and cross sections through several points at E-2, E-3, E-4, E-5, and E-6. The weld was built up by means of additions of melted filling wire at the front of the work, regularly, so that the surface advanced along the groove approximately parallel to itself. The bottom of the groove was closed by material from the sides of the groove and from the filling wire, (see E-5); then the thickness of metal was gradually increased until somewhat greater than that of the surrounding plates. As each drop of melted filler reached its place, the blowpipe was directed against it until it spread out over the molten material below and lost its outline. The oxide on the surface was driven off before more filler was added. Usually the distance from the flame to the metal was 50% to 100% of the length of the first cone.

41. *Strip AB.*—Only one clamp was used for this strip and it was applied at the raised end opposite that where welding started. The thin plates sagged, one more than the other in places, which made an offset in the weld, reducing its area.

The fractures showed a rather dead or dull gray surface, slightly spongy, with small dark spots at intervals. See Table 5 for data.

The average efficiency was 72.1%, the highest 77.9% and the lowest 62.5 %.

42. *Strip AC.*—Both clamps were used as in the first series, preventing sagging somewhat. On account of the small allowance for creep, the plates overlapped so that satisfactory work was impossible. The weld was carried within about two inches of the end of the seam but only about the first 13 in. was cut into specimens. Of these, only the following three, No. 10, 11, and 12, were welded on both sides in an attempt to fill up the angle due to the offset.

The fractures were similar to those for strip AB. See Table 5 for data. A rise in strength was noted for specimens No. 9, 10, and 11, due probably to welding both sides of the plates. Specimen No. 11 broke first outside the weld; then, when retested, in the weld. The greater load was used in computing the stress on the cross sectional area of the weld, and this applies to all specimens of this series which were retested to cause rupture in the weld.

The average efficiency was 69.1 %, the highest 82.0% and the lowest 54.4 %.

43. *Strip AD.*—Satisfactory allowance for creep (½ inch) was made for this strip and the weld completed. Some offset occurred due to sagging of the plates, but they were welded from one side only.

The fractures showed some dark spots in the dull gray, spongy surface and also a few crystalline spots at intervals. See Table 5 for data. A rather remarkable increase occurred in strength as work progressed along the weld.

The average efficiency was 78.2 %, the highest 94.8 % and the lowest 72.0 %.

44. *Strip AE.*—To prevent sagging of the plates when heated, the clamps previously used were bolted up on pipe spacers, as shown in Fig. 3. These spacers held the lower T-sections of each clamp in a definite relation to each other. The plates were then clamped with the clamps parallel to the weld. This arrangement kept the plate surfaces nearly in the same plane—an important matter with thin plates—so that the weld has nearly the cross sectional area of the rest of the specimen.

The fractures showed generally a clear gray surface with a slight spongy appearance. There were very few dark spots. See Table 5 for data. Great strength was shown by specimens No. 8, 9, 10, and 11. This is partly explained by the fact that all others had a band of metal about $\frac{1}{32}$ in. wide at the bottom of the weld which appeared to be poorly welded. Possibly fusion did not take place there.

The average efficiency was 75.6 %, the highest 90.0 and the lowest 59.9 %.

45. *Strip AF.*—The clamp used for strip AE was improved by welding the spacers and bolts to the T-sections, making the clamp stiffer. The upper T's were then removed and the bearing surfaces, for the plates, finished in the shaper. This assisted greatly in bringing the plate surfaces into the same plane and avoiding offset in the weld. This clamp was used for all subsequent work for this series.

The fractures showed a bright surface with almost no dark spots. While it tended toward dull gray, it was not spongy. Specimens No. 6 to 10, inclusive, had a gray surface with crystalline spots while No. 11 to 16, inclusive, were largely crystalline. Specimen No. 17 showed a dark band across the weld. See Table 5 for data. An increase in strength was shown by specimens with crystalline fracture.

The average efficiency was 72.0 %, the highest 87.4 % and the lowest 44.8 %.

46. *Strip AG.*—As the strength of the welds up to this time had shown little increase, the molten metal for strip AG was hammered frequently as it was put into place. A small riveting hammer was used, having a handle 11 in. long, and a head weighing 11.5 ounces. After extending the weld about ¼ in., 10 to 15 light blows, (2 in. stroke) were delivered rapidly upon the sloping surface at the end of the weld. During this time the metal usually became very dull red and required some time to bring it to the fusion temperature again.

The fractures showed no crystals but rather a dull gray spongy surface, covered by many dark spots. These, perhaps, aggregated a quarter of the total area. See Table 5 for data. The wide and erratic fluctuations in strength lead to the conclusion that alternate hammering and welding do not produce uniform work. The fact that the average efficiency was lower than for any strip so far in this series also throws doubt upon its value. It is difficult to see how hammering can increase the density of metal which is immediately afterwards heated to fusion to continue the weld. The amount of work required of the operator is largely increased, as well as the time.

The average efficiency was 64.4 %, the highest 76.8 % and the lowest 50.9 %.

47. *Strip AH.*—A gasoline torch was used to preheat the beveled edges of the specimens of strip AH. Its flame was directed against the seam, from below, an inch or two in advance of the end of the weld. This did not interfere with the welding as the blowpipe was used from above as usual. The torch supplied enough heat to bring the bottom of the groove to redness, which reduced, considerably, the time required to melt the metal. The preheating also noticeably increased the allowable freedom in using the blowpipe. It could be swung over a greater area of weld and also be held at a greater distance; moreover, the filler flowed quickly into the weld. Though the welding rate is lowered, rather than raised, delays due to stopping the work entirely are included so that the rate, as given, is incorrect. A rough estimate would put the rate of welding for preheated plates about twice that for cold ones. The rapidity and ease with which the filler united with the weld would lead one to think, also, that great strength should result.

Work progressed continuously until specimens No. 5 to 11, inclusive, had been welded, then there was a delay of a minute or more to pump up the pressure in the gasoline tank of the torch. Specimens No. 12, 13, and 14, were next welded; then the gasoline became exhausted, making it necessary to complete the weld without preheating. This portion includes specimens 15,16,and 17.

It had been noticed that many of the preceding welds showed after rupture a narrow strip just at the bottom of the groove which apparently was poorly welded. This defect is indicated in A-3, Fig. 15, by a black spot which the usual grinding of the weld surface did not remove. After rupture, the fracture presented the appearance shown in B-6, which is a cross section of the specimen. The band of poor welding, shown in solid black, is along the bottom of the weld. It varies somewhat in thickness; above the poorly welded part is gray or crystalline material which had evidently been melted. To determine the strength of welds, from which this defect is removed, specimens No. 7, 10, 13, and 16 were grooved with a half round file along the bottom of the weld, as shown in B-3. The fractures for these showed no poorly welded band. The specimens showed a rather spongy dull gray surface with a large number of dark spots. An exception to this was specimen No. 15, which was almost entirely crystalline with no dark spots.

See Table 5 for general data for strip AH. As nearly as could be determined, the interruptions to the work occurred at specimens No. 11 and 14. These were noticeably low in strength. The specimens grooved to remove imperfect welding, No. 7, 10, 13, and 16, on the other hand, showed remarkable strength compared with the others. The high values for No. 10 and 13 may be due more to this fact than to the preheating. Evidently, this poorly welded portion of the specimens has been an important factor in causing low efficiencies, especially in these thin plates which had generally been left about $\frac{1}{32}$ in. thick at the beveled edge to prevent the blowpipe readily melting through the bottom of the groove. It is peculiar that specimen No. 15, welded without preheating, showed a good crystalline fracture while all preheated specimens had poor ones.

The average efficiency was 69.5%, the highest 88.0 % and the lowest 56.5%.

48. *Strip AJ.*—This strip was welded before the results for the previous one were available, so no precautions were taken to avoid poor welding at the bottom of the groove. The weld was built up, perhaps $\frac{1}{16}$ in., above the plate surface, as shown in B-1, Fig. 15, (p.38). After cutting the specimens, a 3-in. gauge length was laid off and prick-punched, having the weld in the middle. These specimens were then heated in a forge and drawn down on an anvil to a uniform cross section with a hand hammer. Two heats were required for this usually. The specimens were allowed to cool slowly. They showed an average elongation (see B-2) in the 3 in., due to forging, of 0.086 in. The greatest was 0.11 in. and the least 0.07 in. The surfaces of the weld were then ground smooth.

When tested, the poorly welded portion at the bottom, shown at B-1, appeared to have been drawn out in forging, (see B-2), causing a fracture similar to that shown at B-4. Specimens No. 12, 13, and 17, broke in this way, about half the thickness of the last being unwelded.

The first three specimens showed rather poor fractures but the remainder were better. There were no dark spots. Specimen No. 15 showed remarkable ductility in the material actually in the weld, B-5, and a good fine grained fracture. The same indications of ductility were shown in a lower degree by other specimens also. The average per cent elongation, 12.5, was high compared with previous welded specimens which average about 3 % in 6 inches.

See Table 5 for data. While the results are somewhat erratic, forging is evidently of value in increasing the ductility as well as the strength.

The average efficiency was 85.4%, the highest 124.6 % and the lowest 54.1%.

49. *Strip AI.*—To allow the poorly welded portion at the bottom of the weld to be ground away, leaving in the test weld only material which had been thoroughly fused, the plate edges, C-1, Fig. 15, were bent downward from $\frac{1}{32}$ in. to $\frac{1}{16}$ in., as in C-2, by hammering over the edge of an anvil. The weld when completed was much like C-3, and was then ground about as shown by the horizontal dotted lines.

The fracture showed very few dark spots on a gray surface and no poorly welded portion. Specimens No. 11, 12, and 15, showed a crystalline surface.

See Table 5 for data. The strength of this strip showed quite conclusively that lack of thorough welding was largely responsible for previous poor results.

The average efficiency was 86.6 %, the highest 104.6 % and the lowest 65.2%.

50. *Strip AK.*—To determine the effect of improper flame regulation this strip was welded with an excess of oxygen. The blowpipe flame was shortened by reducing the amount of acetylene until about half its length when properly regulated. This caused frequent "back firing", as the short flame made it necessary to work with the blowpipe close to the metal.

The method of working was the same as for strip AI, including thickening the weld by bending down the beveled plate edges. The fractures were much like those for the preceding strip. See Table 5 for data.

The average efficiency was 84.7 %, the highest 100.5 % and the lowest 72.5 %.

51. *Strip AL.*—This strip was welded in the same way as the last, including the thickened weld, except that an excess of acetylene was supplied. The second cone was, as nearly as could be estimated, 50 % longer than the first cone. As the second cone had a very fine point, its exact length was hard to determine.

The fractures were much like those for the preceding strip. See Table 5 for data.

The average efficiency was 83.1 %, the highest 92.0 % and the lowest 72.1%.

TABLE 5.

RESULTS OF STRENGTH TESTS OF WELDS —SECOND SERIES.

Strip	Efficiency per cent			Rate of Welding ft. per hr.
	Av.	Max.	Min.	
AB	72.1	77.9	62.5	1.32
AC	69.1	82.0	54.4	0.75
AD	78.2	94.8	72.0	1.55
AE	75.6	90.0	59.9	1.75
AF	72.0	87.4	44.8	1.51
AG	64.4	76.8	50.9	1.39
AH	69.5	88.0	56.5	0.92
AJ	85.4	124.6	54.1	1.17
AI	86.6	104.6	65.2	1.03
AK	84.7	100.5	72.5	0.90
AL	83.1	92.0	72.1	1.44

52. *Properties of Steel Plates.*—The unwelded specimens from these plates had sheared edges. Table 6 shows the average strength of specimen with sheared edges and with machined edges. The following method was used to compute the ultimate strength of a machined edge specimen from one having sheared edges. Two of the four specimens, for a number of the sections, were machined on the edges.

TABLE 6.

PROPERTIES OF STEEL PLATE—SECOND SERIES

	Sheared Specimen	Machined Specimen
Average ultimate stress, lb. per sq. in..	53 100	56 400
Range of variation from the average, per cent,................	11.3	6
Average width, inches,.	1.619	1.313
Average elongation in 6 in., per cent,	9	18

A study of Table 6 shows that, if the width of a sheared specimen is reduced 40% of the thickness of the plate for each sheared edge and this width used in computing the ultimate stress, it will agree closely with the average for a specimen having machined edges.

The same result may be obtained if the widths of specimens are nearly uniform as in this work by increasing the stress by a proper percentage; in this case six per cent. While this approximation saved much time in preparing specimens it is not to be recommended for work requiring a high degree of accuracy. In this case, however, it is believed that the data, upon which the correction is based, are taken from enough specimens to be reliable.

53. *Slope of Plates.*—During the process of welding all strips were sloped upward in the direction of welding about 1 inch in 7.7 inches. The greatest slope was 1 in 5, and the least 1 in 19. The exact amount is a matter of little consequence and will depend upon the preference of the operator and the conditions under which the work is done.

54. *Creep of Plates.*—The allowance for creep averaged 0.5 in. which was 2.56 % of the length of the weld. Two strips were welded satisfactorily with an allowance of $\frac{7}{16}$ in. and two with $\frac{9}{16}$

in. An attempt to weld a strip (AC) with only $\frac{3}{8}$ in. caused overlapping of the plates.

55. *Rate of Welding.*—The average rate of welding, 1.24 ft. per hr., for this series, seems very low when compared with the catalog value of 15 ft. per hr. Fig 16 shows the rates for all strips. The very low value of strip AC was due, doubtless, to the overlapping of the plates. Hammering the weld for strip AG and delays in working the torch when preheating strip AH lowered the rate for both these strips. The very short flame and frequent "back firing" also noticeably lowered the rate for strip AK, but there is no apparent reason why the remaining values should not be higher. Possibly the operator did not extend the weld as fast as circumstances permitted. If the only result was the low welding rate, it is of small consequence, but possibly the prolonged action of the blowpipe upon the metal was detrimental, causing lower efficiencies than would be found with a higher welding rate. The lower rates for the thickened welds, AI, AK, and AL, were doubtless due to the greater amount of filler to be added and the radiation from the greater mass of metal. Even for the first sections, the size larger blowpipe, No. 6, might have produced better results.

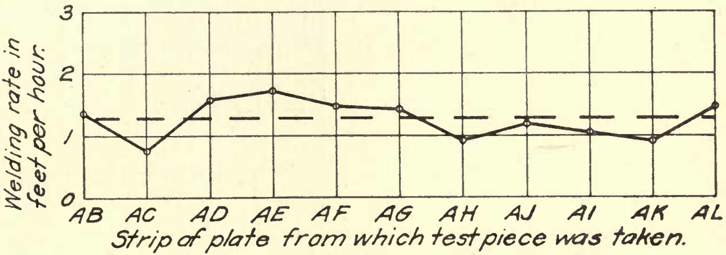


FIG. 16. RATE OF WELDING—SECOND SERIES.

56. *Hammering, Preheating, and Forging.*—While the results are far from conclusive, they tend to show that hammering the weld during the blowpipe operation is laborious and detrimental rather then beneficial.

Preheating undoubtedly increased the welding rate and so lowers the cost, but in so far as these results show, has little effect on the strength of the weld.

Forging produced a decided increase in the strength of the welds and also in the ductility of the fused metal. Apparently the increase in efficiency is about 10 %.

The average efficiencies and also the range of efficiency is shown in Fig. 17. Minimum efficiencies are shown both for end specimens and for inside specimens.

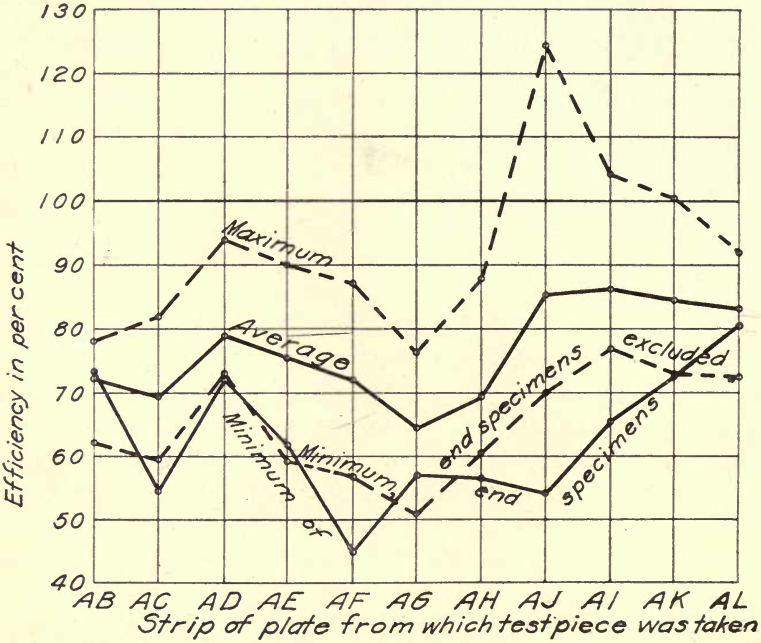


FIG. 17. EFFICIENCY OF WELDS —SECOND SERIES

57. *Effect of Thorough Fusion.*—The most important results of this series are obtained from the last three strips in which thorough fusion took place throughout the test weld. The average efficiencies were the highest obtained in these tests. The high average efficiency for strip AI, 86.6 %, confirmed as it is by the values for strips AK and AL, may be expected to be fairly representative of welds in $\frac{1}{8}$-in. steel when fusion has occurred throughout the weld.

58. *Effect of Flame Regulation.*—The variation of efficiency with the flame regulation is seen in Fig. 18. If it is remembered that the excess oxygen flame was difficult to manipulate, and that the second cone of excess acetylene flame was very conspicuous, it seems fair to assume that an ordinarily skillful workman would in practice have only about half the variations, either way, shown

here. If this were true, his blowpipe flame regulation would always lie between that shown in Fig. 4 (b) and that in Fig. 4 (d) with very slight corresponding variation in the efficiency of the welds.

The decrease in efficiency due to the excess oxygen flame was only 1.9 % and for the excess acetylene flame 3.5 %. There seems to be no excuse for a greater variation in commercial work due to improper regulation.

For comparison the results for strip D of the first series are given also in Fig. 18. When it is remembered that thorough fusion did not take place throughout this weld, the slight rise in efficiency for the excess oxygen flame is not surprising. Upon the whole the results for strip D confirm the results found for the second series very well.

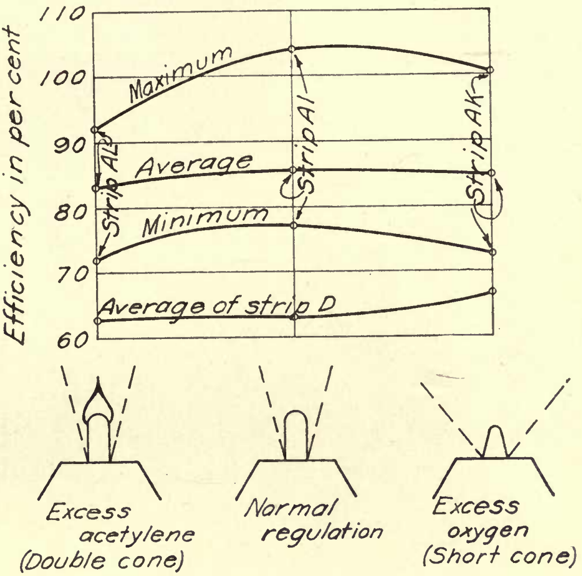


FIG. 18. EFFECT OF VARIATION OF FLAME REGULATION ON EFFICIENCY OF WELDS.

It would seem that a considerable variation from the normal flame regulation may be allowed without danger of greatly reducing the efficiency of the weld.

IV. Tests of Gases and Flame Regulation.

59. *Sampling Gases.*—As varying the flame regulation seemed to have little effect upon the welds in the second series, interest was renewed in the proportion of acetylene in the discharged gas and the variation in this amount for visible changes in the flame. Apparently the only way to determine the proportion of acetylene was to light the blowpipe and secure the desired regulation, then, after extinguishing the flame, to collect a sample of the discharged gases and make a chemical analysis.

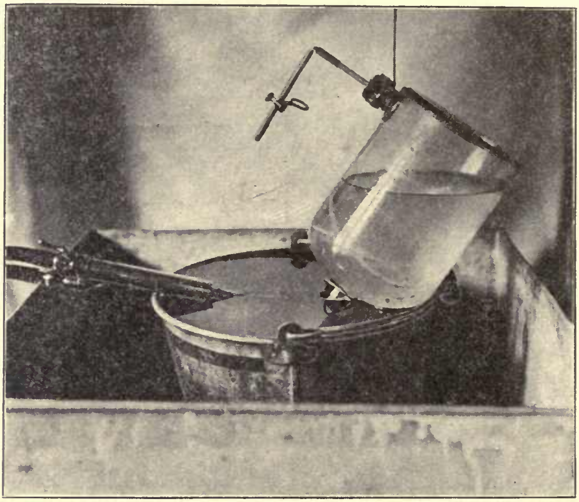


Fig. 19. Apparatus for Sampling Gases.

The apparatus for collecting samples of gas is shown in Fig. 19. A bottle was suspended by a slip noose at a fixed height for all samples. With the bottle placed mouth downward full of water and with the mouth of the bottle submerged under the surface of water in a pail, the blowpipe was thrust into the neck of the bottle and the discharged gas collected. This arrangement maintained atmospheric pressure upon the blowpipe tip so that the rates and proportions of the gases were the same as for the flame. Care was taken to keep the blowpipe tip on a level with the water outside the bottle. Probably the greatest variation from the proper level was a quarter inch, or possibly half an inch. The edge of the pail acted as a weir to maintain a constant water level outside the bottle. The time required to fill the bottle was observed. As the time was taken with an ordinary watch the greatest error may have been a second or two.

60. *Flame Regulation.*—For the first twelve gas samples taken the flame was extinguished by closing the tip for an instant, but back firing sometimes resulted, rendering the sample worthless. For all subsequent samples the acetylene cock on the hydraulic back pressure valve was closed to extinguish the flame, then reopened and the gas sample taken. By this method the positions of the cocks on the blowpipe, used in regulating the flame, were unchanged. After obtaining the sample the blowpipe was again lighted to prove that the regulation had not altered.

Three characteristic flame appearances were selected for this work, similar to those previously used (see p.13). In using the oxacetylene blowpipe the best results are usually obtained with a flame showing a single cone of the largest size possible. This regulation is termed "O K" or normal regulation. For this regulation slight variations in appearance were purposely introduced to determine their effect. Any sample of gas obtained with "O K" regulation showed a flame like that in Fig. 4 (c), or in some cases with a cone slightly shorter than that shown in Fig. 4 (c). So far as the results of the analyses show, the slight shortening of the cone was entirely inappreciable with the experimental errors which occurred in this work.

The regulation in which the length of the flame was 50% longer than when properly regulated is here termed the double-cone regulation, and is shown in Fig. 4 (b) fairly accurately. This regulation was used to determine the effect of excess-acetylene flame. For any flame there is some difference between its appearance in a photograph and when seen directly. It also makes considerable difference whether or not blue goggles are used. Although the outer cone flickered considerably at times, care was always taken to obtain as nearly as possible the appearance shown.

The excess-oxygen regulation obtained by reducing the amount of acetylene until the length of the first cone was one-half to two-thirds that when normally regulated, as is shown in Fig. 4 (d), was used to determine the effect of an excess of oxygen. Usually half-length of cone was obtained only with difficulty due to frequent "back fires". This regulation is termed short-cone regulation. Generally a scale placed parallel and close to the flame was used to assist in regulation.

For all these regulations, the oxygen cock on the blowpipe was full-open and the desired flame appearance was secured by adjusting the acetylene cock. In a few cases this latter was also full-open.

61. *Chemical Analysis of Gases.*—No attempt was made to determine the impurities in either oxygen or acetylene, simply the proportion of each with reasonable accuracy. The apparatus used is shown in Fig. 20. The gas sample was in bottle A, from which a measured volume was transferred to the graduated tube B. The acetylene in the mixture was absorbed by fuming sulphuric acid in C, and the remaining acid fumes by caustic potash in D. The volume remaining in the tube was then noted. This consisted of oxygen and the impurities contained in both the oxygen and acetylene.

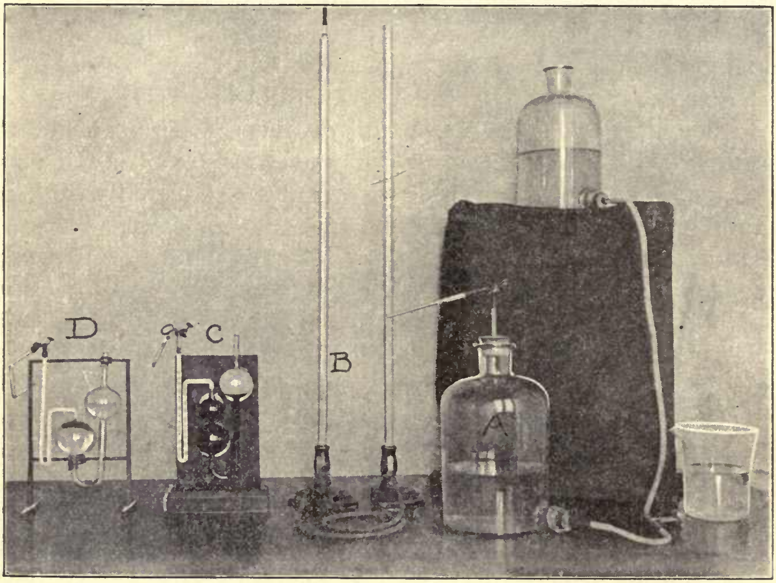


FIG. 20. APPARATUS FOR THE ANALYSIS OF GASES.

The data for representative samples are given in Table 7, which is largely self-explanatory. The volume of acetylene was, obviously, the difference between the initial and final volumes; but

TABLE 7.

SAMPLE GAS ANALYSES FOR OXYACETYLENE BLOWPIPE.

Sample No.	Blowpipe No.	Flame Regulation	Pressure of Acetylene in inches of water	Oxygen Pressure lb. per sq. in.	Initial Volume, cc	Final Volume, cc	Acetylene Volume, cc (A)	Oxygen Volume, cc (O)	Corrected Volume, cc (T)	Per cent Acetylene ($\frac{A}{T}$)	Per cent Oxygen ($\frac{O}{T}$)	Ratio of Oxygen to Acetylene	Bottle filled in seconds	Gas Rate, cu. ft. per hr.	Acetylene Rate, cu. ft. per hr.	Oxygen Rate, cu. ft. per hr.
1	5	OK	12	12	100.0	57.85	42.15	56.0	98.15	42.9	57.1	1.33				
					100.0	57.4	42.6	55.8	98.2	43.4	56.6	1.31				
									Av.	43.2	56.8	1.32				
2	5	OK	13⅜	0	99.9	1.1	98.8			99.0			100	5.34	5.34	
					99.7	1.3	98.4			98.6						
					98.3	1.0	97.3			99.0						
3	5	OK	13¾	0	86.1	2.0	84.1			97.5			100	5.87	5.87	
					95.8	2.4	93.4									
4	5	F	13¼	12	96.0	44.7	51.3	43.4	94.7	54.1	45.9	.846	35	16.8	8.96	7.83
					91.5	43.4	48.1	42.0	90.1	53.4	46.6	.873				
					92.2	43.7	48.5	42.4	90.9	53.4	46.6	.875				
					93.3	45.0	48.3	43.6	91.9	52.5	47.5	.905				
									Av.	53.4	46.6	0.875				
5	5	D	13⅜	12	92.1	50.8	41.3	49.3	90.6	45.5	54.5	1.19	43	13.65	6.14	7.51
					90.1	50.3	39.8	48.7	88.5	45.0	55.0	1.22				
					93.0	52.5	40.5	51.0	91.5	44.3	55.7	1.26				
					89.4	58.1	31.3	56.4	87.7	35.7*	64.3*	1.80*				
					96.1	62.7	33.4	60.9	94.3	35.4*	64.6*	1.82*				
									Av.	45.0	55.0	1.22				

F, Both acetylene and oxygen cocks full open.
D, Double-cone regulation.
*, Results omitted from average.

the oxygen volume was not so easily obtained. To make the results as accurate as possible, the impurities of both the gases were estimated and proper allowance made for them. The oxygen is guaranteed to be 95% pure and Dr. Jesse found by analyzing samples from a number of cylinders, none of which, however, was used for this work, that the highest per cent of oxygen was 98 and the lowest 96. It was, therefore, assumed that this oxygen was 97% pure. The first fifteen samples were from one oxygen tank and the remainder from another.

The acetylene manufacturers claim absolute purity for their gas. Attempts to analyze acetylene samples showed 99% for the first and a lower value for the second. Difficulty was found in manipulating the gas, due to the almost complete absorption, so that they seem to show only that the impurities could not exceed one per cent. Due to the lack of other definite information the statement of the manufacturers was accepted and the assumption made that the entire final volume was from the oxygen tank, 97% of which was oxygen. The sum of the acetylene and oxygen volumes gave the corrected volume upon which to base the oxygen and acetylene percentages as indicated in the column headings.

62. *Gas Consumption.*—The time required to fill the bottle varied from 110 to 15 seconds. If there was a possible error of 2 seconds in these readings the resulting gas rates would be in error 1.8 and 13.3%, respectively. Due to this fact, the oxygen impurities were ignored and the total gas rate apportioned between the oxygen and acetylene by the average percentage of each for the sample.

To determine the volume of gas collected, the bottle was weighed when full of water and again when bubbles escaped from the mouth. This was done by closing the mouth with the palm of the hand and weighing after removing the bottle from the pail. The gross weight was 6380 grams and the tare 1759 grams, making a net weight of 4621 grams. Neglecting temperature changes, this numerical value also measured the gas volume in cubic centimeters. The rate in cubic centimeters per second was then multiplied by the reduction factor 0.127 to obtain the gas rate in cubic feet per hour.

63. *Regulation Curves.*—The percentage of acetylene was chosen to measure the flame regulation, because it was the acetylene which was varied directly, although the ratio of oxygen to

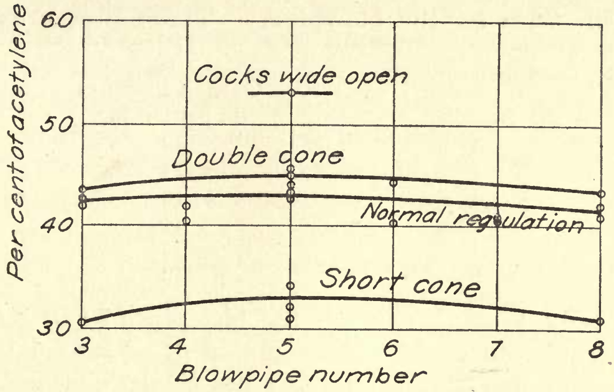


FIG. 21. EFFECT OF FLAME REGULATION ON THE COMPOSITION OF GASES.

acetylene might as well have been used. The average percentage for each sample is plotted in Fig. 21.

64. *Gas Consumption Curves.*—In a similar manner, the values for total gas consumption, or rate, and for acetylene were plotted in Fig. 22. In Fig. 22 are also plotted the rates given by the manufacturers of the blowpipe in their catalog.

65. *Oxygen Pressure and Regulation.*— For the previous graphs values are plotted only for samples taken with normal

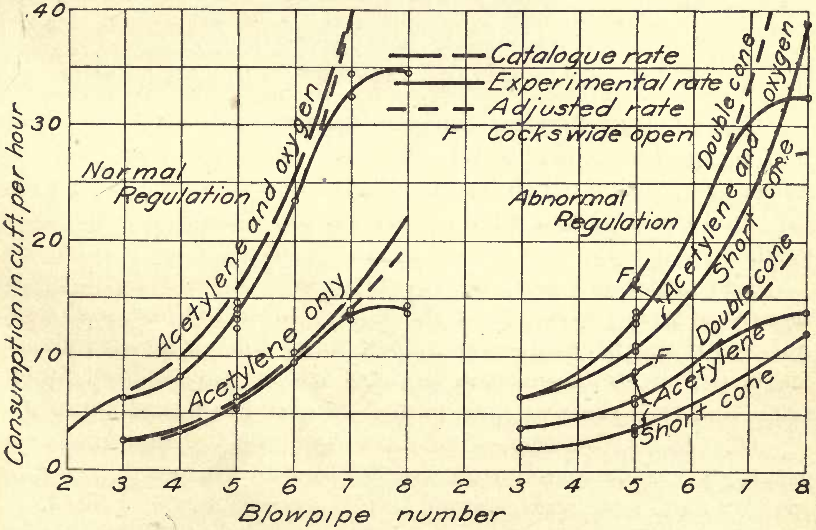


FIG. 22. GAS COMPOSITION WITH BLOWPIPES OF DIFFERENT SIZES.

oxygen pressure on the blowpipe. These pressures were as follows:

Blowpipe Number	Oxygen Pressure lb. per sq. in.
3	10
4	11
5	12
6	14
7	16
8	19

The only exceptions were for blowpipes 7 and 8 for which normal regulation could not be obtained, as is explained later. The acetylene was supplied under a practically constant pressure of about one foot of water for all series.

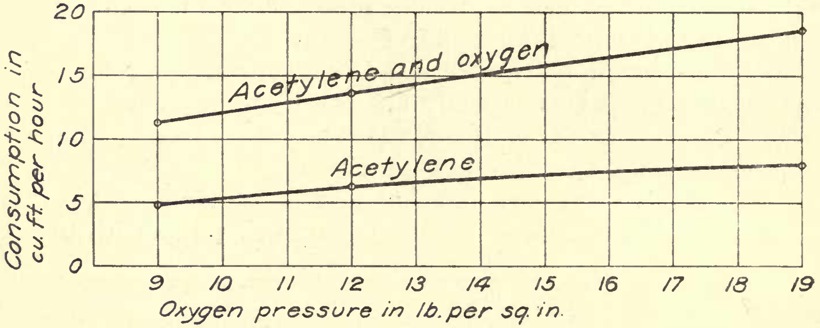


FIG. 23. EFFECT OF OXYGEN PRESSURE ON GAS CONSUMPTION.

The effect of varying the oxygen pressure upon the regulation and gas rates is shown in Fig. 23. Blowpipe 5 was used and normal regulation carefully maintained in each case. The values for the normal pressure (12 lb. per sq. in.) were those previously used.

The maximum and minimum pressures were fixed by the facts that trial proved that the flame "blew out" or was extinguished if the pressure was raised to 24 lb. per sq. in., making 19 lb. per sq. in. about the highest which gave a satisfactory flame and that the pressure gauge used did not read below 9 lb.

66. *Cost of Welding.*—The data given in the manufacturer's catalog for gas consumption for different blowpipes do not differ greatly from the data obtained in the tests herein described. It would seem then that the catalog data may be utilized to give the

cost of welds sufficiently accurately to allow comparisons to be made. Fig. 24 has been made up from these data. The cost of acetylene was taken as 1 cent per cu. ft.; of oxygen as 3 cents per cu. ft.; and of labor as 30 cents per hour. The curves need little explanation. The costs as shown by Fig. 24 are probably rather high, and lower costs may be obtained in practice. This applies in general to both the labor and gas items.

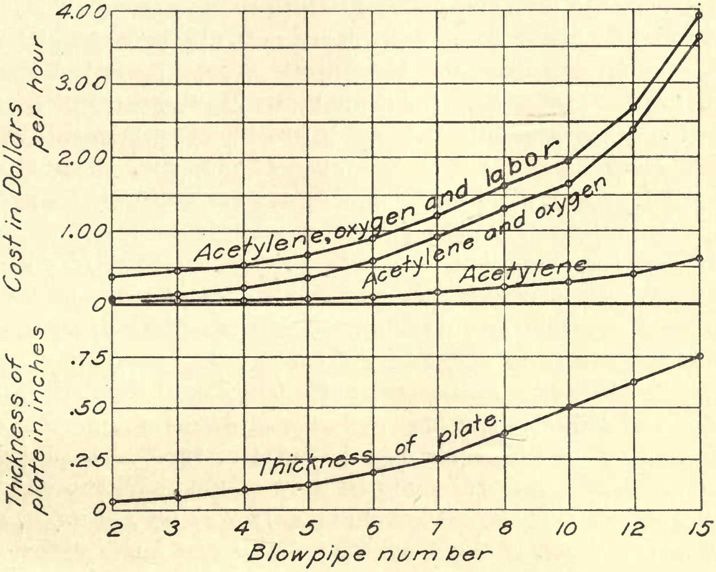


FIG. 24. COST OF OPERATION OF BLOWPIPES OF DIFFERENT SIZES.

67. *Discussion of Results.—Flame Regulation.*—The most striking feature of this work is the remarkable characteristic appearance of the blowpipe flame and its sensitiveness in showing changes in regulation. It seems safe to conclude that a change in the amount of acetylene of one per cent of the gas volume could be detected by the change in the appearance of the flame, provided, of course, that this occurred at or near the normal regulation. The flame is much more sensitive, also, in indicating excess acetylene than excess oxygen, so that a slight feathery flame tip is preferable to a slight or incipient shortening. All sizes of blowpipe appear to have practically the same regulation curve.

The proportion of acetylene for all sizes of blowpipes at normal regulation averages 42% in the tests. This is a ratio of 1.38 volumes of oxygen to one of acetylene, which is much less than the ratio 1.7 usually given. The ratio computed from the catalog rates for blowpipes 2 to 8, inclusive, is 1.61 to 1. The ratio of oxygen to acetylene does not seem to correspond to any definite stage in the oxidation of the acetylene gas. It does, however, appear to be a definite property of oxyacetylene blowpipe flames. As the gases are mixed before issuing from the blowpipe tip, it would appear to be a property entirely independent of the particular style or make of blowpipe. It may be noted that one manufacturer states that for their blowpipe the ratio of 1.28 oxygen to 1 of acetylene has been "adopted". Also that this is nearly the ratio fixed by the Academy of Science, France, which selected 1.30 to 1. The latter two values are nearer to those found by the tests than that given by the manufacturers and may be more nearly correct, but it would be interesting to know how the ratios were established. It would also be of interest to know whether a blowpipe can be designed which will show normal regulation for any ratio which may be selected at random.

Although experiments upon effect of flame regulation on the strength of welds in the first and second series did show a slight deterioration for improper regulation, the results tend to show that the effect must ordinarily be very slight. With a change in the amount of acetylene of perhaps only 2 or 3%, at most, of the total gas volume, it is difficult to believe that much difference in the chemical composition of the materials in the weld can result, especially when the short time that the flame is in contact with any particular portion of the material is considered.

68. *Gas Consumption.*—As was to be expected, the gas rate increased with the size of the blowpipe. The experimental rates are very nearly those given in the catalog of the manufacturers of the blowpipe, particularly for the acetylene. As the ratio of acetylene to oxygen, from the catalog, differs considerably from that found from analyses, it is impossible for both the oxygen and acetylene rates to check very closely with those in the catalog.

The gas rates for blowpipes No. 7 and 8 with double cone regulation appear low, and should follow the dotted lines in Fig. 22. It was noticed when gas samples for these were taken that no second cone appeared with both oxygen and acetylene cocks full-open. There was, therefore, an insufficient supply of acetylene for normal regulation with normal oxygen pressure. The oxygen pressure was therefore reduced to produce normal regulation. This accounts for the low gas rate. The blowpipe body was intended for use only with heads up to and including No. 7, but the No. 8 head was supplied for this work by request. Evidently the acetylene passages, in the body, are barely large enough for the No. 7 head and totally inadequate for the No. 8. Increasing the acetylene pressure might overcome this difficulty. In all the gas consumption curves, therefore, the portion for blowpipes 7 and 8 should be considered abnormal, due to a varying oxygen pressure. The regulation curves show, however, how persistent is the flame's characteristic appearance for these abnormal conditions.

69. *Oxygen Consumption.*—Due to the low pressure of the acetylene, about 0.4 lb. per sq. in. (12 in. of water) and the high oxygen pressure (12 lb. per sq. in. for blowpipe No. 5), it appears probable that the oxygen rate remained constant, or nearly so, for all flame regulations. If any change occurred, it would be a decrease in the oxygen rate as the acetylene rate increased. Omitting abnormal samples, the averages of the oxygen rates for blowpipe 5 are as follows: Both cocks full-open, 7.83; double-cone regulation, 7.48; normal regulation, 7.69; short-cone regulation, 7.53; average, 7.63 cu. ft. per hr. The variations from this average are just the opposite from those expected. The variations range from 2.6% above to 2.0% below the average, and might be caused by an error of one second in the time reading. This leads to the conclusion that the oxygen rate is practically constant for any given blowpipe and oxygen pressure, and is independent of the acetylene rate. This would have been more apparent in the graphs if the oxygen rate had been plotted below the acetylene rate.

The strikingly high gas rate for blowpipe No. 8, for short cone regulation, shown in Fig. 22, is explained by the high oxygen pressure used. If it is assumed that the rate is proportional to the square root of the pressure, the curve for short-cone regulation acetylene and oxygen in Fig. 22 may be corrected approximately as shown by the dotted line.

The increase of oxygen rate with increase of pressure is very noticeable in Fig. 23, and there is a nearly proportional increase in the acetylene rate. Although this increase is not exactly proportional to the square root of the pressures, the difference appears to be less than the experimental error.

70. *Cost of Operation.*—The great increase in the cost of operation as the size of blowpipe increases may be seen from Fig. 24, as well as the small proportion of the cost represented by labor even at the high rate of pay assumed. This indicates that oxyacetylene blowpipes are best adapted, commercially, to plates up to about ½ in. in thickness.

The fact that the welding rate, based on the cross sectional area of weld, is very nearly constant at 17.5 sq. in. per hr. is seen in Fig. 25. This is the value used in estimating the probable welding rate on any given thickness of plate.

The cost of welding plates of any given thickness may be estimated also at 25 cents per cubic inch of filler used. This is, of course, subject to the assumed costs and would be proportionally altered for other values. This cost holds, however, only for plates over ⅛ in. in thickness and must be doubled for 3/64 in. plates. It should also be noticed that, provided this rate holds for any type of grooved joint, if the plates were grooved from both sides, as shown at (c), Fig. 8, the cost per foot of weld would be only half that for plates grooved from one side only, as shown at (b), because the required amount of filler would be reduced one-half.

71. *Summary for Tests of Gases.*—The appearance of the blowpipe flame is a very sensitive indicator of changes in the proportions of oxygen and acetylene when near normal regulation.

The average proportion of acetylene at normal regulation is 42.0%, a ratio of 1.38 volumes of oxygen to 1 of acetylene.

The oxygen consumption is practically constant for any given size of blowpipe and oxygen pressure and independent of the acetylene rate.

Apparently the oxygen rate is proportional to the square root of the oxygen pressure.

The percentage of acetylene is very nearly constant for normal regulation with any oxygen pressure.

The minimum oxygen pressure is reached when the flame "back fires" so frequently that satisfactory work is impossible.

The maximum oxygen pressure is reached when the flame "blows out" or is extinguished by the high velocity of the gases.

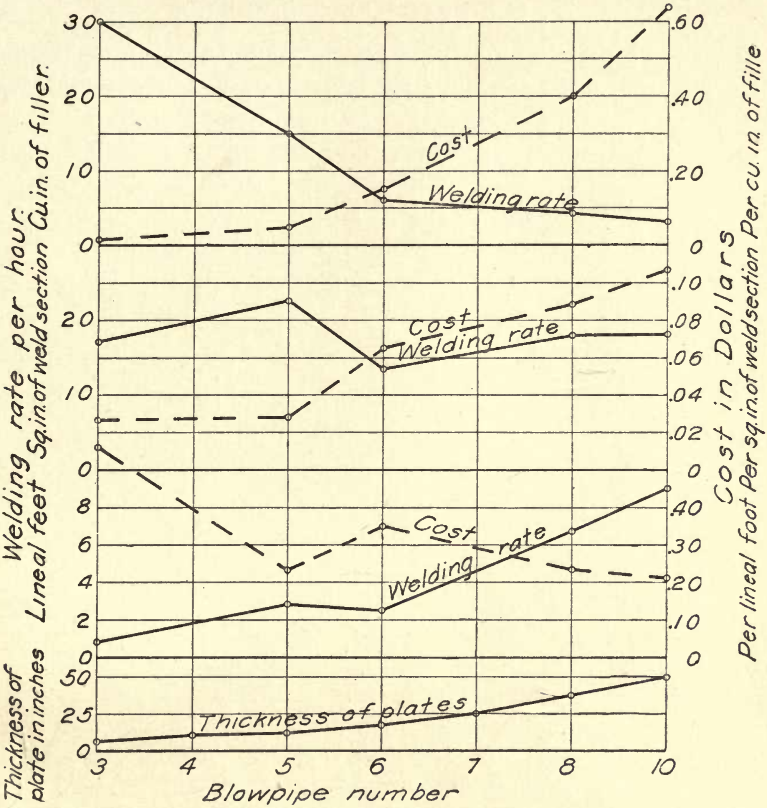


FIG. 25. WELDING RATE AND COST IN TERMS OF LENGTH OF WELD, SECTION OF PLATE, AND VOLUME OF FILLER FOR BLOWPIPES OF VARIOUS SIZES.

Normal regulation is impossible at the maximum oxygen pressure and is obtained only at some lower pressure.

The cost of operation for oxyacetylene blowpipes rises very rapidly as the thickness of plate is increased, reaching, possibly, four dollars an hour for the gas and labor for work on plates of three-quarter inch thickness.

The welding rate is nearly constant at 17.5 sq. in. of weld section per hour.

The cost of welding beveled plates is about 25 cents per cubic inch of filler, assuming oxygen at three cents per cubic foot, and acetylene at one cent per cubic foot, and labor at 30 cents per hour.

V. GENERAL CONCLUSIONS.

72. *Heat Treatment.*—The meager amount of information obtained regarding the effect of heat treatment and subsequent working of the welded material leaves an important and probably very fertile field still to be covered. The rather remarkable results obtained by forging after welding appear to be in agreement with the known properties of metals. Highly heated steel, upon cooling, has a coarse crystalline fracture and low tensile strength. This condition can be improved by reheating to the lowest temperature which will produce a fine grain and then cooling. In this way, the finest grain and also the highest tensile strength will be obtained. Steel heated to, or near, fusion is "burnt" and greatly damaged. The injurious effects of "burning" of steel appear to be due, in part at least, to the "oxidation of the faces of the crystalline grains which compose the metal, by inward diffusion of the atmospheric oxygen" (Howe). The oxyacetylene blowpipe flame, if properly regulated, is a reducing flame as is shown by the reduction of the surface film of oxide of the filler wire, and the injurious oxidizing effect may be small in metal welded by an oxyacetylene flame. "Burnt" metal can never be completely restored to its original condition. While annealing alone will restore steel if merely overheated, steel which is "burnt" requires mechanical working, such as hammering or rolling while hot to cause much improvement. For a discussion of the cause of and remedies for "burnt" steel see Howe's "Iron, Steel and Other Alloys," pp. 241—276.

It seems probable that the coarse crystalline fractures and low efficiencies found for these oxyacetylene welds are produced necessarily by the very nature of this or any other welding process which requires fusion of the material. It is even possible, then, that blowpipe welding may prove superior to other methods involving the use of gas or coal, since the reducing action of the oxyacetylene flame may prevent the oxidizing of the crystals found in "burnt" steel. In any case, maximum efficiencies can be obtained only by using every available means to reduce the effects of overheating. This would require annealing and, if practicable, hammering or rolling.

It is often claimed that welds can be strengthened any required amount by adding filler to increase the thickness. This, however, is obviously only a partial remedy, as the material adjacent to that where filler is added is always overheated. When rupture occurs just outside the weld, due to this overheating, the weld can not be considered to be as strong as the rest of the material.

73. *Efficiency.*—Skill in the manipulation of the oxyacetylene blowpipe and in making welds may readily be acquired by the ordinary workman. As already stated, the appearance of the flame is a delicate indication of proper regulation. The principal precaution to be observed by the workman is to be sure that thorough fusion has taken place.

The data on consumption of gases, and on pressure and regulation given in IV. Tests of Gases and Flame Regulation may be applied to various conditions of operation. The cost of operation of a blowpipe rises very rapidly as the thickness of the plate to be welded increases, and this fact may limit the field of usefulness of the oxyacetylene blowpipe to the welding of thin plates and parts and to emergency repair jobs.

The efficiencies of welds obtained in the investigation are summarized rather fully in paragraphs 31 to 36, 53 to 58, and 67 to 71. A consideration of the results leads to the conclusion that thorough fusing of the material in the weld and forging of the finished weld were the only conditions which resulted in any noticeable increase in the efficiency of the welds. Forging after welding produced a decided increase in the strength of the welds and also in the ductility of the fused metal—apparently the increase in efficiency of the weld was about 10%. In the three strips in which thorough fusion took place throughout the weld, the average efficiency was the highest obtained in the tests. In view of the comparisons hitherto made, the efficiency found for one of these strips, 86.6 %, may be expected to be fairly representative of welds in $\frac{1}{8}$-in. steel when fusion has occurred throughout the weld.

The average technical article describing this process apparently lays too much emphasis upon the necessity for very careful flame regulation and for pure oxygen and acetylene, as well as on the value of preheating and hammering the weld as it is made, in securing high efficiency. A claim of 100% efficiency is insupportable. It appears that 85% is about as high as may be expected in practice if the weld is of the same thickness as the plate.

In spite of certain inherent defects the oxyacetylene process is well adapted to many welding operations, and it is likely to grow in favor as its advantages are understood.

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