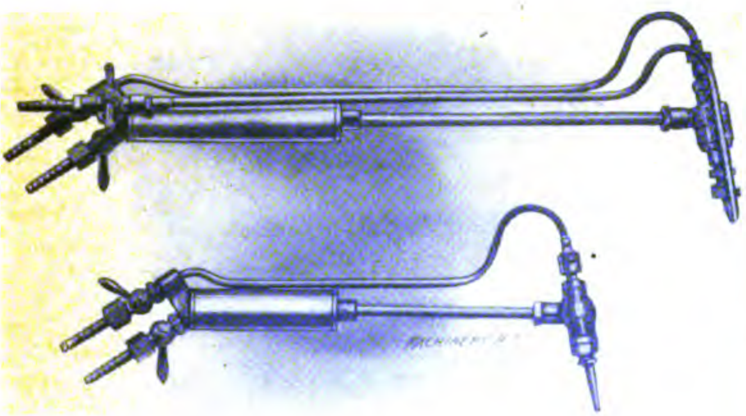
PRICE 25 CENTS

AUTOGENOUS WELDING

THE OXY-ACETYLENE AND OXY-HYDROGEN PROCESSES FOR WELDING AND CUTTING METALS



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AUTOGENOUS WELDING

CONTENTS

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INTRODUCTION

During the last fifteen years several interesting and valuable processes for joining metal parts have been developed. The processes of ordinary forge welding, soldering, and brazing are very old, having been used from time immemorial. Forge welding is applicable only to the joining of wrought iron, low carbon steel and a few alloys. For the sake of accuracy we must except gold which in the pure, annealed state has the curious property of welding cold under pressure; but commercially speaking, forge welding is limited to wrought iron and mild steel. Soldering can be used only on small, light work for joints which are exposed to ordinary temperatures and those slightly above the boiling point of water, inasmuch as the melting point of solder is about 400 degrees F. Brazing, that is, the joining of parts by the fusion of a spelter, is applicable to iron, steel, copper, brass, and other metals. On many kinds of work it is a process rather uncertain in results, even in the hands of experts, unless a good equipment is provided for controlling the heat and manipulating the work.

Until within a few years, cast iron could not be brazed successfully, because of the presence of the free carbon in the iron. The brazing of cast iron was made possible by the "ferrofix" process, which first decarbonizes the joint, placing the metal in much the same condition as wrought iron, so far as the action of brazing is concerned, and then brazing follows in the usual manner. Prior to this discovery the Thompson electric welding process had been developed, by which almost all commercial metals except cast iron are quickly and homogeneously welded together, the joint being raised to incandescence by the flow of the electric current. This process has had a very successful commercial development, and is now used for making thousands of welds daily. The electric welding processes are essentially "autogenous," an expression that will be explained further on.

The thermit process developed by Goldschmidt is unique. Intense heat is produced by the chemical reaction of pure aluminum and iron oxide in a finely divided state, the temperature rising as high as 5,400 degrees F. One product of the reaction is pure molten iron or mild steel so hot that when poured upon the broken ends of a forging, surrounded by a suitable mold, the parts are instantly melted, and the whole fushed together with a mass of hot metal which, as it cools, binds the joint together with a perfectly homogenous union.

The latest development in the joining of metals, which is now assuming the proportions of an important commercial development, is the so-called autogenous gas flame process. The term autogenous welding is in some danger of becoming applied exclusively to various systems of gas flame welding. The flame produced by the combustion of hydrogen and oxygen, or acetylene and oxygen, is so hot that the parts adjacent to the metal joint are quickly melted together, forming a perfect union; but the meaning of autogenous welding is simply a welding of its own kind, the parts being joined together without the introduction of spelter, solder or any foreign material. Hence any method of joining metals by fusion of the joint which does not require the introduction of foreign material to make the weld is autogenous. Right here it may be said that the autogenous weld is the only reliable joining of aluminum parts that has been discovered.

An autogenous joint, when properly made, must be as strong as the adjacent metal, provided no change has been made in the charactertics of the metal because of the heat. A broken forging that has been subjected to special heat treatment to improve its physical characteristics could not be autogenously welded and made as strong in the joint as before, without, of course, again being heat treated. The importance of gas flame autogenous welding in jointing thousands of manufactured articles, which are now brazed, riveted or bolted together, is obvious.

CHAPTER I

THE OXY-ACETYLENE AND OXY-HYDROGEN PROCESSES OF METAL CUTTING AND AUTOGENOUS WELDING

Within the past few years a valuable tool, unique in its characteristics, has been developed for cutting, shaping, and welding metals. This is the oxy-acetylene "torch," which now is so well advanced that it bids fair to displace other emergency cutting and welding means to a large extent. The oxy-acetylene process had its inception in France, the first experimenter being Mr. Edmund Fouche, of Paris, who began his work on it in 1901. The principle of the oxy-acetylene torch or burner is essentially the same as that of the oxy-hydrogen blow-pipe, which has been used for many years for generating intense heat. But though the oxy-hydrogen flame is intensely hot, the flame produced by the oxy-acetylene torch is so much hotter that the two are not in the same class. The temperature produced by the oxy-hydrogen flame is rated by authorities at about 4,000 degrees F., while that of the oxy-acetylene flame is estimated at about 6,300 degrees F. Not only is the flame of acetylene much hotter than hydrogen, but the number of B. T. U. per cubic foot is about five times as great, being as 330 to 1600. Hence both the intensity and amount of heat is greatly increased in the flame of the oxy-acetylene torch. A comparison between the two instruments has been aptly put as like that of "a finely pointed tool and a blunt instrument."

Definition of Autogenous Welding—Brief Explanation of Method

As already mentioned in the introductory paragraphs, the process of fusing and uniting metals by the application of intense heat without compression or the use of a flux is termed "autogenous welding." The temperature required is obtained by the combustion of a mixture of gases, such as oxygen and acetylene or oxygen and hydrogen. One or both of these gases may be under pressure. The gases are mixed in the nozzle of the torch prior to combustion. Ordinarily, the weld is formed by fusing in additional material between the surfaces of the joint. This material is in the form of a rod or wire and may or may not be of the same composition as the material being welded.

Development of Oxy-acetylene Process

The commercial development of metal-cutting and autogenous welding has been taken up by several concerns in the United States and Europe. The processes are essentially the same, the difference being in the construction of the torches and the manner in which the gases are generated. Great difficulties were at first met with in cheaply producing pure oxygen gas. The cheap production of acetylene had, to a great extent, been satisfactorily solved in the extensive development of acetylene lighting, but even this art had to be further developed to meet all the requirements of metal welding and cutting work. There are four or five commercial means of making oxygen, these being principally the oxone or barium process, the liquid air process, the epurite process, and the chlorate of potash process. The latter process is used by the Davis-Bournonville Co., New York, and the following notes relate to the development of the art of metal cutting and autogenous welding, as reached by this concern.

A few of the purposes for which cutting and welding torches are commonly used are as follows: For cutting steel wreckage, steel piling, steel beams in structural work, risers from steel castings, openings through steel plates, etc.; for welding seams, reclaiming cracked castings, filling blowholes in castings, adding metal to worn surfaces to secure the original thickness, welding piping without removal, filling holes that have been incorrectly located, replacing broken gear teeth by welding in new material, sealing riveted seams to secure tight joints without calking, etc.

Generating the Oxygen and Acetylene

The chlorate of potash process of generating oxygen is well known, being perhaps the simplest method. It will be found described in elementary works on chemistry. The oxygen of chlorate of potash can be driven off by gentle heat, and, in practice, the potash is placed in a closed retort and subjected to a comparatively low temperature. The reduction is facilitated by the addition of black dioxide of manganese in the proportion of 14 pounds of manganese to 100 pounds potash. The oxygen gas is passed through scrubbers and is pumped into receivers. The pressure in the receivers is varied according to the use, it being desirable to compress from 125 to 150 pounds per square inch for metal cutting, while 15 pounds pressure suffices for autogenous welding. The acetylene gas is produced in the Davis generator which is adapted to all pressures up to 15 pounds per square inch. The machine is automatic and feeds lump carbide perfectly up to sizes that pass through 1-inch screen. The theoretical quantity of water to carbide is about ½ pound to 1 pound carbide, but to absorb the heat of the chemical transformation the generator is required to have a water capacity of 1 gallon water to 1 pound carbide. For repair shops and work outside of the shop, a portable apparatus is required, and for such purposes the oxygen and acetylene gases are stored in small cylinders. The storage of oxygen is a simple matter of pumping the gas into the cylinders until the required pressure has been reached. The storage of undiluted acetylene under pressure in tanks is impracticable, but fortunately, it was discovered in 1896 by Claude and Hesse, two French engineers, that acetone, a fluid derived from the dry distillation of wood, is a remarkable solvent for acetylene, being capable of absorbing 25 times its volume at 60 degrees F. for each atmosphere. At ten atmospheres, or 150 pounds pressure per square inch, a gallon of acetone absorbs 250 gallons of acetylene gas. When absorbed by acetone, acetylene is non-explosive under heavy pressure. A red-hot wire might be thrust into the receiver with absolutely no effect, provided there is no free space occupied by acetylene gas. To prevent the possibility of there being free spaces for the accumulation of gas, acetylene storage tanks were designed by Mr. Edmund Fouche, which are packed with porous brick, asbestos or other neutral porous material, thus filling the entire free spaces and affording storage for the acetone and acetylene gas only in the cells of the filling.

Impurity of Oxygen

It is of considerable importance to understand the effect of impure oxygen. The impurities which have any especial claim to attention are those which arise through the presence of nitrogen or hydrogen. If the oxygen is prepared by the liquefaction of air, some percentage of nitrogen will be very sure to be present. Nitrogen itself seems to be harmless, in so far as any ill effect on the metal is concerned. It is, however, practically unburnable, and so clogs the action of the oxygen. It probably also tends to cool the heating flame and thus retard the work. In the manufacture of oxygen by the electrolytic process, the principal impurity will probably be hydrogen. As hydrogen is a gas that is readily combustible it has but little effect on the heating flame, but in the cutting stream of oxygen its presence doubtless gives rise to a clogging effect similar to that of nitrogen. At all events, whether we account for the result in one way or another, the presence of nitrogen or other impurities in the oxygen supply has the effect of retarding the cutting operation. This retardation means a labor loss in addition to a gas loss, besides hindering output. Certain experiments carried out abroad will assist us in seeing just how serious the retardation is.

Table 1 gives the results of twenty-six experiments, all tried on sheets of the same kind, of the same thickness, and with the same style of torch.

It will be seen at once that the purity of the oxygen plays a most important part in the efficiency with which cutting may be accomplished. With oxygen 85.5 per cent pure, it requires three times as long to cut the 1.18-inch plate as with oxygen 99 per cent pure. This means that the cost is three times as much. Exen the one-half of one per cent drop from the 99.0 per cent oxygen to the 98.5 per cent quality means an increase in the expense amounting to 16 per cent. So even if the better grade of oxygen should cost more, we see from the foregoing that it would have to cost a great deal more to make it a matter of no importance which grade of oxygen is used.

TABLE I. TIME REQUIRED FOR OXY-HYDROGEN CUTTING OF METALS

Siemens-Martin sheet steel, 1.18 inch thick. Oxy-hydrogen procedure. Gas consumption per minute: Hydrogen, 1.06 cubic foot; oxygen, 0.28 cubic foot. Oxygen pressure = 1.5 atmosphere = 22 pounds per square inch.

Purity of Oxygen, expressed as Percentage	Length of Cut, in Inches	Time required in Making Cut, in Seconds	Time required to Cut One Foot, in Minutes	Average Time required to Cut One Foot, in Minutes
99.00	28.0	182	1.30	1.30
99.00	21.3	140	1.31	
99.00	18.9	120	1.27	
99.00	34.3	228	1.33	
99.00	29.9	196	1.31	
98.50	31.5	210	1.33	1.52
98.50	41.7	330	1.58	
98.50	41.7	320	1.53	
98.50	39.4	310	1.58	
98.50	27.6	225	1.63	
98.50	18.9	150	1.58	
95.50	44.5	426	1.91	1.91
95.50	32.3	295	1.91	
94.75	25.2	270	2.14	2.21
94.75	21.7	240	2 21	
94.75	33.9	364	2.15	
94.75	23.6	270	2.29	
94.75	41.6	475	2.28	
90.50	34.3	480	2.80	2.88
90.50	36.6	500	2.73	
90.50	32.7	480	2.94	
90.50	35.4	495	2.80	
90.50	29.9	470	3.14	
85.50	43.3	870	4.02	3.99
85.50	21.7	420	3.87	
85.50	23.6	480	4.07	

Machinery

In Table II the same kind of steel and the same thickness of sheets are to be understood as in Table I. The pressure of the oxygen is increased, however. Note especially that here we have the alternative procedure with acetylene gas.

It will be noted that we do not have any experiments here with 99 per cent oxygen. Comparing the 98.5 per cent purities in Tables I and II, we see that the acetylene cutting has the advantage. The result with 94.75 per cent oxygen, hydrogen cutting, when compared with the work done with 94.50 per cent, acetylene cutting, indicates that the efficiencies at this degree of impurity are about the same. This would become all the clearer by drawing curves illustrative of the last columns in Tables I and II and then superimposing them on each other. It must be borne in mind, however, that the oxygen pressure is distinctly higher with the acetylene experiments.

TABLE II. TIME REQUIRED FOR OXY-ACETYLENE CUTTING OF METALS

Siemens-Martin sheet steel, 1.18 inch thick. Oxy-acetylene procedure. Acetylene consumption per minute: 0.153 cubic foot. Oxygen pressure: 2 atmospheres = 29.4 pounds per square inch.

Purity of Oxygen, expressed as Percentage	Length of Cut in Inches	Time required in Making Cut, in Seconds	Time required to Cut One Foot, in Minutes	Average Time required to Cut One Foot, in Minutes
98.50	17.3	123	1.43	1.40
98.50	28.3	192	1.36	
98.50	32.3	228	1.41	
98.50	33.9	230	1.36	
98.50	28.3	200	1.41	
98.50	28.3	202	1.43	
96.50	33.9	255	1.50	1.63
96.50	45.3	360	1.59	
96.50	47.2	380	1.61	
96.50	37.8	320	1.69	
96.50	58.3	480	1.65	
96.50	44.1	370	1.68	
96.50	41.7	340	1.63	
96.50	30.7	245	1.60	
96.50	44.9	380	1.69	
94.50	34.6	400	2.31	2.33
94.50	43.3	510	2.36	
94.50	43.3	520	2.40	
94.50	35.4	400	2.26	

Machinery

The Oxy-acetylene Torch

Fig. 1 shows the Davis-Bournonville Co.'s cutting and welding torches. The upper illustration is the cutting torch and differs from the welding torch shown in the lower illustration simply in that it has an auxiliary detachable oxygen tube secured to the side. The welding torch has an acetylene gas tube and an oxygen tube which combine in a tip or nozzle from which the united gases flow and burn. The upper tube in each illustration is for oxygen, while the lower tube is for acetylene, the two gases uniting at the end of the removable tip within the body of the torch.

In Fig. 2 is shown a line engraving of a standard oxy-acetylene torch for medium and heavy welding. As will be seen, there are two small pipes which have hose connections at one end. The opposite ends are attached to a head which holds the torch tip or nozzle. The pipe for acetylene opens into a cylinder which serves as a handle and is packed with a porous material that makes it impossible for the flame to pass this point. However, "flash back" is not likely to extend back of the tip. The tips are interchangeable, different sizes being required for various classes of work. The mixture of the oxygen and acetylene gases takes place within the tip. The acetylene is admitted under lower pressure than the oxygene, and through inlets at right angles to the oxygen inlet to insure thorough mixing. Regulators on the storage tanks serve to control the working pressures of both gases.

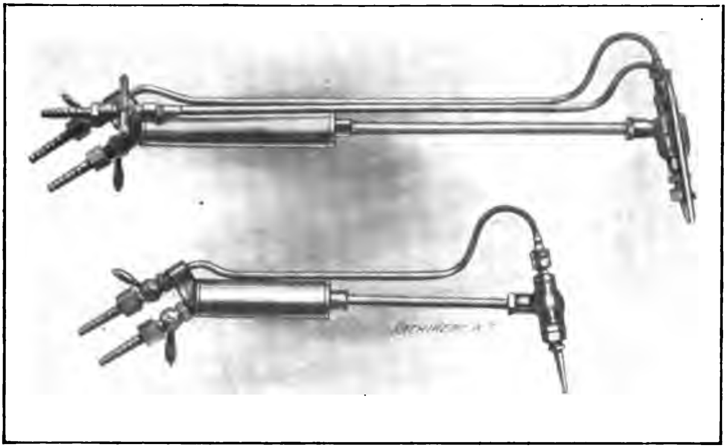


Fig. 1. Davis-Bournonville Oxy-acetylene Cutting and Welding Torch

Adjusting the Torch

Before lighting the torch, the regulator on the oxygen tank should be set to give the required pressure. The average pressures used for welding different thicknesses of metal are given in Table III. The acetylene is lighted first, the regulator being adjusted so that there is a fairly strong flame. The full pressure of the oxygen is then turned on, after which the acetylene pressure is varied by means of the regulator until the two cones which appear in the flame at first are merged into one smaller cone. After this cone is formed, no more oxygen should be added. It is also well to occasionally test the cone by increasing the acetylene pressure slightly, which will immediately cause an extension at the point of the cone. When the cone is properly formed, it will be neutral, so that it will neither oxidize (burn) or carbonize the metal. An excess of oxygen will cause burning and oxidation, whereas an excess of acetylene will carbonize the metal. The tip of the cone should just touch the metal being welded, but not the point of the torch, as this might cause a "flash back." An excessive discharge of sparks indicates that too much oxygen is being used and that the metal is being burned or oxidized, although when welding thick metals, there will be a considerable volume of sparks, even though the flame is neutral.

Size of Torch Tip

The proper size of tip to use for welding depends upon the thickness of the work and the rate at which the heat is dissipated. Sometimes the rate of conduction and radiation is affected by the location of the parts to be welded. In general, heavy parts will conduct the heat more rapidly from the working point, and to offset this loss of heat a larger tip is used. In any case, the tip should be as small as is compatible with good work, to economize in the use of gases. If the flame is too small for the thickness of metal being welded, the heat will be radiated almost as fast as produced; hence, the flame will have to be held so long at one point to effect a weld that the metal will be burned. On the other hand, if the flame is too large, the radiation may be insufficient to prevent burning the molten metal. The tip should give a flame that will reduce the metal to a plastic, molten condition (not too fluid), covering a width approximately equal to the thickness of the metal being welded.

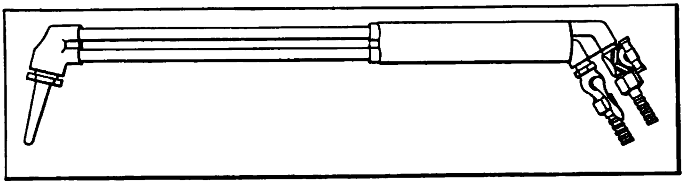


Fig. 2. Oxy-acetylene Torch for Medium and Heavy Welding

High- and Low-pressure Torches

The difference between high- and low-pressure oxy-acetylene welding and cutting torches, according to the generally accepted meaning of these terms, is in the pressure of the acetylene gas. The oxygen, in each case, is under a pressure of one or two atmospheres. With a high-pressure torch, the acetylene gas has a working pressure of one pound or more (depending upon the nature of the work); in the low-pressure type, the acetylene gas only has a pressure of a few ounces. The operation of the low-pressure torch is on the principle of an injector, in that the jet of oxygen draws the acetylene into the mixing chamber which is in the torch tip. The proportion of oxygen to acetylene varies somewhat with different torches; it usually ranges between 1.14 to 1 and 1.7 to 1, more oxygen being consumed than acetylene.

Making Autogenous Welds

To become proficient in the art of autogenous welding requires experience and practice, but a knowledge of some of the fundamental principles will enable the operator to make more rapid progress. It is advisable to begin by welding thin strips of iron or steel not over ⅛ inch in thickness. Such light metals can be welded without the addition of a filling-in material. The torch should be given a rotary motion accompanied by a slight upward and forward movement with each rotation. This movement tends to blend the metal and reduces the liability of overheating. If comparatively thick materials are to be welded, the edges should be beveled (by chipping, or in any other convenient way), as shown in Fig. 3. The beveled surfaces are then heated by a circular movement of the flame, care being taken to melt them to a soft, plastic state without burning the metal. Wherever fusion occurs, new metal should be added from a "welding rod," the composition of which is suitable for the work in hand. In continuing the heating operation, the flame should be swung around in rather small circles and be advanced slowly to distribute the heat and prevent burning. The surface should be thoroughly fused before adding metal from the welding stick, and the latter should be held close to, or in contact with, the surface. The heat is then radiated from the welding rod to the work, whereas if the metal were allowed to drop through the flame, it might be burned to an injurious extent. When the weld is completed, it is advisable to pass the torch over it, so that all parts will cool from a nearly uniform temperature.

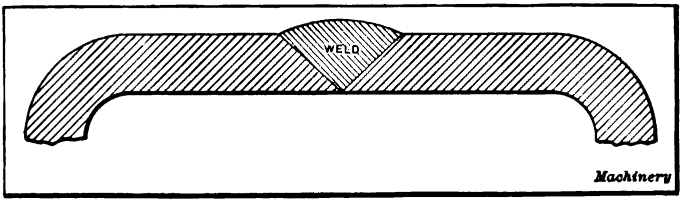


Fig. 3. Method of Welding Thick Materials

When welding two parts together, it is important not to heat one more than the other, because the hottest piece will expand most and the weld may crack in cooling as the result of uneven contraction. When making heavy welds, the parts should be brought to a red heat for a distance of about three times the thickness on each side of the weld, for thicknesses up to one inch, the distance being increased somewhat for heavier parts. The following suggestions are given by the Davis-Bournonville Co., and apply to the welding of various metals.

Welding Cast Iron

If the work is in such a form that it may crack in cooling, it should be pre-heated, but not enough to warp the metal, no part being heated to a dark red except at the welding point. (See Chapter II.) Whether the metal is pre-heated or not, it should be covered as soon as the weld is finished and be allowed to cool slowly. If the metal is more than ¼ inch thick, the edges should be beveled at an angle of about 45 degrees on each side. For comparatively heavy welds, it is well to leave three small points of contact for aligning the broken parts in the original position. To make the weld, the flame should be passed for some distance around the fracture and then be directed onto it until the metal is cherry-red. When this occurs, have an assistant throw on a little scaling powder, and when the metal begins to run, add cast iron from the cast-iron "welding stick," which should be of specially refined material. Powder should only be added when the metal does not flow well, as little as possible being used. Never attempt to re-weld pieces that have been previously welded or brazed, without first cutting away all of the old metal.

TABLE III. APPROXIMATE HOUR COST OF OXY-ACETYLENE WELDING
(Davis-Bournonville Co.)
Oxygen at 3 cents per cubic foot, acetylene at 1 cent per cubic foot

Tip No.	Thickness of Metal, Inches	Acetylene Pressure, Pounds	Oxygen Pressure, Pounds	Cubic Feet per Hour		Lineal Feet Welded per Hour	Cost of Gases	Cost of Labor	Total Hour Cost	Cost per Lineal Foot
				Acetylene	Oxygen					
1	1/32	1	2	3.21	3.65	30	$0.142	30 cents per hour	$0.442	$0.015
2	1/16	2	4	4.84	5.50	25	0.213		0.513	0.020
3	3/32	3	6	8.14	9.28	20	0.360		0.660	0.033
4	1/8	4	8	12.50	14.27	15	0.553		0.853	0.057
5	3/16	5	10	17.81	21.32	9	0.818		1.118	0.124
6	1/4	6	12	24.97	28.46	6	1.103		1.403	0.234
7	5/16	6	14	33.24	37.90	5	1.469		1.769	0.354
8	3/8	6	16	41.99	47.87	4	1.856		2.156	0.539
9	1/2	6	18	57.85	65.95	3	2.557		2.857	0.952
10	5/8	6	20	82.50	94.05	2	3.646		3.946	1.973

Welding Steel

Steel less than ⅛ inch thick can be welded without the addition of any welding metal. If the thickness exceeds ⅛ inch, the edges should be beveled or chamfered. It is very important not to add the welding material until the edges are fused or molten at the place where the weld is being made. The welding metals should be of special wire, and in no case should the flame be held at one point until a foam is produced, as this is an indication that the metal is being burned. Do not hold the flame steadily in the center of the weld, but give it a circular motion with an uplifting movement at each revolution, the object being to drive the molten metal toward the center of the weld. When welding a crack located in the middle of a heavy steel sheet, begin by chamfering the metal on each side of the fracture at an angle of 45 degrees, the slope extending to the bottom; then apply the welding torch to the sheet beyond the end of the crack, until there is sufficient expansion to open the crack perceptibly. The weld should then be made, and, as a rule, it will be found that the expansion will compensate for the contraction when cooling. A slight excess of oxygen is less harmful than an excess of acetylene, but it is important to so adjust the gases that the flame is neutral. When the weld is completed, pass the torch over it and the surrounding metal, as previously mentioned.

Welding Aluminum

Aluminum that is to be welded should be scraped and cleaned, and if the stock is more than ¼ inch thick, it is advisable to chamfer the edges. The oxy-acetylene flame can be reduced or "softened" by using an excess of acetylene to a degree which will be indicated by the extension of the acetylene cone from 1 to 1½ inch beyond the white cone. This excess of acetylene does not injure aluminum, but lowers the flame temperature which is desirable when welding aluminum. Before welding this metal, heat the entire piece in a charcoal fire or furnace to about 300 or 400 degrees below the melting point. Then cover it with asbestos or other material (leaving an opening where the weld is to be made), in order to keep the work hot until the weld is completed. When the weld is made it should be covered completely, as a protection against drafts, to insure slow cooling and prevent shrinkage cracks. Many aluminum parts can be welded without pre-heating, such as lugs or projecting pieces broken off completely. When a welding flame is applied to aluminum, it will be noticed that the metal does not run together. A flattened iron rod should be used to puddle the aluminum, and this rod should be wiped frequently, so that it will not become coated. The rod should not be allowed to reach a red heat, thus causing oxide of iron to form on it, as this would cause a defective weld. A good aluminum flux will be found advantageous. The aluminum to be added should be in sticks of special composition, obtainable from the makers of welding apparatus. The quality of the welding metal has much to do with the quality of the weld.

Welding Brass and Copper

For brass, adjust the flame until there is a single cone, as for steel welding. Keep the point of the white flame slightly away from the weld, according to the thickness of the piece, so that the heat will not be sufficient to burn the copper in the brass or volatilize the zinc. If a white smoke appears, remove the flame, as this indicates excessive heat. A little borax should be used as a flux. For brass welding, it is advisable to use a tip about one size larger than for the same thickness of steel. As the weld is really cast brass, it will not have the strength of rolled sheet brass. Do not breathe the fumes while welding brass.

To weld copper use the same kind of flame as for steel, but a much larger tip for corresponding dimensions, because of the great radiating property of copper. Pre-heating is neessary when a large piece of copper is to be welded, as otherwise so much heat from the torch will be dissipated by radiation that little will be left for fusing the metal. Copper will weld at about 1930 degrees F.; hence, the flame need not have so high a temperature as for steel and it must not be concentrated on so small a surface. On account of the radiation, however, the total quantity of heat must be greater. Welded copper has the strength of cast copper, but can be rendered more tenacious by hammering. The radiation of heat from copper can be considerably lessened by covering it with asbestos sheets while heating. To weld copper to steel, first raise the steel to a white heat (the welding point); then put the copper into contact with it and the two metals will fuse together. When the copper begins to flow, withdraw the flame slightly to prevent burning.

Fig. 4. Welding together the Parts of a Drawn Steel Retort. The Operator feeds the Joint with a Special Grade of Iron Wire

Welding Miscelianeous Metals

To weld high-speed steel to ordinary machine steel, first heavily coat the end of the high-speed steel with soft special iron, obtainable from the makers of welding outfits. This can be done without heating the high-speed steel to the burning point. After cooling, the high-speed steel can be welded to ordinary machine steel without burning, but experience is required to make a good weld of this kind.

To weld cast iron to steel, cast-iron rods are used as welding material. The steel must be first heated to the melting point, as cast iron melts at a lower temperature. A very little scaling powder should be used.

The welding of malleable iron is difficult for several reasons. If malleable iron is raised to the melting point and kept there for any length of time, the metal becomes spongy and changes to what is practically cast iron. To weld it, coat the edges with soft special iron, using a little scaling powder, and then finish the weld by the addition of special iron. To fill blowholes in malleable iron, use cast iron for a filler, and to avoid hard spots, pre-heat the metal so that the oxy-acetylene flame is used as little as possible.

Certain grades of cast steel can be welded more easily than ordinary rolled steel, but other grades, especially of high-carbon composition, are very difficult to weld and some cannot be welded at all. When difficulty is experienced, the addition of one or two drops of copper, melted into the weld, will cause the metal to flow and a fairly good weld can be made, but copper is likely to harden the metal so that it cannot be machined except by grinding.

Filling Blowholes

To fill large blowholes in brass or copper castings, pre-heat the casting to a temperature between 200 and 400 degrees F. below the melting point, or to a bright red color. Have some of the same metal melted in a crucible ready to pour; then apply the torch to the blowhole to be filled and when the walls of the hole have been brought to the melting point, gradually pour in the metal, keeping the walls fused by using the flame. Continue mixing the poured metal with the molten metal of the walls, until the blowhole is filled.

Spots in Welding

When making heavy welds, there often is a spot in the middle of a weld where the metal refuses to flow, because the metal is not hot enough surrounding this spot, the heat being absorbed by the cold metal; consequently, the added metal is chilled. To remedy this, play the flame in a radius of from ½ to 1 inch, around the refractory point until the surrounding metal is at a white heat; then apply the flame to the spot itself and it will quickly unite with the other molten metal.

Examples of Welding Operations

Fig. 4 illustrates the welding of thin steel retorts for generating oxygen gas. The material for the retorts is bought in drawn shape, one part being made with a collar and the other having a rounded bottom. The length of the retort is too great to permit its being drawn in one piece, hence the necessity of welding the two parts together near the center. The following is the approximate cost of welding 1/16-inch metal. The consumption of acetylene is 2.8 cubic feet per hour; of oxygen 3.6 cubic feet at a pressure of 8 to 10 pounds. The rate of welding is about 50 feet per hour, and with labor at 30 cents per hour, the total cost per hour is 43.6 cents, or less than 9/10 per cent per lineal foot. The cost of welding increases with the thickness of material, of course, reaching an estimated cost of 80 to 95 cents per lineal foot for 7/16- to ½-inch thick metal.

In Fig. 5 is illustrated the welding of a broken flange on a casting. This job, which would have been difficult and expensive by brazing, was easily accomplished. In this illustration, as in Fig. 4, the operator is shown feeding material into the weld, the same as a tinner feeds solder when soldering. For welding steel and wrought iron a special iron wire is used as already mentioned, and for welding cast iron, rods of cast iron.

Pre-heating

Parts to be welded together autogenously are often pre-heated by the use of a blow-torch, gas furnace, charcoal fire, etc. This pre-heating is done either to economize in gas consumption or to expand the metal before welding, in order to compensate for contraction in cooling. Usually it is advisable to pre-heat comparatively heavy, thick metals (especially if cast) before welding. This equalizes the internal strains, and very materially reduces the cost. In many instances, it is much better to produce expansion before welding, than to attempt to care for the contraction afterward. When there is a straight crack, it can usually be opened uniformly by heating the metal at each end and keeping it hot while the weld is being made. As a rule, the expansion obtained by heating at the ends will compensate for the contraction which accompanies cooling. When a part has been pre-heated, it is well to place sheets of asbestos over it to protect the operator and prevent heat radiation, the surface to be welded being exposed. Where

Fig. 5. Welding the Broken Flange of a Cast-iron Base. The Operator feeds the Joint with a Cast-iron Rod

a piece of metal has been severed completely or a projection has been broken off, pre-heating will not be necessary. This subject will be dealt with in detail in a following chapter.

Cutting Metals with Oxidizing Flame

The oxy-hydrogen and oxy-acetylene flames are especially adapted to cutting metals. When iron or steel is heated to a high temperature, it has a great affinity for oxygen and readily combines with it to form different oxides which causes the metal to be disintegrated and burned with great rapidity. The metal-cutting torch operates on this principle. Ordinarily, two jets or flames are used: First there is an ordinary welding flame for heating the metal, and this is followed by a jet of pure oxygen, which oxidizes or burns the metal. The kerf or path left by the flame is suggestive of a saw cut. On some torches the oxygen jet is obtained by the application of a separate cutting attachment to a regular welding torch. This attachment is little more than a pipe containing a tip, which supplies a pure oxygen jet located close to the regular heating flame. Torches are also designed especially for cutting.

Operation of Cutting Torch

When starting a cut, the steel is first heated by the welding flame; then the jet of pure oxygen is turned on. The flame should be directed a little inward, so that the under part of the cut is somewhat in advance of the upper surface of the metal. This permits the oxide of iron produced by the jet to readily fall out of the way. If the flame were inclined in the opposite direction or in such a way that the cut at the top were in advance, the oxide of iron would accumulate in the lower part of the kerf and prevent the oxygen from attacking the metal. The torch should be held steadily and with the cone of the heating flame just touching the metal. When accurate cutting is necessary, some method of mechanically guiding the torch should be employed.

Thickness of Metal to be Cut

The maximum thickness of metal that can be cut by these high-temperature flames depends largely upon the gases used and the pressure of the oxygen; the thicker the material the higher the pressure required. When using the oxy-acetylene flame, it might be practicable to cut iron or steel up to 7 or 8 inches in thickness, whereas with the oxy-hydrogen flame the thickness could probably be increased to 20 or 24 inches. The oxy-hydrogen flame will cut thicker material principally because it is longer than the oxy-acetylene flame and can penetrate to the full depth of the cut, thus keeping all the metal in a molten condition so that it can easily be acted upon by the oxygen cutting jet. A mechanically-guided torch will cut thick material more satisfactorily than a hand-guided torch, because the flame is directed straight into the cut and does not wabble, as it tends to do when the torch is held by hand. With any flame, the cut is less accurate and the kerf wider, as the thickness of the metal increases. When cutting light material, the kerf might not be over 1/16 inch wide, whereas, for heavy stock it might be ¼ or ⅜ inch wide.

Cutting Metal under Water

A German engineer has designed a burner which makes it possible to use the hydrogen-oxygen flame for cutting metals under water. The burner consists of a bell-shaped head which is screwed onto an ordinary burner and which allows the flame to continue to burn below the water in a supply of compressed air. This process has been so improved of late that the cutting of metals under water is claimed to be effected almost as quickly as above the surface. At tests made with the new apparatus at the harbor at Kiel, before prominent engineers and representatives of the German government, a diver went down into the sea to a depth of about 16 feet, and, after boring a hole into an iron bar 2½ inches square, cut off the bar in about thirty seconds. An iron sheet ⅞ inch thick was drilled through and cut for a distance of one foot in ninety seconds.

Fig. 6. Cutting Off Steel Sheet Piling with Oxygen Cutting Torch showing Portable Apparatus

Example of Metal Cutting

Fig. 6 illustrates the use of the cutting torch cutting off steel sheet piling. This work is done with rapidity, and is a very spectacular performance. In the case of cutting, the combustion of the steel materially raises the temperature and assists in the work. This was pointed out by Chevalier C. de Schwarz in a paper read before the May, 1906, meeting of the Iron and Steel Institute, and it gives one a startling idea of the power of the oxygen cutting flame when the concentration of the heat units produced is known. Burning 1 pound of acetylene with oxygen produces from 18,250 to 21,500 B.T.U. The mean value may be taken as about 19,750 B.T.U. per pound, and the number of cubic feet at atmospheric pressure at about 14½. Now, the burning of 1 pound of steel with oxygen produces approximately 2,970 B.T.U., but at atmospheric pressure 1 pound of acetylene gas fills 6,750 times the space of 1 pound of steel. Hence, the intensity of the heat with perfect combustion of the steel in oxygen will be, theoretically, $\frac{6750 \times 2970}{19{,}750} = 1{,}015$ times the intensity of heat of the oxy-acetylene flame. As a matter of fact, of course, this enormous temperature is not even remotely approached, because the metal dissolves at a far lower temperature and passes off in sparks, which are speedily cooled by the atmosphere.

Cost of Cutting Metals with the Oxy-acetylene and Oxy-hydrogen Flame

The following figures will give an idea of the cost of cutting metals by the processes described. Assuming oxygen at 3 cents per cubic foot and acetylene at 1 cent per cubic foot, 2 feet of ¼-inch thick steel can be cut per minute at a cost of 1.3 cent per foot, and 1 foot of 1½-inch thick steel can be cut per minute at a cost of 7.6 cents per foot. This cost is for gas alone; the cost of labor must, of course, be added. The figures given are for machine-guided torches. When cutting with a hand-guided torch, the gas consumption will be approximately one-third more and the number of feet cut per hour, one-third less, than when the torch is mechanically guided by a special cutting machine. The variation, of course, depends to some extent upon the skill of the operator.

When cutting with the oxy-hydrogen flame and assuming the cost of oxygen at 3 cents per cubic foot and the cost of hydrogen at 1¾ cent per cubic foot, the cost of the gas per foot for cutting ¼-inch thick steel is about 7 cents and the cost of cutting 1½-inch thick steel, about 18 cents per lineal foot. Cutting with a hand torch increases the cost slightly. While the oxy-hydrogen process is thus more expensive than the oxy-acetylene process for thin stock, it has the advantage that it can be used on much heavier material than the oxy-acetylene flame, as explained in a previous paragraph.

CHAPTER II

PRE-HEATING METALS TO BE WELDED BY THE OXY-ACETYLENE PROCESS

The use of the oxy-acetylene torch for heating the work from the ordinary open-air or room temperature to that of, say, red heat, is a rather wasteful method. It is frequently more economical to do this pre-heating by some cheaper method and then to complete the heating with the torch. Various methods are used for pre-heating; as a rule these methods are comparatively simple. A number of examples will be described in the following.

In pre-heating a large cast-iron kettle, a charcoal fire was employed. The kettle weighed about 18,000 pounds and the metal around the crack, which was about two feet long, was several inches thick. The crack was in the bottom and so the kettle was overturned in order to make the crack more easily accessible. The pre-heating was then done from within the kettle, and, in this case, was not only economical but probably essential, as it would have been difficult to obtain the required amount of heat by the torch flame alone. Asbestos sheeting was employed to protect the operator from the heat radiation.

Repairing a Locomotive Cylinder

In repairing a break in a locomotive cylinder, Fig. 1, the pre-heating was also done with charcoal, a temporary oven having been built up of loosely laid bricks, as shown in Fig. 2. The fire was kept going for two and one-half hours, at which time a dull red heat was secured. This condition was maintained for six hours longer during the welding operation. It is often possible to use an ordinary blacksmith's forge for the pre-heating, and if a great many similar parts are to be handled, a special forge and bellows may be found of advantage. In addition to the use of charcoal, torches using illuminating, producer, or natural gas, oil, or gasoline, may be employed; in fact, any method for obtaining a large amount of heat, but not necessarily a high temperature, can be employed. In one case, in welding a break in a locomotive engine frame, a gasoline torch was employed for the pre-heating, the torch being applied throughout the welding operation. In cases of repetition work, special arrangements of pipes and burners may be advisable.

Various Methods of Pre-heating

In one plant in Europe, where tubing is manufactured with the aid of power-driven gas-welding machines, provision is made for the rolled but unwelded tube to pass through a muffle just before reaching the torch, so that the tube is bright red when passing under the torch. Sometimes the outer flame of the torch itself may be used for pre-

Fig. 1. The Broken Cylinder

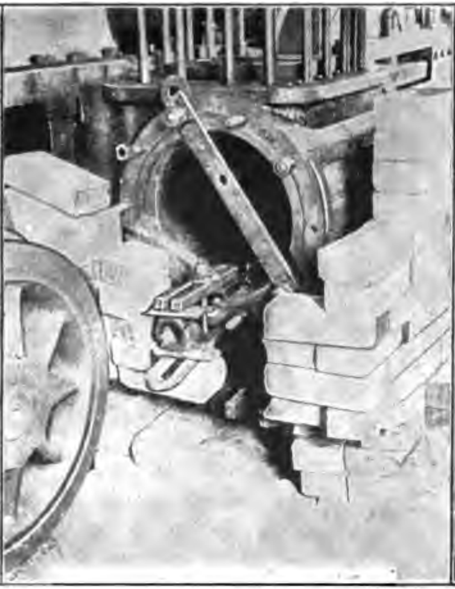


Fig. 2. Arrangement for Pre-heating

Fig. 3. After Welding, before Cleaning Weld

heating. Thus the Edison Storage Battery Co. employs a machine in welding a straight seam on the containing cans of their batteries. The torch, the work, and the clamping devices are so arranged that the outer flame of the oxy-acetylene jet is divided into two long streamers. One of these impinges upon the seam several inches ahead of the place where it is reached by the working flame. It is possible that this arrangement was not provided with a view to pre-heating, but that is the effect, and a consequent economy in gas consumption is the result.

The use of the outer flame for pre-heating may come to be an important factor. A large quantity of heat is generated by this flame. In the machine referred to, the clamps arranged along the sides of the seam are beveled to afford access to the torch, the bevels being quite steep—about 60 degrees. The writer would suggest that similar clamping bars be formed in connection with regular hand-welding work, so as to provide a canyon-like working groove. In hand-welding larger sizes of tubing, it would also be practicable to provide a series of gas jets on a single supply pipe beneath the joint. In this way the edges could be pre-heated with cheap gas.

Pre-heating to Prevent Unequal Expansion or Contraction

Pre-heating is often resorted to for reasons other than those of economy of gas consumption. It is used where the effects of expansion and contraction are objectionable. The rise of 2000 degrees in the temperature of a metallic body occasions considerable expansion in every direction. For example, a 12-inch steel bar will lengthen about 5/32 inch. It is easily seen that the sudden swelling and resultant shrinking of only a small part of the work may, at times, have disastrous results. Take as an example the spoke of a fly-wheel with a piece broken out. This piece just fits into its place. If we repair this by making the required grooves and then filling them with new metal, thus producing an apparently good weld, we will find that, upon cooling, a break will frequently occur in the weld or at some other point, due to the contraction. A similar case is met with in a crack in a casting. It is chipped out in order to obtain beveled edges for the flame, the faces are heated, and new molten material filled in. When the weld cools off, however, the new material is likely to shrink away from the walls of the crack.

Now what can be done to meet this condition? If we could uniformly heat the whole piece inside and outside, we should probably have an ideal solution, but one of the great objects in oxy-acetylene welding is to localize the heating. We can, however, pre-heat a larger portion of the whole body than is required for the welding alone, and in this way distribute the stresses. In the case of the flywheel, the broken spoke, the adjacent spokes, and the intervening rim may be heated to a red heat, gradually diminishing toward the other parts of the wheel, so that the pre-heating itself does not introduce new stresses. When the new material for making the joints is filled in, the spoke is naturally longer than it will be at ordinary temperatures, and while there is a local contraction of the weld, there is also a general contraction of the whole spoke and those adjacent, which diminishes the effect. In the case of a cracked cylinder casting, the pre-heating of the metal beyond each end of the crack, if properly done, will ordinarily open up the crack so that when it is filled with new metal, the amount which is used will be sufficient, when the cylinder cools off, to fill the original space. Ordinarily, the walls of the crack should be held apart until the weld is completed, so that the width of the crack and the new metal will contract together. If the crack runs from a point within the periphery all the way to the edge it may be opened up by heating at a point a little further in than the beginning of the crack. The welding is begun at the inner end of the crack, working toward the edge.

The pre-heating should ordinarily be done rather slowly so as not to introduce sudden temperature changes and stresses. Slow heating is especially to be advised when there is a combination of thin and heavy parts. Similar remarks apply to the cooling, which should be slow to be safe; the cooling may be retarded by the use of asbestos sheeting or by packing the object in heated ashes or heated slaked lime.

Temporary Furnace for Pre-heating

When it is possible to pre-heat the entire casting, this seems to be the best way of taking care of expansions and contractions. Castings the size of which makes necessary special arrangements may be placed on a bed of fire-brick arranged with spaces between them. A temporary wall or furnace is then built around the whole, fire-brick being used for this also. These are arranged, of course, without the use of mortar, with very narrow openings between them, one method of constructing such a wall being shown in Fig. 4.

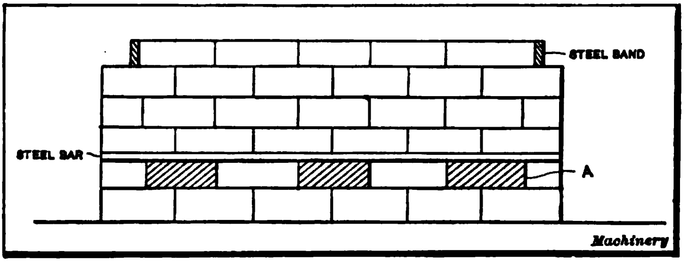


Fig. 4. Arrangement of Temporary Brick Furnace

Flat steel bars may be employed just above the separated course of bricks *A*. The top course may be held in place by a steel band. The object of the open spaces is to provide a draft. Charcoal is now filled in between the casting and the wall and the fire started. A sheet of asbestos is used as a cover. This cover should contain a number of holes so as to provide an exit for the gases.

Hood used for Pre-heating Operations

Another method is to make a hood of a material that is a poor conductor of heat. Such a hood is shown in vertical section in Fig. 5. The walls consist of two sheets of wire netting with an intervening space filled with asbestos. A hole, the wall of which is made of sheet iron, is provided at the top. Another aperture also lined with sheet iron is provided on one side of the vertical cylindrical wall. The bottom of the hood is furnished with an annular base ring of sheet iron, the netting and sheet iron being joined by welding. Provision should be made for lifting and lowering the hood, so that it can be let down over the casting which is to be pre-heated. To make a tight joint with the floor, some loose asbestos may be used as a foundation for the hood. A kerosene or other torch may now be inserted through the aperture in the side. Some kind of shield may be used just inside of the side opening to divide the flame, so that, as far as possible, the casting will be encircled by it. Sometimes it is advisable to use auxiliary fires on shelves above the main fire at the bottom. This is especially to be recommended for tall castings, so that there will be no severe concentration of heat at one point. As already mentioned, the heating should be done slowly, the fires being started in a moderate way and gradually increasing in intensity. During the welding the hood must, of course, be raised, and when the welding is completed the hood may again be lowered into position in order to retard the cooling. The oil torch should be brought into service again for a short period. It may then be shut off and the openings of the hood covered. In this way, slow and even cooling is assured.

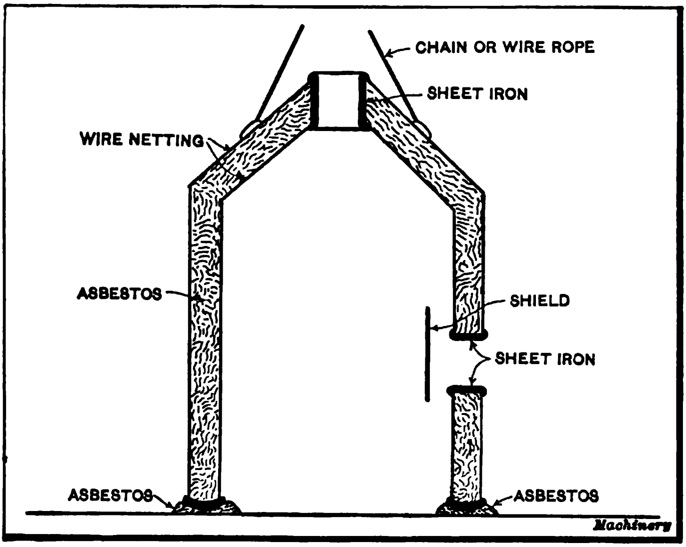


Fig. 5. Hood used for the Pre-heating Operation

In general, after a welding operation, the casting should be reheated as soon as the welding is completed, and then covered with asbestos wool or scrap asbestos. The casting may also be buried in any of the materials ordinarily used for retarding the cooling of steel which is to be annealed. If the casting is of such a shape that it is not likely to crack, it may be cooled in the bed of charcoal in which it has been heated.

Pre-heating Temperatures

Cast iron may be pre-heated to about 700 to 1000 degrees F. Generally speaking, the higher the temperature of pre-heating, the less the danger of cracking when cooling. Aluminum castings should be preheated to about 600 or 700 degrees F., the heat if possible being maintained during the entire time of welding. To accomplish this, it is often advisable to cover the casting with asbestos and to leave only the working area exposed. Asbestos sheeting will be found satisfactory for keeping any class of work hot during the welding.

Example of Repair Work by Oxy-acetylene Welding

It may be of interest to refer to a specific case of welding performed by the Pullman Co. of Chicago. The bed of a hydraulic press was cracked; the casting weighed about 10 tons, and the crack was about 10 inches long and 26 inches deep. The material of the bed was cast steel. The casting was placed on supports of brick about 14 inches high and a fire of wood and charcoal was maintained during the night, with the result that when the welding was begun the metal was at a red heat. A No. 10 Davis-Bournonville tip was used with a soft steel welding rod, two workmen carrying out the work. The time consumed for the welding operation was about five hours. The necessary enlargement of the crack was made by the oxy-acetylene flame. The expense was estimated at $19.16, and the result of the welding was very satisfactory. As the gas cost of the Pullman Co. is extraordinarily low, for ordinary conditions the expense would, perhaps, be as follows:

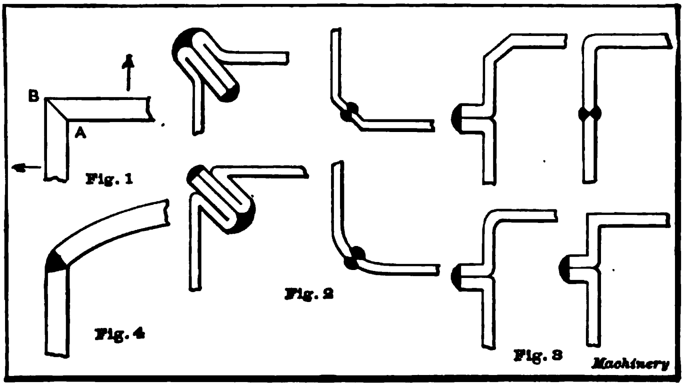
357 cubic feet of oxygen at 3 cents per cubic foot......	$10.71
143 cubic feet of acetylene at 1 cent per cubic foot......	1.43
Labor	7.40
Fuel for pre-heating and annealing....................	4.00
	$23.54

The expense of replacing the casting by a new one would have been about $600.

CHAPTER III

OXY-ACETYLENE WELDING OF TANKS AND RETORTS

One of the most important applications of the oxy-acetylene welding process is in connection with the manufacture of tanks and cylinders from sheet metal. In this field the new process promises to supersede soldering and riveting to a very large extent. The advantage over soldering consists principally in the increased strength of the joint and the equality of the expansion and contraction of the metal in the seam and in the work. There is also much less likelihood of the occurrence of poisonous corrosions.

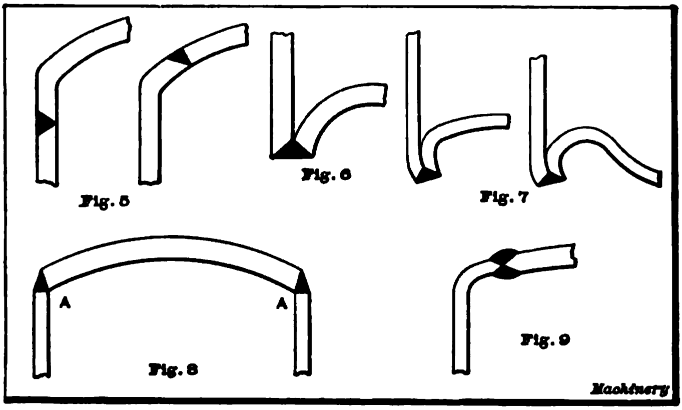


Figs. 1 to 4. Illustrations showing Various Methods of Making Welded Joints

In constructing vessels of sheet metal which are subjected to alternations of high and low internal pressures, it is generally advisable to use special forms of joints at the corners or to avoid corner joints entirely. The stresses on the corner joints become very severe if the corners are of right-angled shape. If the corner is rounded, the effect of the internal pressure at the joint is reduced. In Fig. 1, for example, if the welded joint is made at the square corner *AB*, it will be located at the point where the stresses on it, acting as indicated by the arrows, will be most severe. By forming the joint in the various ways shown in Fig. 2, the weld will be considerably strengthened as compared with a weld that merely joins the two sides at the corner *AB* in Fig. 1. It is still better, however, to remove the joint from the corner altogether. In Fig. 3 are shown the methods used for doing this. The best method of all to relieve the welds of the excessive corner stresses is, of course, to change the horizontal section to that of a circle.

Tops and Bottoms of Sheet-metal Vessels

One of the most difficult operations in the welding of tanks and retorts is the attaching of the tops and bottoms to cylindrical vessels. One of the first methods employed was that of making a joint as shown in Fig. 4. The welding was done from the outside and could be well finished. However, when the vessel was subjected to pressures from within, a combination of compressive and tensional stresses was produced at the weld, thus causing cracks. To overcome this difficulty, joints as indicated in Fig. 5 were made. Where the metal is quite thin, sufficient contact of the surface can be secured by bending the metal outward to form a kind of a flange. By using more welding material than necessary to produce a joint flush with the adjoining surfaces, a stronger weld can also be made.



Figs. 5 to 9. Methods of Welding Tops and Bottoms to Cylindrical Shells

In all these cases, the top or bottom is assumed to be convex on the exterior. Another method, shown in Fig. 6, is to make it concave on the outside. Such forms are especially suitable for bottoms. In Fig. 6 the rim of the bottom is bent and the edges of the bottom and of the cylinder are both beveled to provide a welding groove. Another method which does not necessarily include concaving is to bend up the rim of the bottom for a short distance, the dimensions of the piece being such that this rim snugly envelops the cylinder; the two may then be welded together.

The use of flat tops and bottoms should, of course, be avoided. The expansion and contraction of these during welding are different from those of the cylinder. The flat piece does not yield to the cylinder, and, hence, the work is likely to be distorted. The convexing and concaving of the tops and bottoms provides a suitable margin for yield. Two forms of bottoms are shown in Fig. 7, in both of which elasticity in the diameter is provided for. The bending in of the edges enables the cylinder wall to support the bottom when the latter is under pressure from within. In some cases it may be necessary to prevent diametral expansion of the cylinder when welding. A heavy removable band of metal in the form of a hoop may be used for this purpose. It is placed close up to the location of the seam. Most of the heat from the cylinder will then be absorbed and dissipated by this hoop.

An interesting example of the application of the foregoing principles is afforded by a large containing vessel constructed by Munk & Schmitz, Cologne-Bayenthal, Germany. This vessel is a cylindrical shell, closed at top and bottom, and is formed of sheets 0.40 inch thick in the cylindrical portion and 0.83 inch thick in the end portions. The vessel is 15 feet high and over 9 feet in diameter. All joints were made by the oxy-acetylene torch and the vessel successfully withstood, when tested, a pressure of 90 pounds per square inch.

General Considerations in Welding Tops and Bottoms to Cylindrical Vessels

If the joining of the top to the cylindrical shell were made at the precise point where geometrically the side of the wall joins the top, as shown in Fig. 8, an outward pressure exerted from within and tending to produce a spherical shaped bottom would tend to make the angles at *A* more obtuse and would thus produce a tensional stress on the inner portion and a compressive stress on the outer portion of the weld. Hence, it should be carefully noted that this method of joining ends to cylindrical shells is objectionable, and that the methods shown in Fig. 5 should, in general, be adopted.

It is also very important in forming welds of the type described not to forget the effects of expansion and contraction. It is recommended that the weld be hammered during the cooling-off process. The hammering should be discontinued while the metal is still quite hot, and should not be continued below the point where a horse-shoe magnet attracts the iron; in fact, at this point, one has perhaps gone a little too far. Subsequent to the cooling, the region that has been exposed to the high temperature should also be well annealed. This may be done by using two oil torches for gradual re-heating, one from the inside and one from the outside. Incidentally it might be mentioned that in performing the welding operation it is also often advisable to use two welding torches, in which case a weld of the double-V character, as shown in Fig. 9, will be produced. The bottom of such a vessel should be so arranged that the weld is not located where the weight of the vessel itself comes upon it.

As an interesting practical example, the illustrations Figs. 11, 12 and 13 are shown, indicating the progressive steps in welding a cylindrical shell, as well as the welding of a top and bottom to it. A diagrammatical view of a section of the welded container is shown in Fig. 10, the work being done by the Vilter Mfg. Co., Milwaukee, Wis. It will be seen that the top is convex and the bottom concave, as viewed from the outside. The shell is of ⅜-inch boiler iron; the metal in the heads is ½ inch thick. The tank is 20 inches in diameter and 24 inches long. Both heads fit the inside of the shell as indicated.

After welding, this tank was tested at a pressure of 1200 pounds per square inch. For carrying out the test, a hole was drilled on one side of the shell and a nipple inserted after tapping. The tank was then connected with a hydraulic press pump. At 1100 pounds pressure the nipple started to leak, but there was no leak at the welded joints. A No. 7 Davis-Bournonville tip was employed in making the straight weld in the shell, and a No. 8 tip was used for the ends. The straight weld was made in 45 minutes at a cost of $1.62 (exclusive of labor, but including depreciation); the circular weld at the convex end required 2.67 hours and cost $6.99; the circular weld at the concave end required two hours and cost $5.24. At thirty cents per hour, the labor cost would be about $1.63, making a total cost of $15.48. These tanks are used at a maximum working pressure of three hundred pounds per square inch. A water cooled torch was employed in part of this work.

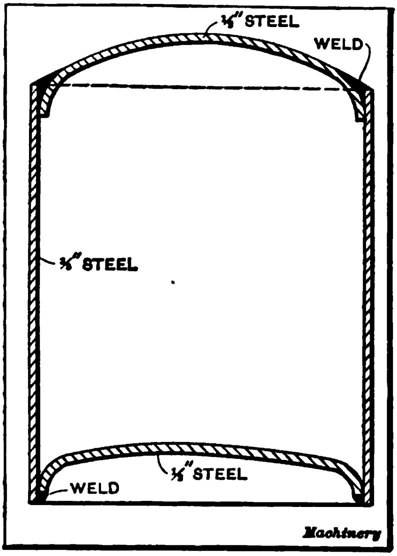


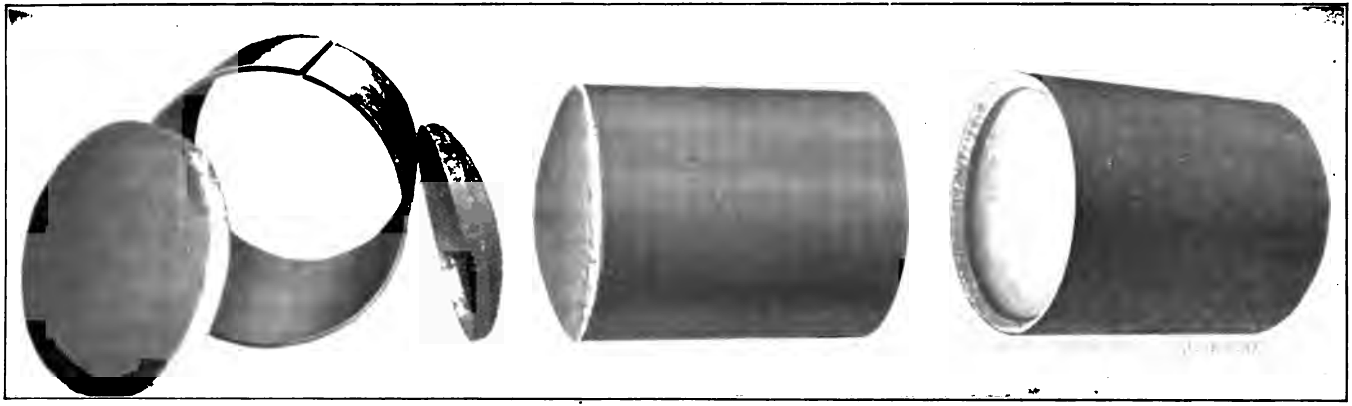
Fig. 10. Example of Tank welded by the Oxy-acetylene Process

Autogenous Welding of Copper

While copper is normally tough and ductile, it enters a brittle stage when heated to about 1650 degrees F. This brittleness continues up to the melting point (at about 1930 degrees F.) In order to weld copper it must be heated to this critical stage. At these high temperatures copper possesses a remarkable capacity for absorbing certain gases. If exposed to the atmosphere while at a white heat it absorbs oxygen.

Another quality of copper is that when heated to a high temperature, quenching in water has a softening or annealing effect. Copper that has been highly heated and oxidized will, however, begin to fracture when one commences to hammer it, even if it has been annealed; hence, it is very important to prevent oxidation when welding, and by proper management of the outer flame of the oxy-acetylene torch the operator may succeed in preserving the new copper in the weld from oxidation. To make perfect work, however, it is necessary also to preserve the old copper, and here is where difficulties are met with. On account of the great heat conductivity of copper, a high temperature will be found for some distance on either side of the joint to be welded. Unless the operator can protect this outlying region, the results will not be satisfactory.

It is well known that phosphorus has a great avidity for oxygen. If, then, instead of a very pure copper we use a phosphor-copper alloy



Figs. 11, 12 and 13. Progressive Steps in Making the Tank shown in Fig. 10

when welding, good results may be expected. A welding powder containing a percentage of phosphorus may also be used to secure a deoxidation. Investigations along these lines have been carried on in Germany; it can be stated, in a general way, that good welding powders for copper can be made of such mixtures as borax, phosphor-natrium and prussiate of potash. The borax is not commercial borax, but that which has been subjected to a high temperature in a crucible and has then been pulverized.

Boracic acid may be used instead of borax. The powder is prepared by mixing the boracic acid and the phosphor-natrium. Welding powders of this description form a film over the work and thus exclude the atmosphere. It is recommended when welding copper sheeting to spread the powder containing phosphorus for about 1½ inch on either side of the joint. This powder is then melted before the welding operation proper is begun. As there is some possibility of blowing away some of the powder when used in this way, it would seem desirable to apply it in the form of a paste.

See also the section "Welding Brass and Copper" in Chapter I, where some additional information on this subject is given. It is also well to consult the catalogues of firms making autogenous welding outfits.

The Welding of Aluminum

The coefficient of expansion of aluminum is equal to twice that of steel and its melting point compared with that of copper and steel is rather low, being about 1215 degrees F. It is also comparatively weak in tension. Cast aluminum resists a tensional stress of about 10,000 pounds per square inch. Because of this weakness, and on account of its high rate of expansion and contraction, it is a difficult material to weld. As its heat conductivity is high, it is also difficult to localize the region of the high temperature. Oxidation of aluminum, however, can be avoided by the use of a proper flux.

While the total expansion and contraction from 100 degrees F. to the fusion point or welding temperature is about the same for cast iron and aluminum, because of the fact that the fusion point of cast iron is at a temperature about twice that of the fusion point of aluminum, the expansion and contraction, due to temperature changes, take place much more rapidly with aluminum, and the operator must use special care on this account. The low temperatures dealt with when welding aluminum make the pre-heating easier, but the operator must guard against not exceeding the fusion temperature. It is sometimes possible to make slight saw cuts here and there, and thus assist in making the effects of expansion and contraction harmless. These cuts, of course, must be repaired when the main operation is completed. Aluminum should never be welded without a flux. If welding is attempted without a flux, little globules consisting of aluminum within and a coating of alumina (oxide of aluminum) will appear. In order to eliminate these by heat, it would be necessary to raise the temperature to the melting point of the oxide of aluminum, which is about 5400 degrees F. A flux consisting of the following ingredients has been recommended: chloride of sodium, 30 parts; chloride of potassium, 45 parts; chloride of lithium, 15 parts; fluoride of potassium, 7 parts; and bisulphate of sodium, 3 parts.

When melting new metal from a rod, it is good practice to keep the rod constantly submerged in the molten bath of the metal in the welding groove, which for aluminum should be much larger than usual. If no powder is used, the oxidation is then confined to the upper surface. The main point to remember when welding aluminum is that the fusion point of this metal is very low; hence, the working flame should be kept further away from the metal than is usually the case when welding cast iron and steel. The torch should be so adjusted as to furnish an excess of acetylene. There need be but little fear of carbonizing the metal, for the reason that the temperature of the work is comparatively low.

The Welding of Household Utensils

Some forms of household utensils, such as, for example, coffee and tea pots, cause considerable difficulties in their manufacture, particularly in connection with the attachment of the spout. Soldering has been used to a great extent in making these joints. However, the basic material of the solder is altogether different from the material united. The uses to which the vessels are put expose the joints to the action of acids, and galvanic currents are set up which injure the joint. Aluminum vessels are especially exposed to the action of these currents, because this metal is electro-positive to nearly all of the common metals. One means to obviate the difficulty is to bend the metal of the main vessel or body inwards at the hole for the spout. The material of both body and spout is then bent into a fold on the interior, no soldering material being used. The presence of this fold on the inside, however, is very objectionable. Even though it is closed when the vessel is new, the effect of repeated heatings is liable to open it, and the crevice becomes a trap for various small particles, which prevents effective cleaning. The oxy-acetylene welding presents the best solution of the foregoing difficulties.

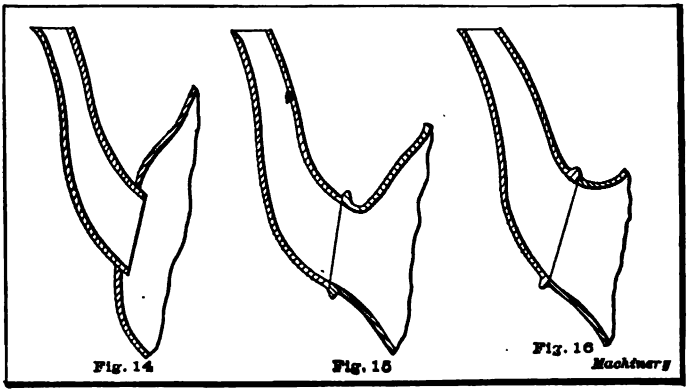


Fig. 14 Fig. 15 Fig. 16
Machinery

Figs. 14, 15 and 16. Methods of Welding Spouts to Household Utensils

When seeking to unite the spout and body by the oxy-acetylene torch, the worker is, however, confronted with several difficulties, especially if the sheet metal be aluminum. The expansion and contraction of aluminum, due to temperature changes, as already mentioned, is very rapid, so that the operator must guard against distortions of the work. The melting point of the metal is low, so that holes are apt to be made in thin metal. Heated aluminum is very readily oxidized with the result that a proper intermingling of the material is difficult. In view of these facts, it is recommended that the joint be placed away from the main body, that welding wire be dispensed with, and that a suitable flux be employed. In Fig. 14 is shown a joint which eliminates the necessity for the welding wire; the spout fits closely into the hole and is introduced far enough to protrude about 1/8 inch into the interior, the projection thus furnishing the welding material. There is considerable advantage, of course, in thus eliminating the handling of the wire as far as the worker is concerned, and another advantage is that the welding material is precisely the same as the material of the work. It is difficult, however, to operate on the interior, but this difficulty may be reduced by using a tip of special form. The appearance of the exterior, however, is good.

Another form of joint is shown in Fig. 15. Here the diameter of the hole is first made smaller than the interior diameter of the lower end of the spout. The material is then bent outwards to form a ridge of the same diameter as that of the spout end. The body and spout can then be butt-welded by using welding wire. It is preferable, however, to bend the edge of the projection from the vessel outward, thus supplying the needed welding metal, or the auxiliary metal may be provided by bending the edge of the spout outwards, a joint of this kind being shown in Fig. 16. In either case, the ring of metal protruding at the joint will not be thicker than 1/8 inch in a radial direction. In both cases, the interior is smooth.

Fig. 17. Example of Welding Copper. Kettle is 5 feet 6 inches in Diameter, 31 inches deep and used under Pressure. All seams are welded on Both Sides

CHAPTER IV

AUTOGENOUS WELDING AS A MEANS OF REPAIRING CYLINDERS

Breakages in automobile cylinders can be divided into three main classes which cover at least ninety per cent of the cases. The majority of these breakages can be satisfactorily repaired by means of the oxy-acetylene flame, the cylinder being as good as new. Additional metal is added where necessary from a rod of the same material, and the process consists in practically recasting the part locally.

Autogenous welding is proving a great boon to those who are unfortunate enough to have their automobile cylinders broken, as they can be satisfactorily welded and in the majority of cases, with a little trimming off, the repairs will not show. Cylinders with cracks are sometimes brazed, but owing to the necessity of heating the whole cylinder to a good red heat to even up the contraction strains, so as not to crack when cooling, the bore of the cylinder is generally warped, and the job requires a lot of finishing as the spelter and flux spread considerably and are difficult to remove. Also, owing to the dirt and rust in the crack it is difficult to get the brazing below the surface; the high temperature necessary will sometimes crack the cylinder elsewhere.

Water Jackets Broken by Freezing

The largest class of cylinder breakages—mainly due to carelessness or misfortune, probably in most cases the former—is caused by allowing the water jacket to freeze, resulting in the breaking of the water jacket wall. Also, it has frequently happened that when shipping a car by rail in winter the drain cocks were opened, but due to some pocket in the water system (in some cases very small ones) which did not drain, the cylinders have become fit subjects for the autogenous welder.

Curiously enough the majority of cylinders cast from the same patterns will break in just the same place when frozen. In a number of cases the break causes a piece of the wall of the water jacket to be entirely detached, and the breaks occur so nearly alike, in similar cylinders, that it would be possible to take the detached piece from one and weld it into another, even the smaller irregularities coinciding.

When a break of this nature is autogenously welded, by means of the oxy-acetylene flame, the crack or edge of the broken part is prepared so as to leave a groove nearly through the metal. The whole part is then uniformly heated to about five hundred degrees F. This temperature is not high enough to warp the bore, as has been repeatedly proved by careful measurements before and after treatment. The sides of the groove are fused together and filled from a rod of cast iron. The resulting weld is very neat in appearance; it generally requires no finishing and is as strong as the original wall. As a very small number of heat units are absorbed by the part, owing to the intense heat of the flame fusing the metal before the heat has time to spread, there is seldom any trouble with cracks when the metal contracts in cooling. The cylinders *A* and *B*, Fig. 1, show common types of breakages which are being satisfactorily welded every day. The crack in *A* is seventeen inches in length. Both cylinders are grooved out ready for welding.

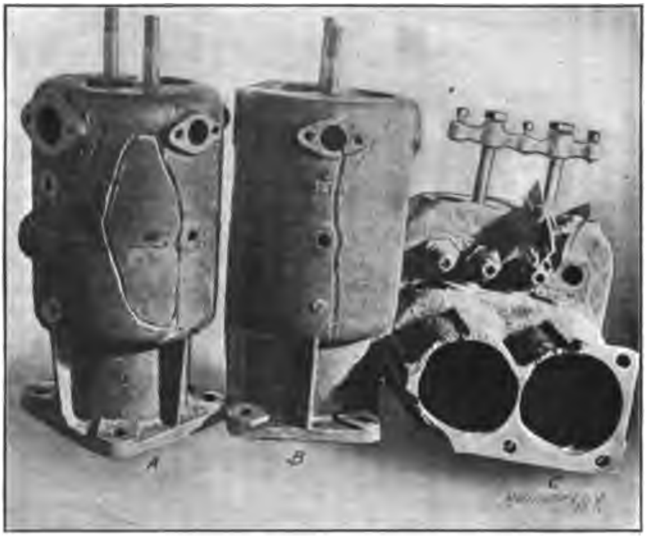


Fig. 1. Two Cylinders with Cracked Water Jackets prepared for Welding. Twin Cylinders with Broken Flanges to be Welded

Cylinder Wall Broken

The next class of breakages, in order of frequency of occurrence, is that in which the wall of the cylinder, combustion or valve chamber, is broken or cracked. These breaks are, in most cases, due to freezing, but a certain number of them are due to the designer making a large flat surface without adequate ribbing to support the pressure of the explosion.

Another cause is the breakage of the connecting-rod, allowing the piston to strike the top of the cylinder. Serious damage from this cause occurs most frequently in two-cycle engines as the deflector on the piston readily punches a hole in the combustion chamber wall.

This class of breakages is the most difficult to repair, as it is necessary in most cases to cut out a section of the water jacket to be able to work on the inner wall, the only exception occurring when the break happens to be opposite a large hand hole. This operation has a singular resemblance to the well-known trepanning operation performed upon the human skull.

It can be readily seen that it is practically impossible to make a repair when the break occurs between two cylinders or behind the valve chamber, as these parts cannot be reached with the small flame. If the crack occurs in the bore, it is necessary to carefully weld to within a sixteenth inch of the bore, or the finished surface will be spoiled; the crack left in this way is of small importance, as sufficient metal can be built on the outside so that there is no doubt about the strength. After welding the break, the section of the water jacket which was removed is welded back in place.

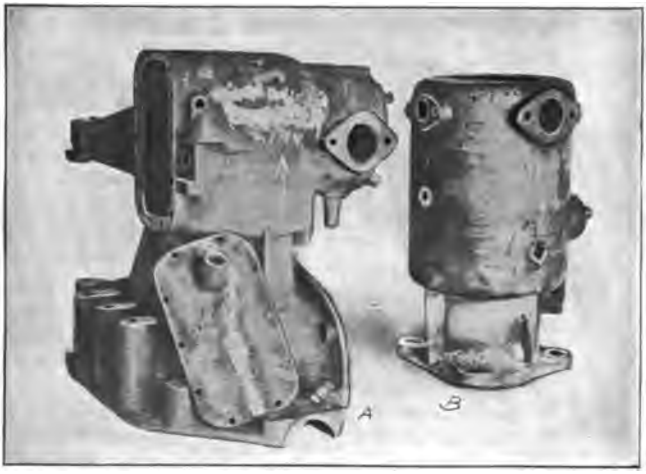


Fig. 2. Cylinder A repaired by inserting a Steel Piece, bent to Shape, and autogenously welded in Place. Cylinder B has had Flange repaired

As it often is impossible to determine the length or exact locality of the cracks before cutting away the jacket and as it is desirable to remove as small a section as possible, it often is found necessary to cut additional pieces out, thus necessitating welding a number of small pieces back in place when finishing the job. To restore these pieces sometimes is impracticable, and a sheet steel substitute must be hammered out and welded in place. With care this piece can be shaped so as to coincide with the piece removed, and cannot be detected when welded in place. The part cut away was thus neatly replaced by sheet steel, as shown at *A*, Fig. 2.

The water in freezing will often crack both the water jacket and cylinder wall. The former being readily seen is generally thought to be the full extent of the damage, particularly as it is practically impossible to make a test until the crack is repaired. The work may then have to be cut out to find further defects.

The cover plate on the cylinder shown in Fig. 2 was also broken in freezing, at the same time as the cylinder wall was broken, and is shown welded.

Fig. 3 shows a cylinder having a crack eight inches long, located at the corner of the combustion head, that was welded. The part cut out of the water jacket is also shown. It will be noticed that this operation required cutting through a supporting lug.

Broken Flanges

The next order of breakages in point of number are those in which all, or a portion of the flange, which holds the cylinder to the crank case is broken away, due either to insufficient metal to withstand the strain or to carelessness in assembling.

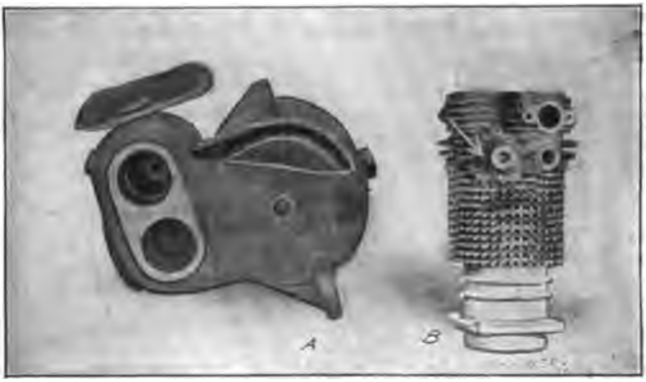


Fig. 3. Cylinder Cracked in Inner Wall, showing Large Section of Outer Wall removed to weld the Crack

Fig. 4. Air-cooled Cylinder on which Boss for Ignition Plug was autogenously welded

These breakages occur in two ways; the wall of the cylinder may be broken away or part of the flange may be cracked off. In the latter case it is an easy matter to make the repair, but when the break runs through into the bore of the cylinder considerable care is required. First it is necessary to consider whether it is desirable to weld in the bore which would then require machining or at any rate filing out, or only groove and weld from the outside to within a sixteenth inch of the bore, sufficient metal being added to the outside to insure strength. The latter method, of course, leaves the crack on the inside, which can, however, be smoothed down and is not objectionable for a repair job, as it does not interfere with the satisfactory operation of the motor in any way.

In addition to these three classes, there is a large variety of other breakages, no two of which are alike, that can be repaired successfully by the oxy-acetylene torch. Considerable welding can also be carried out by the manufacturer, such as the welding on of additional bosses for dual ignition systems, as shown in Fig. 4, building up bosses that did not "fill" in castings, etc.

CHAPTER V

MANUFACTURE OF TUBING BY AUTOGENOUS WELDING

The trend of industrial processes, today, is in the direction of continuity. If a process can be made continuous, a great advantage is gained, other things being equal. It is no wonder, then, that in consequence of the enormous demand for water, gas and steam piping, very determined efforts have been made to produce tubing by the process of rolling. The efforts have been successful, and steel tubing is now made in large quantities by this method. Strips of flat steel are rolled longitudinally between successive pairs of rolls until the edges meet or overlap. They are then butt- or lap-welded.

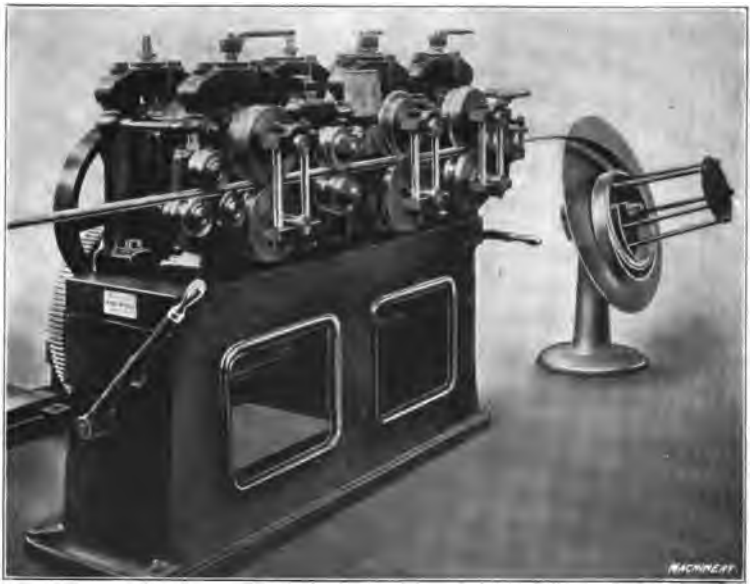


Fig. 1. Tube Rolling Machine built by August Schmitz, Dusseldorf, Germany

In Germany, tubing is being made by the rolling of sheet metal and the subsequent welding with oxygen and acetylene, the process being continuous, and a special welding machine being used. The rolling machine is of the type shown in Fig. 1. This machine receives the metal in long flat strips, which have either been specially rolled or cut to the required width. The first operation is accomplished by a pair of rolls which bend the longitudinal edges upward. These bent-up edges will ultimately form the "roof" of the tube. It is important that the degree of curvature of the bends shall be precisely that of the finished tube. Another pair of rolls just ahead receives the strip and bends it into a U-shaped form; the upper ends of the U-curve, however, are bent toward each other because of the side bends formed by the previous pair of rolls. Another pair of rolls is now employed to receive the U-shaped strip and cause it to approximate still more closely the tube-shape. Finally, another pair of rolls complete the bending to shape; a mandrel is employed with this pair. In case very elastic material is employed, it is advisable in the first pass to bend the axial portion so that when the tube is shaped it will point in toward the inside of the tube. In the last operation, this bend will be eliminated by the mandrel. The object is to obtain a joint with no tendency to open.

When a strip which has been cut from a sheet in the ordinary way is thus bent together, there will be a V-shaped groove along the joint.

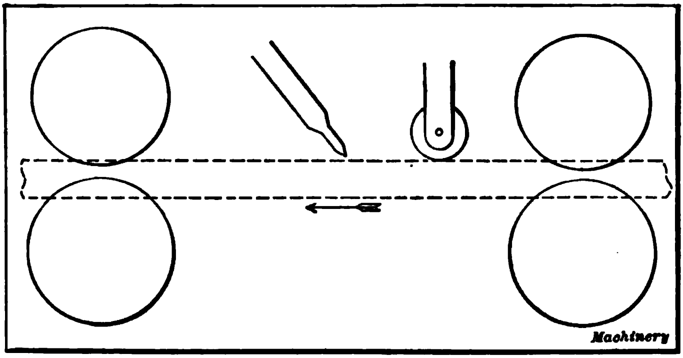


Fig. 2. Principle of Autogenous Tube-welding Machine

The reason for this is that the external circumference of an annular ring is longer than the internal one. The strip is of the same width on both sides, so that when one side is bent to form a complete inner circle there is not enough material for the outer circle. The weld can still be made, but as machine welds use no additional metal, the section at the weld will be thinner than it ought to be. If the tubing is made of quite thin metal, no especial difficulty will arise from the formation of a groove; but when the wall is rather thick, strips which have been especially rolled to provide a greater width on one side than on the other should be used. When such a strip is bent to the final shape, we have a narrow V-shaped groove with ridges on each side. A narrow groove is advisable, because it admits the flame to the entire depth of the joint.

The welding machine is rather simple. Two pairs of compression rolls are placed a short distance apart, as indicated in the diagrammatical view, Fig. 2. These rolls carry the tube along, the one pair receiving it from the tube rolling mill. Between the two pairs of rolls a standard is placed to which is secured the device which holds the torch. This latter has its tip directed downward and toward the unwelded joint. The angle of inclination is about 45 degrees. The tubing, as it is fed along by the first pair of rolls, can scarcely be depended upon to keep its unwelded joint in a constantly uniform position. It is, however, necessary that the working flame of the torch and this joint shall be in an exact relation to each other. Therefore, a holder is provided which carries a roll or wheel having a thin edge or projection on its periphery. This edge enters into the groove at the joint and controls its position just before it reaches the torch. This machine is made of the duplex type, so that two welding operations may be handled at the same time; a torch and the necessary rolls are arranged on each side of the bed. Comparatively thin tubing, say 0.04 inch in thickness, can be welded at the rate of about 8 inches per second, or about 40 feet per minute.

It is frequently the custom in the bicycle industry to draw tubing to an oval or elliptical section. The most severe stresses to which such elliptical tubing is subjected would tend to injure the weld if the latter should be located at the end of either axis of the ellipse. It has been found advisable, therefore, to locate the seam to one side of the "sharp" end of the ellipse. A Swedish charcoal iron, containing very little carbon, is said to be most suitable for this class of work.

In the rolling of tubes of small diameter, it is permissible to roll in a longitudinal direction, but when we come to greater diameters, it becomes necessary, or at least advisable, to discard the continuous method and use rolls or other devices whose axes are parallel with that of the tube. Machines specially built for this service bend the sheets quickly to the required cylindrical form. Diameters of 3 to 10 inches are readily handled, the material having a thickness up to ¼ inch. The forming process requires from 7 to 12 minutes for each section of tubing, according to the length. Large tubes are usually welded autogenously by hand.

That large pipe made by the oxy-acetylene process is reliable is indicated by the following test: Two sections of such pipe, each about 39 feet long and 35 inches inside diameter had their flanges bolted together to form a single length of nearly 80 feet. The supports were placed at the ends so that the full length between them was unsupported. Then the double length of tubing was loaded with about thirty men, or, in other words, a load of more than two tons was supported. Of course this test does not take into account the question of the "water-tightness" of the weld. However, a test was carried out upon another piece of welded tubing—this time a bend—of about 2 feet inside diameter. The tube did not leak under a pressure of about 365 pounds per square inch. Another piece of tubing about 31 or 32 inches in diameter has been made by the welding process from material which was about 0.4 inch thick. A drainage system for a lock of the Kaiser-Wilhelm canal contains about 2000 feet of pipe welded by the autogenous process. One German firm is manufacturing hot water heaters by the same process.

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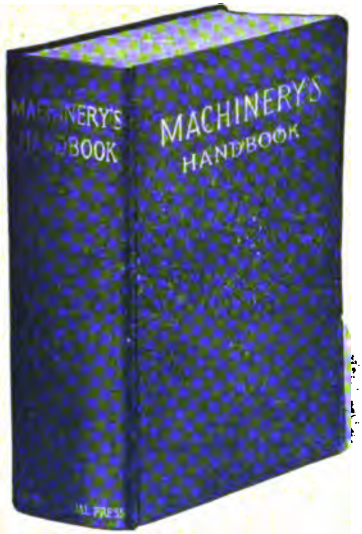
No. 19. Belt, Rope and Chain Drives.
No. 20. Wiring Diagrams, Heating and Ventilation and Miscellaneous Tables.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