Electric Welding*

The Various Methods in Use and Latest Improvements

By J. H. Bryan

THE art of welding, which may be broadly defined as the joining together of metals into intimate and permanent union, dates back to the early days of history. Until within the last half century, the only practicable method of making a weld was by a process with which we are all familiar, namely, that of heating the pieces to be joined at the point where the union was to be made, then, when they were almost at fusing point, placing them in their proper relation and completing the weld by hammering. The introduction of the electric arc welding process and the kindred ones of incandescent electric welding, and also of the gas welding processes, have, however, very greatly increased the field of possibilities, and we are now able to produce results which it was theretofore impossible to obtain.

Before going further, it might be well to outline some broad definitions of the different processes of welding. These may be first divided into two, the first known as Autogenous welding and the second welding by pressure or hammering. The first of these terms, Autogenous welding, may be defined as the fusing together of two metals without pressure by causing them to melt, then unite as they cool. Welding by the use of the electric arc or by the various processes employing gases, such as the oxy-acetylene or oxy-hydrogen method, come under the heading of Autogenous welding.

The blacksmith's weld is one form in which hammering is used to obtain a union of the pieces to be joined. Incandescent welding is another application of the same principle. In this method, as it is most commonly used, the two parts to be joined are placed in contact with each other and by means of suitable equipment a heavy current is caused to pass from one piece to the other. The value of this current is such that it heats the metals to the fusing point, when the two parts are pressed together and the weld thus completed.

A recent modification of incandescent welding is that known as electro percussive welding. It differs from the better known processes in that it is practically instantaneous, this property enabling us to weld metals having widely differing melting points or metals which are not commonly susceptible of being welded. Although this process is of a very recent origin, it has proved very valuable.

ELECTRIC ARC WELDING.

Referring again to electric arc welding as a commercial process, this may in turn be divided into two general classes:

First, Benardos or carbon electrode process in which the arc is drawn between the metal to be welded and a metal electrode.

Second, Slavianoff or metal electrode process in which the arc is drawn between the metal to be welded and a metal electrode.

These two processes are generally referred to as carbon or graphite electrode and metal electrode welding, respectively.

In addition to these there is the Zerener process, in which the arc is drawn between two carbon electrodes, as in an arc lamp, and the metal to be welded is placed in contact with the arc. This is, however, not considered as a commercial proposition, in this country at least, as its field of application is limited, and the apparatus itself is unwieldy.

CARBON ELECTRODE PROCESS.

In carbon electrode welding, the metal to be welded is made one terminal of a direct current circuit, the other terminal being a carbon electrode. Upon closing the circuit by bringing the carbon electrode into contact with the metal and then withdrawing it to a distance, an arc is drawn between the two terminals. Through the medium of the arc, which is the hottest flame known (having a temperature between 3500 degrees and 4000 degrees Centigrade—6300 degrees to 7200 degrees Fahrenheit) the metal may be either entirely melted away, molded into a different shape or fused to another piece of metal as desired.

In the first attempts to weld by this process the carbon electrode was made the positive side of the circuit and the metal to be welded the negative. Practice, however, shows that it is better to reverse these conditions, for if not, since the flow of current is from positive to negative, particles of carbon will find their way into the welds, thus tending to make them exceedingly hard and consequently difficult to machine. A further very important advantage is gained by making the metal to be welded the positive terminal. It is a well known fact that in a direct current arc the highest energy consumption—about 75

per cent of the total—and therefore the highest temperature, occurs at the positive terminal, and, while no very extended data are available regarding the behavior of arcs having either or both electrodes of metal, there is considerable information regarding carbon arcs and it is fair to assume that, with reference to this particular point, there is not a wide difference between them.

METAL ELECTRODE PROCESS.

The metal electrode process of welding is a somewhat later development and it differs in that a metallic electrode is substituted for the carbon.

The essential requirements for arc welding are:

1st. A suitable source of direct current supply. 2nd. A steadying resistance to be placed in series with the arc, together with means for adjusting same, i. e., suitable control equipment. 3rd. A means of holding the electrode so that it may be properly manipulated by the operator. 4th. Protective covering for the operator. 5th. Suitable filling material. 6th. Miscellaneous material such as flux, fire-clay or carbon blocks for making molds, etc.

Taking up this equipment in order, the direct current supply can be obtained in any one of several different ways. If direct current is available from a shop or commercial circuit, welding can be done directly from this source of supply, but this method has been found to be very wasteful of power and should not be resorted to except where welding is to be done only at very infrequent intervals. An additional disadvantage of the use of the shop circuit as a source lies in the fact that, unless arrangements are made for insulating the work from ground, the shop circuit is grounded, with attendant danger to other employees in the shop, as well as to the welding operators. A much more economical method is that of using a motor generator set, the motor being constructed with characteristics suitable for operation from the shop or other circuit, and used to drive a low voltage generator.

As different welds require different strengths of current, it is at once evident that there must be some means of regulating the current supply. This is usually effected by inserting resistance in the welding circuit connecting it in series with the arc. Without this resistance, a condition of practical short circuit would occur at the moment the electrode was touched to the work when striking the arc, and, even after the arc is drawn and normal operation begun, the series resistance is necessary for the purpose of steadying the arc, much as is the case in the ordinary arc lamp.

Suitable electrode holders must be provided both for carbon electrode and for metal electrode welding, the construction of the holder being such that the electrode may be renewed in a minimum of time.

Protective equipment is necessary for the operator on account of the fact that exposure to the rays of the arc causes an irritation and subsequent peeling of the skin if the exposure has been sufficiently long, say, several minutes. The irritation is very similar to sunburn and is uncomfortable, but no serious consequences ensue and at the end of a few days all traces of the burn disappear. The clothing has been found to be ample for the protection of the body. For the eyes and face of the operator a hood or shield is provided, both of these being arranged with windows of thick colored glass, through which the welding is observed. The hands and wrists of the operator should be shielded by gauntleted gloves, which are preferably of leather, although canvas gloves have been found satisfactory. The window of the hood or shield should be provided with several pieces of glass in layers, one or more of ruby glass, and one or more of blue or green, the combination of these colors being much more satisfactory than any one of them used alone. There are a number of special welding glasses on the market at the present time, most of which will prove satisfactory.

FILLING MATERIAL.

When the carbon electrode is used, the filling material is usually of the same metal as that being worked upon and may be used in any convenient form. For instance, when welding steel and iron, filling material may be in the form of rods, clippings from boiler plate, steel clippings, etc. For cast and malleable iron, soft iron rods, punched iron scrap or special cast iron filler may be used.

These filling materials are fed into the welds and fused into place much as solder is applied with a blow-torch.

When metal electrodes are used for welding iron and steel they should be of the best quality of soft iron or steel wire and may range in diameter from $\frac{1}{8}$ inch or less up to $\frac{1}{4}$ inch. The length most generally used is about

12 inches. Copper, bronzes and brasses with a low percentage of zinc may also be welded by this process, in which case the electrodes should be of the same material as that being welded. Where the zinc content of brasses is high, it volatilizes to such an extent as to make the work porous and brittle.

PROCEDURE.

In making a weld by the carbon electrode process, the work is connected to one terminal of the machine, usually the positive, the electrode holder being connected to the opposite terminal. The resistance of the circuit having been adjusted to what is considered the proper value for the work in hand and the circuit breaker and main switch being closed, the operator assumes his position in front of the piece to be welded, taking the electrode holder in one hand and having flux (if same is used) and filling material within easy reach. He finally closes the window of the hood, touches the carbon electrode to the metal to be welded and instantly withdraws it to a distance of 2 inches or more, thus striking the arc. Experience has indicated that with a long arc there is less opportunity for carbon particles to enter the metal and in this way produce a hard weld; the heating effect is also more regular and more evenly distributed. For these reasons the arc should be as long as possible, about 3 inches to 4 inches being the usual length.

After the arc is drawn it is allowed to play upon the work, being given a rotary motion by the hand to heat a comparatively large area of the surface about the weld so that the consequent cooling will take place more slowly and there will be less danger of cracking the work or of making a hard weld. When the metal flows, the flux (if used) and the filling material should be added a little at a time, the arc, of course, being continued until the metal is thoroughly melted and the weld made. As soon as the metal commences to cool it should be hammered thoroughly in order to prevent sponginess and to give the metal a finer grain. All oxide and other impurities must be kept out of the weld. It is advisable, therefore, to make, if possible, one continuous application of the arc. When, however, more than a single application is necessary, care should be taken to remove all the scale. This may readily be done in most cases by means of a stiff wire brush. Similarly the metal should be cleaned before commencing the weld. To accomplish this, chipping may be resorted to or the piece may be tilted, the arc applied and the impurities allowed to run off by gravity as fast as melted.

The current required for carbon electrode welding varies from a minimum of about 200 amperes to a maximum of around 700 amperes, or even more in very heavy work. In general, however, 300 to 400 amperes has been found to be sufficient for ordinary carbon electrode work.

As is indicated in the foregoing, carbon electrode welding is more or less of a puddling process. A considerable amount of heat is generated and this is, in many cases, objectionable on account of the expansion of the work, in which strains may be set up on subsequent cooling and shrinking. In work where trouble of this nature is liable to be experienced, pre-heating may often be used to advantage. On small work this may be done by the use of the carbon electrode. The arc is drawn just as in welding, but it is moved about over the piece without being held in any one place long enough to cause fusion. With larger pieces, a temporary furnace may be made by laying fire brick together loosely to form an inclosure around the work and over it. Heating may be done in any convenient manner either by the use of oil, gas or coal. When the work has reached a red heat, the cover is removed and the welding done without taking the piece from the furnace. After the welding has been completed, the cover is replaced and the work allowed to cool slowly, either with or without a second application of heat.

METAL ELECTRODE PROCESS.

The metal electrode process, though a considerably later development than the carbon electrode method, has a field of application very distinct in many cases from the other process.

A principal advantage of its use is in work where it is desirable to localize the heat to the greatest extent possible, thus minimizing strains due to expansion and subsequent contraction. An example of this is in the welding of sheet metal or of a broken bridge in the flue sheet of a boiler. Another advantage of this process is that it enables welding to be done in a vertical plane or even from the underside of the piece to be repaired. This class of work is done daily in railroad shops in

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repairs to the side sheets and crown sheets of locomotive fire-boxes.

The method of using the metal electrode differs from that with the carbon electrode in the fact that a much shorter arc, generally $\frac{1}{8}$ inch to $\frac{1}{4}$ inch in length, is used and also in that the electrode forms the filling material as it melts and flows into the fused portion of the work.

With the metal electrode much lower currents are used than in the carbon electrode process. The maximum value hardly ever exceeds 150 to 175 amperes. For a greater portion of the work a current of about 90 to 130 amperes is found satisfactory, although the amount of current required will vary with the size of the electrode and the class of work being done.

CUTTING BY USE OF CARBON ELECTRODES.

The carbon electrode process is also well adapted for cutting of metals. In cutting the arc is drawn just as in welding and is played along the line to be cut, provision being made for the melted metal to run off. Very rapid work of this sort can be done, especially if heavy currents are used.

This process of cutting is used to advantage in work such as cutting off risers and sink heads from castings in a steel foundry, cutting up scrap, and the like, where rapidity and cheapness are of more importance than absolutely smooth finish and accurate work.

APPLICATIONS.

In spite of the fact that arc welding as a commercial process is of comparatively recent origin, it has been found to have a considerable and ever widening field of applicability. It has shown itself to have a distinct range of usefulness, in which it is unsurpassed either by blacksmith welding or by any of the systems of gas welding.

In the repair work of steam railroad shops arc welding equipment has shown itself to be an exceedingly valuable adjunct.

The following figures, taken from records of actual repairs made in a large railroad shop in the Middle West, give a comparison between the actual cost of welding and that of putting the apparatus back into service by methods previously used, either by replacement or by repair of the old parts. The arc welding costs were based on a power cost of 51 cents per hour for the carbon electrode and 17 cents per hour for the metal electrode, together with cost of labor and overhead charge of 40 per cent.

	Cost of Welding.	Cost by other Methods.
Plugging 51 holes in expansion plate holes 1 inch dia. by $\frac{1}{2}$ inch deep...	\$2.75	\$10.15
Repairing mud ring.....	6.50	34.57
Cutting four 6 inch holes in tender deck sheet $\frac{1}{2}$ inch thick.....	1.08	8.35
Welding eccentric strap, broken through neck.....	1.08	41.28
Welding two spokes in driving wheel center.....	7.98	99.98
Welding cracks in side sheets.....	26.15	31.79
Repairing fire-box.....	134.89	869.58
Building up flat spots on locomotive driver.....	.40	225.00

Numerous other figures could be presented showing similar savings.

With reference to the last item given above, namely, that of building up flat spots on locomotive drivers, the repair in this case is effected by welding at the roundhouse without withdrawing the locomotive from service. The tire is simply built up at the flat spot and filed to shape, using a template. Against this the cost of repair by other methods would include the sending of the locomotive to the shop and having the entire set of drivers turned down, which usually means putting the locomotive out of service for at least a week or ten days, as well as the loss of at least one year's wear on the tires. Taking into consideration the loss of revenue from the idle engine, the cost of the older method might easily be \$500 or more.

ELECTRIC RAILWAYS.

Electric railways have found an instrument of great value in electric arc welding. In addition to the use of this process in their shops for repairs to their rolling equipment, they are using arc welding for a wide variety of track work, such as rail bonding, frog and switch repairs, low joints, etc.

A large number of electric railways are at the present time doing welding from the trolley circuit, using resistance in series with the arc to hold the current at the required value. Satisfactory work can be done by this method, but it has two very important disadvantages; one of these being it is extremely wasteful of power, and the other, that the danger to the welding operator is very considerable, on account of the fact that one side of the welding circuit is grounded and the operator is in constant danger of serious or fatal injury from shock.

MARINE REPAIR WORK.

An industry of comparatively recent origin is that of the repair of marine boilers. Practically every large harbor now contains one or more repair barges, which are

equipped with an arc welding equipment and a compressor for furnishing air for sand blast and pneumatic tools; and are employed in the repair of the boiler equipment of vessels that may arrive in the harbor in need of such repairs. The barge is brought alongside the vessel while the latter lies at the dock, thus enabling the necessary work to be accomplished without loss of time on the part of the steamer.

GENERAL REPAIR WORK.

There are a number of minor applications of arc welding equipment, among which may be classed general repair work in large shops, work in steel plants, cutting up scrap, etc.

Repairs to be taken care of in these shops consist of broken shafts, worn journals and keyways, broken gear-teeth, worn rolls, etc. The welding equipment may be installed permanently and wiring carried to different sections of the shop where welding is likely to be required, or may be made portable and suitable connections for the motor end of the equipment arranged for, as may be required. Still another method is that of installing the motor generator and wiring permanently, and using a portable welding control panel which is connected to the circuit by plugging in at the point where work is to be done.

In steel mills it occasionally occurs that the tap holes or tuyeres of blast furnaces will become plugged with cinder or cold metal. Without the use of the electric arc this would necessitate, in many cases, the loss of the heat and the closing down of the furnace to allow the chipping out of the slag or metal by hand, which is a very slow and tedious process. By the use of the carbon electrode the obstruction may be cut away so rapidly that in most cases operation of the furnace need not be suspended. Where the obstruction consists mainly of metal, it is only necessary that one terminal be connected to the furnace so that a path of reasonably low conductivity to the obstruction is secured. Where, however, cinder is present in such quantities as to make the obstruction of high resistance, it may be necessary to drive an iron bar through the cinder in order to obtain satisfactory results, the bar being melted away and with it the cinder.

The arc welding process has been found to be very well adapted to certain classes of commercial manufacturing operations, replacing smith welding and showing very great savings.

But it is not to be inferred that arc welding is a manufacturing operation primarily, as such is not the case. Its greatest field of usefulness lies in repair work, as distinguished from incandescent welding, which is not at all suited to anything except repetition work, as in manufacturing quantities of duplicate pieces.

No hard and fast rules can be laid down in regard to equipments, as no two installations will be alike in their requirements, and the matter of selection of apparatus of proper capacity is largely one of judgment and experience. It may be said, however, that in general for miscellaneous repair work around large industrial plants a 300-ampere equipment, which is of sufficient capacity to take care of two operators on metal electrode work, or to do, where necessary, light carbon electrode work, is usually satisfactory. For electric railways for track work, a 200 or 300 ampere outfit will be found to be about the proper size.

INCANDESCENT ELECTRIC WELDING.

We come now to a consideration of the other main branch of electric welding, namely, incandescent welding.

Incandescent or resistance welding, as it is sometimes called, is based upon the well known fact that in an electric circuit the introduction of resistance such as is made by a poor contact or conductor, tends to produce heating. There are two distinct processes of this kind, namely, the Thomson and the LaGrange-Hoho, of which the former is almost exclusively used.

The Thomson process is due to Prof. Elihu Thomson and, as stated in his original application which was granted in 1886, "the invention consists in a novel art or process of and apparatus for forming joints between metal wires, bars and the like by the agency of an electric current."

Present commercial processes of incandescent welding, usually spoken of as spot or butt welding, are based on the original Thomson patent. This method will be referred to again in more detail.

The LaGrange-Hoho process, sometimes spoken of as the "water-pail forge," is not, so far as it is possible to ascertain, in use in this country to-day. "In this process an electrolytic bath is employed made from a solution of carbonate of potash and borax in water. . . . The metals to be welded are fastened to the negative terminals of a direct current circuit of 125 to 150 volts, while to the positive terminal is fixed a comparatively large plate of lead, carbon or other suitable conductor. Upon passing current through the circuit the electrolyte commences to decompose, depositing apparently hydrogen on the metal pieces and so developing a gaseous resistance at the points of contact with the liquid. This resistance causes the metal to heat and finally to become incandescent.

"The disadvantages of this process when compared with the Thomson process are apparent, as in the latter the same work is accomplished in substantially like manner without the use of the bath, which item is at all times a nuisance." (Mr. C. B. Auel, *American Machinist*, 1914.)

Referring again to the Thomson process, the apparatus required consists of a source of alternating current, a transformer arranged with a primary coil of suitable characteristics for connection to the A. C. source, and a secondary coil arranged to give exceedingly large currents at potentials varying from one half to 7 volts. The secondary winding of the transformer, since it must handle very heavy currents, is made massive and usually of only a very few turns. Connections are brought out from the secondary circuit to heavy clamps or jaws, water-cooled in the larger sizes, into which the metals to be welded are inserted and gripped. The adjacent ends of the metals which are to be welded are carefully filed and butted together. "Upon closing the primary circuit, current flows through the metals, heating them rapidly at their point of contact to the fusing temperature. While in this softened condition they are forced together either automatically or by hand, thereby uniting perfectly. The shoulder which accompanies each weld is readily removed by a hand file, although on certain classes of work an automatic hammer and anvil are employed for the purpose."

This process has been steadily developed since its inception in 1886 until it is now utilized in an infinite number of ways including the joining of wires or rods of the same or even of dissimilar metals, the making of chains, tires and cylinders, the bonding and welding of rails, the uniting of pipe, the annealing of armor plate, the welding of high speed steel to machine steel, the manufacture of boilers, car wheels and the like.

The amount of current used for any given weld is regulated either by a rheostat or choke coil under the control of the operator, so that heating may be accomplished slowly or quickly as desired.

The heating commences at the center and progresses outwardly; there is no wasted energy. Further, as no foreign substances are used to produce the heat of fusion, such as coal, coke or gas, as in other processes of welding and as no flux is employed, there is no deleterious action upon the metals from these sources. Moreover, there is no change in the electrical conductivity. Tests as to the tensile strength of the welded material indicate that there is a weakening of the metal either directly at the weld, or more usually at a short distance to one side of it, the reduction being given by various investigators as 20 to 30 per cent.

The two classes of work taken care of by the Thomson process are known usually as "butt" and "spot" welding. "Butt" welding is used for welding wires, rods and bars end to end. This is as distinguished from spot welding where the two metals are joined only in spots thus securing the two pieces, much as is the case with rivets. Spot welding is coming into very extensive use at the present time, taking the place of rivets on thin work.

"An interesting application of the incandescent welding process is that of welding street car rails. For welding rails, about 30,000 amperes at 5 to 7 volts are required for two or three minutes, with a pressure of approximately 4000 pounds per square inch, the greatest pressure being exerted when the fusing temperature is reached. Three welds are made at each joint in a total of fifteen minutes, the area of each being about $3\frac{1}{2}$ square inches."

ELECTRO PERCUSSIVE WELDING.

Probably the most recent commercial development in the field of electric welding is that of electro percussive welding, a modification of spot welding. Although this process is related to that of incandescent welding, it is distinctly different in a number of features. In the first place a source of direct current power is required, while in the Thomson process alternating current is used. Also the weld is practically instantaneous by the electro percussive method, while a distinct interval of time is required to allow the metal to heat where the Thomson process is used. Again, by the electro percussive process dissimilar metals, including those which are not ordinarily susceptible of being welded, can be successfully joined. An example of this is in the welding of aluminium wires or of copper to aluminium, copper to platinum, etc.

The electro percussive process as at present developed is designed to take care of comparatively small sections only, but the application to larger sizes is only a question of the design of suitable apparatus.

Briefly, the electro percussive process of welding depends upon the discharge of a high capacity condenser through the points to be welded, together with a forging effect which is practically simultaneous. The apparatus required consists of a direct current generator, a condenser, usually of the electrolytic type, suitable resistors and inductors, together with a forging machine or welding tool.

The process of welding is as follows. The wires are secured in the wire grips and the ends cut off as short as

possible with a suitable pair of cutters. A switch short-circuiting the condenser is then opened, which charges the condenser to the proper voltage. A catch is then released, which lets the sliding member of the welding tool fall and brings the ends of the two wires into percussive engagement. At the instant of contact the short circuited current of the condenser goes up to such a value that the ends of the wire are melted by the explosive discharge and instantly forged together by the blow of the falling mass. The weld is then complete, and after being removed from the machine will be found to have the strength of the original wire.

The generation of the heat is so localized, so sudden and so intense that there is no time for unequal heat conduction through the shanks of the wire and the ends will be melted and even vaporized whether the melting point is high or low. For this reason metals of different kinds can be welded together independently of their electrical resistance, melting point or heat conductance. Any combination of metals which has ever been tried will weld together, but the joints will not be permanent with such combinations as aluminium and tin or lead and iron.

The generation of heat at point of contact depends upon having an appreciable resistance offered to the current at the wire ends and it is therefore necessary to cut the ends of the wire in such a way that they will make a point contact, preferably at the center, so that the energy of the condenser will vaporize a small section of metal and melt the rapidly approaching surfaces with the intense heat of the arc. To do this the wires are cut with ordinary pliers, which give a chisel edge. The two wires are cut off in such a way that the two chisel edges are at right angles and the point of first contact will be at their intersection at the center.

Electrically the weld is complete in 0.0012 second and although 23 kilowatts are being dissipated between the ends of the wire at a certain instant, the total energy use at the weld is only 0.0000123 KWH. or enough to light an ordinary 50-watt, 16 candle-power lamp for 0.90 second. The cost of this amount of energy at ten cents per kilowatt hour would be twelve millionths of a cent.

The inclusion of an inductance in series with the condenser and the electrodes may at first sight seem peculiar. Its purpose, however, is to prolong the current until the final contact of the metals and prevent the explosive snap due to a condenser discharge with small inductance in circuit. Without this inductance, it has been found that a very high frequency oscillation is obtained, causing an explosive discharge, and due to the nature of the electrolytic condenser, the current is suddenly damped, and as the arc goes out before final contact, the wires will not be hot enough to form a good weld. The inductance, therefore, serves the purpose of lowering the frequency of the discharge and prevents the rise of current at the first instant of contact being so sudden as it would be without this inductance.

When the adjustments of inductance and resistance are properly made, the condenser discharge at the moment of contact sounds like a splash or thud instead of a sharp crack. With a certain amount of experience the operator can guess at the settings and it will not be necessary to make any trials. As to the mass and drop of the falling chuck, it must be sufficient to slightly forge the wire. After the setting is once made for any given work, the machine will make a perfect weld every time and the speed of turning out work will only be limited by the handling of the product.

One of the chief advantages of electro percussive welds lies in the fact that they can be made without any apparent change in the properties of the two metals being welded.

Tempered spring steel welded, reduced to uniform diameter, and tested has shown equal or greater strength at and near the weld without any noticeable change in temper. Metals such as hard drawn copper, silver, aluminium, etc., which soften with heat, can be welded together without causing any local annealing, and these metals and steel when soft can be welded together without detrimental local hardening.

Several possible explanations of the constancy of the mechanical properties before and after welding can be given. First, such sudden heating and cooling may not allow change in molecular structure. Second, with hard steel, the heated metal at the weld is so suddenly cooled by conduction of heat into the two shanks of metal that it is again hardened. Third, with hard copper, silver, aluminium, etc., the heating and sudden cooling would ordinarily soften the metal, but the cold forge of the blow in welding possibly hardens it again. Fourth, the metal subjected to the sudden heat cycle may be hardened or annealed (depending upon the characteristics of the material welded), but the amount of material affected may be too small to be detected. As an example, assume a No. 18 hard drawn aluminium wire to be welded together, 0.00123 watt hour or 1.06 small calories are dissipated at the welds. Assume none of the energy lost in noise, radiant heat or metallic vapor, and one half of the total propagated in a heat wave in each direction

along the wire. It can be shown mathematically that an annealing temperature will not be reached more than 0.05 millimeter from the weld. The total amount of metal softened would then be a cylinder or disc 0.1 millimeter long and 1.02 millimeters in diameter. A soft insertion of such proportions could hardly be detected. Actual micrographs show that in a case exactly similar to that under consideration the disc of charged metal is only about 0.01 millimeter instead of 0.1 millimeter thick and physical tests fail to show any weakness or softness at the weld after being reduced to uniform diameter by removing the surplus metal of the burr.

Many of the alloys of most metals are very hard and brittle. As an example, there are alloys near both ends of the copper-aluminium series which are unworkable, and yet electro percussive welds between these two metals are so ductile that they may be worked in a die, forged, or rolled into thin foil. Any alloy formed at the weld must range from 100 per cent copper on one side to 100 per cent aluminium on the other; but possibly the brittle combinations are so thin that the joint as a whole is flexible and ductile. This joint between aluminium and copper is of great importance, as copper lead wires, which solder and connect easily, can be readily attached to aluminium coils. At first it was feared that a diffusion of the two metals in service would finally result in a brittle joint, but tests show that after four years the joints are practically as strong and ductile as when first made.

Another feature of particular interest in this process lies in the fact that the electrical resistance of two wires welded together by this process is not appreciably increased. A test made on a wire composed of 85 alternate pieces of aluminium and copper joined with 84 welds in a total length of 23.5 centimeters showed an increase of 0.56 per cent in resistance in three years. This increase is small and it may have been due to a change in the joints or possibly to an error of observation or to oxidation of the wire. The sample in question was rolled and its malleability indicated no appreciable change.

The electro percussive method of welding has opened up a wide field of application hitherto impossible.

In conclusion, it might be said that this method, although it overlaps some of the older processes of welding, meets entirely different requirements and that it will probably never replace these older methods for heavy sections.

Electric Conductors

ELECTRIC cables are used for a great many purposes, such as the transmission of electric power, the conduction of telephonic and telegraphic currents, etc. In some cases a cable carries a great many separate currents, and in some cases only a single current. The use of a cable in the transmission of a single current is in general restricted to the cases where the current is large. This requires a large conductor, which for practical reasons is stranded. It may be either a single group of solid wires, or it may have a more complex structure. A seven-strand cable may be a single conductor made up of seven solid wires, or a single conductor made up of seven groups of wires, or a combination of seven conductors insulated from one another. In the latter case, each of the seven strands may be either solid or itself stranded. When one of the strands of a conductor is composed of more than one wire, each element of the strand is also called a strand. Stranded conductors are very commonly formed of concentric strands, which consist of a central core surrounded by one or more layers of helically laid wires. If used as a completed cable, such a conductor is called a concentric-lay cable. Such a group may be combined with others in the same way in which the wires are combined in the group, thus forming a concentric strand composed of elements each of which is a concentric strand. If a concentric strand so formed is used as a completed cable, it is known as a rope-lay cable.

In the long-distance transmission of power, overhead bare cables of copper or aluminium are extensively used. For underground conduit transmission, cables are heavily insulated and protected by a covering of lead. The insulation may be rubber, varnished cambric, paper, or special compounds. Single-conductor cables of this kind are frequently used for direct current mains. For single-phase alternating service duplex cables are in considerable use. Flat twin cables are most convenient and cheapest where the cable is not unusually large. For alternating currents, two-conductor and three-conductor concentric cables are in great favor. Cables that are to be buried in the earth or used under water have a jute and asphalt covering over the lead, and over that an armor of steel wires or band steel.

Telephone and telegraph cables consist of many wires, each separately insulated with paper, fiber, or rubber, the whole having a light insulating wrapping and a lead sheath. The size of the wires used is more or less standardized, so the size of the cable is roughly indicated when the number of wires is stated, as, e. g., when one speaks of a 200-conductor cable. In a telephone cable the wires are twisted together in pairs.

There are, of course, many special kinds of electric cables, for which trade names have been adopted according to their construction or uses. This holds true also of smaller electric conductors, to which the term "cable" does not apply. The smaller conductors are usually either single wires, stranded wires, or cords. There is a great range of flexibility and of kind of insulation in the various divisions, such as magnet wire, heater cord, lamp cord, etc. The twisted pair is used with many portable electric devices.—Circular 37, U. S. Bureau of Standards.

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