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WELDING PRACTICE.

A concise definition of the word 'welding' to cover the present usage of the term cannot be given. The recent advances and developments made in the art have so widened the scope and number of the processes to which this name is applied that this is impossible. The original use of the term 'welding' is given by the following definition from the Encyclopedia Britannica, 11th edition:- "the process of uniting metallic surfaces by pressure exercised when they are in a semi fused condition". The advances made in the art are concerned not only with the method of applying the necessary pressure formerly done by hammering exclusively, of generating the heat required, but also in modifying the process by the introduction of fused metal for producing the 'weld' or 'bond'. This modification is closely akin to the well known processed of brazing and soldering, but differs in that the 'bonding' metal added is more nearly of the same composition as the material to be welded than is the case in these other processes.

Characteristics of the Types of Welding.

1. Forge or smith welding. This method of welding has been practiced from time immemorial and is familiar to all. It is limited almost entirely to wrought iron and to steels, particularly those of low carbon content. No further reference to it here is necessary. It complies fully with the definition given above.

2. Electric welding. Advantage is taken of the heating effect of electric currents in this type of welding. The heat may be used not merely for softening the metal before pressure is applied but also to fuse metal which is to be added to form the 'bond' of the weld.

a. Resistance welding, Thompson Process. The pieces to be welded are held together by heavy adjustable copper clamps and form part of an electrical circuit. A heavy current is sent through the circuit. The "contact resistance" at the junction of the two pieces to be welded causes the heating of the circuit at that point. When the metals have been softened to the desired degree, the pressure is applied and union of the two is thus effected.

b. Arc welding. The heat of the electric arc is utilized in this method of welding to heat the materials which are to be joined together and also to fuse metal which will be added to

form the bond of union. There are two main distinct types of arc welding, the carbon-arc or Bernardos, and the metal-arc or Slavianoff. In addition there are several other minor modifications.

(1) Carbon-arc or Bernardos Process. In this type the welding heat is supplied by an arc between a carbon electrode (negative) and the material to be welded. Fused metal is obtained from an auxiliary metal rod which is melted as needed by the heat of the arc.

(2) Metal arc or Slavianoff Process. This method differs from the preceding one in the substitution of the metal rod, which is to be fused and form the weld, for the carbon electrode. In the Kjill-berg and quasi-arc processes, metallic electrodes covered with a layer of refractory material are used. The Seimund-Wenzel process is another modification in which a magnetic field around the metallic electrode for directing the molten metal is used.

c. Electro-percussion. The method depends upon sending a heavy current through the points of contact of the metals to be welded at the instant they touch as they are brought together with more or less impact. The intense heat is developed so quickly that it is confined to the surfaces as they fuse together.

3. Hot-Flame or Blow Pipe Welding. This method is similar to arc welding in that it is a fusion process; a very hot and well directed and controlled flame being used to heat the surface to be joined and to fuse the metal which is to form the 'bond'. This method is usually referred to as 'autogenous', that is 'self producing', in that no pressure is required. This term can justly be applied to arc welding also. The term is a misnomer, and its use should not be encouraged. The oxy-acetylene flame is widely used in this type of welding, although, as is quite evident, the flame of any combustible gas may be so regulated in shape and intensity as to produce the local heating necessary for welding. The oxy-hydrogen flame is used to a considerable extent.

4. Thermite Welding. The process depends upon the chemical reaction which occurs in the oxidation of aluminum. Metallic aluminum will reduce most of the metallic oxides to the form of the corresponding metal, the reaction in the case of iron being expressed by the equation:-

$$Fe_2O_3 + 2\ Al = Al_2O_3 + 2\ Fe$$

In welding by this means a mold must be built around the parts to be joined and iron (or soft steel) produced by the "thermite-reaction" i.e. the reaction which occurs upon ignition of an intimate mixture of powdered aluminum and iron oxide, is allowed to flow around and between the surfaces to be joined thus effecting a bond upon solidification.

Electric Welding.

1. Resistance Welding. This process of welding more closely resembles the familiar forge or smith welding than does any of the other new processes. Machines for this process of welding consist principally of (1) a transformer for obtaining high amperage and correspondingly low voltage, (2) clamping electrodes for holding the work and transmitting the current through it, (3) a mechanism for forcing the electrodes together and (4) a means for controlling the current and adjusting it according to the cross-sectional area of the parts to be welded. A single phase alternating current is used as both sides of the work are heated more uniformly by this means than with direct current.

The process is used for butt-welding, T and angle welding, lap and spot welding and similar cases. It may also be used for upsetting, riveting, heating blanks for forging, bending, and hardening and annealing. The process is particularly suited to duplicate of 'repeat'work rather than for miscellaneous repairs. Spot welding by this process is used extensively to replace rivets, lap welding is accomplished by passing the work through rolls which constitute the two electrodes in this particular case. It is used very extensively in manufacturing processes, the following examples may be mentioned: forming chain links, wire fence, and tires; fastening the stems to valve heads, handles to kitchen utensils and the like; making metal window frames, printers chases, and in fact metal frames of all kinds.

Practically all metals and a great many alloys can be welded by this process, as well as combinations such as brass to copper, silver, or gold, mild steel to tool steel, steel to platinum. It is not suited for cast iron. Metals of relatively low melting point, zinc, lead, tin and aluminum may be welded by taking the proper precautions, even magnesium has been welded.

Heavy currents at low voltage are required, approximately 2000 to 5000 amperes, at 1 to 7 volts being used in butt welding $\frac{1}{4}$ inch to 3 inch rounds. The current depends of course upon the cross section. The nature of the load on the generator is different from that of almost any other current consumer on account of the fact that when the circuit is closed the full amount of power required is thrown suddenly on the generator

instead of building up to a maximum. This necessarily creates some disturbance on the line. It is usually best, therefore, to install a separate transformer to supply the welding machine only.

2. <u>Arc Welding</u>. The simplest possible outfit for arc-welding consists of a current source (D. C. generally being used though A. C. may be also employed for the purpose), an adjustable resistance for regulating the current and an electrode holder. For large jobs (repair of castings, etc.) the material to be repaired forms one electrode (positive), the negative one being the one held in the hand. For smaller scale work a permanent metal table (steel or cast iron) on which the article to be repaired is placed forms the positive electrode. Many different types of apparatus for arc welding are now on the market. These are mainly for the purpose of furnishing and regulating the current although welding machines have also been developed and may be purchased in the market. They are essentially devices for maintaining constantly a desired arc-length and rate of feed and are very useful in the hands of a trained operator. The arc process is used particularly for iron and steel. The metal-arc system in which an electrode of "carbonless" iron or mild steel is employed, is used very much more than the carbon-arc. The latter has the advantage of being used for cutting metal, though it is not nearly so efficient nor convenient as the oxy-acetylene torch. The carbon-arc is also the method used in the repairing of castings and cast-iron parts.

The metal-arc is used extensively in all classes of repair and reclamation work for iron and steel such as filling cracks and other defects in castings, building up worn parts of rolls, shafts, etc., welding flues and boiler tubes and hosts of minor uses. It is also used in manufacturing such as welding heads to tanks, joining seams of tanks and boilers, welding fire boxes, boiler tubes, etc. It has also been used for replacing riveting, etc. for example, in ship building and even in the construction of the steel frame-work for building purposes.

The work is raised to a state of incandescence at the point of welding fused metal from the electrode carried over in the form of tiny globules is deposited and fused with it. Since all welding, except possibly the resistance method, is an art the training and skill of the operator is a factor of great importance determining the character of the work. The advantages of electrodes covered with a refractory coating have been widely advertised by the manufacturers. This type of electrode is necessary for 'over head' work. Although the process is used generally for low and medium carbon steels, it may also by proper precautions and by choice of suitable electrode material be used for other types of steel. It is even used for alloy steels, but in view of the fact that the superior properties

of alloy steels depends upon their heat treatment, the saving made by welding this class of material may be questioned.

On account of the nature of the radiation from the arc, it is necessary that the operator be carefully protected. Simply shielding the eyes is insufficient, the head, hands and body must also be protected from the ultra violet rays which form a large proportion of the radiation emitted by the arc. A special glass window which not only shields the eyes from the heat and intense light but also cuts out the ultra violet (invisible rays) is a necessity.

3. Electro Percussion. This is one of the latest developments in electric welding, its action depending upon the discharge of a highly charged condenser at the instant the metal points are brought into contact. It is used a great deal for joining wires and can be employed for practically all metals and alloys as well as for combinations. One of its chief uses at present is the uniting of copper and aluminum wires, which can be done in no other way with uniformly satisfactory results. Metals of widely varying melting points, for example, tin and platinum can be welded by this means. It also finds many applications in the jewelry trade. The method has not yet been developed for anything but small pieces.

Hot-Flame Welding or Blow-Pipe Welding.

The oxy-acetylene process is by far the most efficient of the hot-flame welding methods. A temperature of 2400°C (4350°F) is attainable with the oxy-acetylene flame as compared with 2000°C (3630°F) with the oxy-hydrogen flame. Ordinary illuminating gas under the same conditions gives a considerably lower temperature and is not used for general welding purposes to any extent.

The apparatus consists essentially of means for storing or generating the gases needed and a burner or blow-pipe with suitable connections, for the combustion of the two gases. The oxygen is supplied from the steel tank in which it is transported, it is compressed to about 1800 pounds per square inch. The acetylene is either generated by the action of calcium carbide upon water in a suitable generator as needed or it may be purchased in steel containers ready for use. The compression and storage of acetylene by itself is a dangerous matter. It is supplied commercially as a solution in acetone, which liquid will absorb many times its own volume of acetylene. The steel storage tank contains a porous filling which is necessary to prevent the accumulation of compressed acetylene within the tank since the acetone contracts in volume as the acetylene is used.

The pressufe in the acetone-acetylene tanks is not above 250 pounds per square inch. The use of copper tubing for piping acetylene is to be avoided on account of the explosive compound formed by the action of the gas upon the metal.

The design and form of the torch varies somewhat according to the manufacturer, a set of several different forms of tips is always supplied, however, so that the flame may be varied according to the work in hand.

The method of procedure is quite similar to are welding, the hot well-directed flame is used to heat the surfaces which are to be joined (although preheating by means of a blow torch charcoal fire, or other means is often necessary) and to fuse the metal which is to be added to form the bond. The character of the flame used is of vital importance in welding it should be as nearly "neutral" as possible. There is no simple way of determining absolutely this condition but instructions for the use of different types of torches are always given by the manufacturers. An excess of oxygen in the flame oxidizes the weld metal while an excess of acetylene will carburize the iron.

An important application of the oxidizing flame is in the cutting of metal particularly iron and steel. The metal is first heated as for welding and then a jet of oxygen played upon the hot portion which quickly burns away so that a cut almost as definite as that of a saw results. The tube for supplying the additional oxygen for cutting may be separate from the ordinary burner; the torch may be designed however so that the auxiliary oxygen tube lies within the torch at least at the tip. This is the preferred form. The oxy-hydrogen and oxy-illuminating gas flame are also used extensively for cutting metals. For cutting thick pieces, for instance, over 20 inches, the oxy-hydrogen flame is used in preference to the oxy-acetylene since this flame is much longer than the oxy-acetylene flame and will penetrate to the bottom of the cut.

Oxy-acetylene welding is used for the same general purposes as arc-welding. It is also used for welding copper and its alloys, aluminum and its alloys, malleable and cast iron. Under the name 'lead burning' it is used for welding lead pipe, sheet lead, etc. The range of application of the method is very great and the necessary apparatus can be put into light and portable form. A feature which is emphasized as a disadvantage by the advocates of other methods is that the heat cannot be easily controlled and concentrated and is therefore, a possible source of overheating and oxidation in some types of welds. Thus it is claimed by some that in welding steel sheets, for example, considerable buckling and bulging of the sheets is produced by the wide heating.

It is necessary that the eyes be protected by the use of suitable dark glasses during welding but the elaborate protection necessary for arc-welding is not required here.

Thermite Welding.

This method is generally used for only iron and steel. Its simplicity makes the method particularly valuable for repairs far removed from shop facilities. The broken parts to be joined are cleaned and enough metal chipped away to permit the flow of the bonding metal in between them, clamped rigidly in place and a mold built around them. The character of this depends on the nature of the work to be done. Wax is generally used between the parts to be joined as well as around them. Outside of this sand may be used with fire brick outside. The wax is removed before the weld is made by a hot torch which is applied through an opening left for the purpose, for preheating the material.

The thermite mixture (powdered aluminum and iron oxide) is contained in a sheet iron crucible lined with magnesite and having means for tapping the molten metal off at the bottom when needed. An igniting powder consisting of a mixture of barium oxide and powdered aluminum is used to start the action. A small amount is put on top of the thermite and ignited with a match. An intense chemical action, though not explosive, results with the liberation of a great deal of heat; a temperature of 2500°C (4530°F) has been attained by this means. A considerable quantity of molten 'thermite steel' (0.5 to .10 per cent carbon) is produced by the reaction. This is cast between and around the prepared parts which are to be joined. Different 'thermite mixtures' may be used for special purposes, thus the addition of nickel oxide produced a superior metal, titanium is also claimed to confer valuable properties upon a thermite weld. The weld part is usually annealed by a charcoal fire and allowed to cool slowly.

The thermite weld is essentially a casting. The process is much used for repair of large broken castings, propeller shafts, locomotive frames, rail joints of street car tracks and for similar uses.

Precautions in Welding.

It is manifestly impossible here to do more than list some of the precautions which must be observed in welding. These will of course differ according to the type of welding used as well as the material which is being welded. Of fundamental importance of course are the safety precautions to be observed. Some of these have been referred to above in -

the case of arc-welding.

For the production of successful welds by any process whatever, it is essential that the portions of the metal which are to be joined be <u>clean</u>. For many metals the use of a flux is necessary to insure this although in all cases the parts to be joined must be given a careful preparation and the flux be used to supplement this. For iron and steel a flux is not so important as for such materials as cast iron and aluminum which oxidize very readily when heated, although some skilled welders claim to be able to dispense with the flux in welding aluminum. In every case the flux must be suited to the metal. In those types of welding such as arc-welding in which metal is added in relatively small amounts, the surface of each built-up layer must be thoroughly cleaned by wire brushing or other means before a second layer is built upon the preceding one.

The mechanical features of the weld, that is the preliminary chipping or shaping of the parts, the form of the weld, the alignment of parts, etc. are of vital importance. While some general principles may be stated and will be found in text books on welding, more often each particular case must be treated by itself for which considerable experience is necessary.

It is often desirable, in some cases of welding, to preheat the parts. This allows a considerable saving of materials in the case of hot-flame welding but is also of importance in preventing in many cases cracking occurring during the cooling of the welded part. Here again it is impossible to give general directions, each specific case must be treated by itself. The welding of 'constrained' or rigid portions of any structure is a difficult matter, with any type of welding. Unless special precautions are taken to counteract the stresses due to the contraction during cooling the welded member will invariably crack either spontaneously during the cooling or when struck a light blow with a hammer. The making of a sound weld is a comparatively easy thing to learn but the successful practical application of it in the repair of metal structures of complex shapes and designs is exceedingly difficult. The relative expansion and contraction of the different portions must be carefully studied and allowance made in the design and treatment of the weld.

The material which is added to form the bond in the case of fusion welds must be carefully chosen and should approximate the composition of the parts which are joined. Special cast iron welding-rod (high in silicon and low in manganese and sulphur) must be used for cast iron, and not ordinary cast iron or steel; for copper and its alloys a welding rod of copper-zinc alloy such 'Manganese bronze' has been found excellent. For aluminum, a copper-aluminum alloy of approximately 7 per cent copper, which is a standard alloy of aluminum, will be found to give good results. For iron and steel the welding rod should be carefully chosen but the composition is not limited so closely as in the

previous cases. For most iron and steel welding a low-carbon steel is generally used, often so low as to be 'carbonless'. For high-carbon and alloy steels the welding rod must be of a suitable and corresponding composition.

Properties and Tests of Welds.

It should be borne in mind that all the processes of welding in which molten metal is added to form the bond, result in a casting. This is true of the oxy-acetylene and arc welding as well as for the thermite process. Cast metal never has the high mechanical properties that the same material in the rolled or forged condition does. It is, therefore, evident that the weld-metal in its mechanical properties will be inferior to the welded metal. Allowance is sometimes made for this by an increase of cross section of the weld as compared with the original section. This, however, does not settle the matter.

The tests which are commonly made in the testing laboratory to determine the "efficiency" of a weld include the usual tension and cold bend tests. It is well recognized, however, that these tests do not completely define any material. In particular, they tell but little concerning the resistance of material to repeated or alternating stresses or to shock or impact. The service to which nearly all metal structures are subjected is a very complex combination of which impact and repeated stresses form a large part. In the shop, however, a hammering test of the welded article supplemented perhaps by a cold bend test in the vise will tell a good deal concerning the properties of the weld and its suitability for service.

According to Kent (Mechanical Engineer's Pocket Book) "No welding should be allowed in any steel that enters into structures." While there is considerable difference of opinion concerning this statement, practically all engineers are in agreement that for certain types of service welded materials are entirely unsuited, particularly those involving "fatigue" stresses.

Defects in welds may be due to overheating or, in some cases, even burning of the metal adjacent to the weld. In such a case "the weld is stronger than the metal itself". Oxidation of the weld often results in very inferior properties such as lack of ductility, porosity, and contaminations within the metal. Variation in hardness between weld and original metal often causes trouble. Nitrogen in welds, particularly those made by the arc process, has been claimed to influence its properties. It is very probable, however, that the effects of the grosser imperfections mentioned far overshadow those due to such slight composition changes.

Welded articles which are subjected to service in which corroding influences play a part will sometimes be found to fail

under circumstances which without corrosion would be considered as very mild service conditions.

Much of the contention regarding the relative merits of different welding processes has had to do with the oxy-acetylene and the arc welding processes. It is quite evident, however, that each process has special merits of its own and is particularly well adapted to certain uses. One would find himself severely handicapped if restricted to only one process for all types of work.

Information Concerning Welding.

Details concerning the cost of welding equipment, supplies, and advice concerning the installation and operation of equipment can be obtained by correspondence with firms supplying the apparatus. Advertisements of reputable firms may be found in many of the technical journals such as Machinery, American Machinist, The Welding Engineer, official organ of the American Welding Society, etc.

A very large number of technical articles on welding have appeared within the past few years in various technical journals. Two comprehensive abstracts of such articles of information have been prepared; one (1786-1912) by W. B. Gamble, published by the New York City Public Library; the other (1914-1918) by W. F. Jacobs appeared in the General Electric Review, vol. 21.

The following list includes reference books which will be found valuable:-

"Welding, Its Theory, Practice, Apparatus and Tests." Richard N. Hart, 1914, McGraw-Hill Company, New York, publishers.

"Welding and Cutting Metals". L. A. Groth, 1909, Constable and Co., London, publishers.

"Oxy-Acetylene Welding and Cutting", H. P. Manley, 1916, F. J. Drake & Co., Chicago, publishers.

"Autogenous Welding", T. Kautny, 1916, McGraw-Hill Company, New York.

"Oxy-Acetylene Welding", S. W. Miller, 1916, The Industrial Press, New York.

"Welding: A Practical Manual of Autogenous Welding", R. Granjon and P. Rosenburg, Trans. by D. Richardson, 1919. Chas. Griffin Company, London.

"Electric Welding", D. T. Hamilton and E. V. Oberg, 1918, The Industrial Press, New York.

"Oxy-Acetylene Welding Manual" Lorn Campbell, Jr. John Wiley & Sons, Inc. New York.

The Welding Encyclopedia, Welding Engineer Publishing Company, Chicago.

Most of the Engineer's Handbooks, particularly those for Mechanical and for Electrical Engineers contain considerable information on the subject of Welds and Welding.

Most technical encyclopedias contain comprehensive and authoritative articles on the subject, "Machinery's Encyclopedia" may be mentioned as an example.

The following publications of the Bureau of Standards deal with special phases of the subject of "Welding":-

Technologic Paper 62, "Modern Practice in the Construction and Maintenance of Rail Joints and Bonds in Electric Railways."

Technologic Paper 84, "Failure in Brass: Initial Stress Produced by the "Burning-In" of Manganese Bronze".

Technologic Paper 179, "Electric-Arc Welding; I, Properties of the Arc-Fused Metal".