NOTES ON ELECTRIC WELDING,

The processes of electric welding have attained great prominence in recent years and plant for this purpose is now a recognised and necessary adjunct in all engineering repair works. The expansion of the welding art was particularly rapid during the war because of the great possibilities for saving time and labour which were made evident; the rapidity with which some of the damaged interned German liners in the U.S.A. were repaired particularly served to emphasise the utility and possibility of the welding processes generally. In addition to repair and reinforcing work, welding also plays an important part in constructional work, but in this connection it is generally confined to various types of light work although Lloyd's Register of Shipping have issued regulations under which this body is prepared to sanction its use in the building of ships' hulls, and a few vessels have been so constructed.

The modern processes of welding are generally referred to as autogenous processes, since the weld is more or less automatically generated, as contrasted with the old forge process which involves manual or mechanical pressure. There is one form of electric welding, however, which is not an entirely autogenous method, *viz.*, that generally referred to as resistance welding. In this process both heat and pressure are used to produce the weld. The heat is produced by the resistance offered to the passage of an electric current through the two pieces to be welded. The greatest resistance to the passage of the current takes place at the thin air film at the junction of the two pieces and the metal therefore heats more intensely at this position. When the temperature has risen to the point at which the metals at the junction become fluid, pressure or percussion is applied to effect the weld and incidentally extrude any oxide, and therefore in principle this method is identical with the forge-welding process. The advantages claimed for this process are—

(1) The metal heats from the inside at the surfaces where the greatest heat is required.

(2) There are no gases of combustion and no oxidation, thus eliminating this cause of faulty welding.

(3) The metal becomes one homogeneous mass.

Resistance-welding may be subdivided into three distinct types called respectively Butt-welding, Spot-welding and Seam-welding.

Butt-welding is the method applied to bars, rods, tubes, &c. transverse to the length of the pieces. The two lengths to be joined are held in place by clamps and brought into contact. The electric connections are made to the clamps and the current passes through the two bars and across the thin air film between them, developing great heat at the end of each bar. Pressure is applied by mechanical means operating the clamps as the metal becomes hot and plastic. This pressure is maintained and a distinct burr is formed thus showing that an appreciable amount of plastic flow has taken place and the possibility of any oxide remaining in the weld is slight. The current is then broken and the joint is finished off while cooling by hammering or swaging. This process is used to some extent in building up evaporator and condenser coils for refrigerating plants.

Spot-welding is a method of welding adopted for making a lap-joint between two plates instead of a continuous weld along the edge of each plate. The joint made may be compared with flush-riveted work as the plates are united by a number of small welds spaced in a similar manner to rivets. The two plates to be joined are placed between point electrodes which are pressed together by mechanical means, thus helping to grip the plates closer than can be done by clamps. The electrodes are made of copper and are water-cooled through the centre right up to the tips. On the current being passed the metal is raised to the welding temperature at the joining surfaces in the small area directly between the electrodes. The joint is completed when the desired temperature has been obtained by additional pressure being applied mechanically through the electrodes. Although it is claimed that this method is as efficient as riveted lap joints, tests which have been made in a dockyard do not support this claim. The tests showed that the welds made were not uniform in quality, some being indifferent and others bad, while only a few could be considered good welds. The method has not been adopted in Admiralty service.

Seam-welding is similar to spot-welding, and applicable to thin plate work. Instead of point electrodes, rollers are used and the plates are raised to a welding heat by passing the current through these rollers, which at the same time revolve across the plates. For efficiency the surfaces to be joined must be thoroughly cleaned by sand-blasting or pickled with acid. This system is not used however by the Admiralty.

To a certain extent resistance welding is not so dependent on the use of skilled labour, and probably the metal is left in better condition with this than with the other systems of electric welding, although the heating to the welding temperature must necessarily involve some changes in the physical properties of the metals at the junction.

The disadvantages of resistance welding are that very heavy current is required, and its use is not practicable in confined spaces. Alternating current is almost universally employed, though there is no reason why direct current should not be used, saving the difficulty of dealing with heavy currents. Special transforming apparatus is required to transform from the ordinary commercial source of supply or from a portable alternator to give a low pressure current of from $\frac{1}{2}$ to 6 volts with some hundreds of amperes. The heating and welding operations with this method are very rapid, and it can under suitable conditions be used for a very wide range of metals, *e.g.* iron, steel, brass, aluminium, &c.

Arc-Welding.

There are two kinds of electric arc-welding, known respectively as carbon-electrode welding, and metal-electrode welding. In the former an arc is drawn between a carbon electrode, which is the positive, and the piece to be welded, which is the negative, and the metal to be added is fed into the arc in the form of a wire or rod. This process is subject to certain disadvantages—

(1) It can only be conveniently carried out in the horizontal plane.

(2) The weld is liable to contamination by carbon from the electrode and also to oxidation by the oxygen of the air.

(3) The heat is very great (the temperature of the arc is 3,500°C.) thus leading to possible burning of the weld and adjacent metal, and to possible excessive expansion and contraction stresses; its use in confined spaces is also open to objection.

In general, this weld is not so reliable as is obtained with other processes, and the material at the weld may be so hard that it cannot be easily machined. It is more frequently used on heavy work which is not required to withstand considerable strain, and is considered suitable in special cases for the filling in and repair of faulty castings and similar work.

The current required is at about 90 volts pressure, the amount depending on the size of the work being welded and ranging from about twenty amperes to some hundreds.

The metal electrode process which is more widely applied, uses, as the name implies, a metal electrode, the arc being drawn between the electrode and the piece being welded. The heat of the arc melts the metal of the piece and the metal of the electrode simultaneously. As the metal of the electrode melts, it is drawn across the arc to the metal of the piece where a union is formed. The term "drawn" across the arc, rather than falling through the arc, is used advisedly, since the metal will flow straight overhead as well as vertically downwards.

The advantages of the metal over the carbon method are—

(1) The temperature of the arc is lower.

(2) No carbon is passed into the weld.

(3) The metal of the electrode melts in the arc, and is deposited on the parts being welded so that filling rods are not required and thus manipulation is simpler.

(4) The operation can be carried out in any position and in virtue of the shorter arc and lower temperature, it is more suitable for use in confined spaces. Moreover, the arc is very concentrated and rapidly heats the metal, and

the objections of heating the material over a large area are within limits avoided.

There is still the disadvantage, as with carbon-arc welding, that oxidation of the weld may take place during the process, but the possibilities are considerably lessened because in the first case the electrode is held very close to the work and also because with this system it is easy to apply methods to reduce this action, as will be seen later.

It should be appreciated that oxidation not only affects the initial strength of the weld, but also renders it more susceptible to local corrosion and further weakening in service.

The possibilities of the metal electrode system of welding have led to the development of the flux-covered or coated electrode in which the metal rod or wire is surrounded by a suitable composition. The function of this flux is to form a molten compound around the arc during the welding operation to protect the metal from oxidation during its transit from the electrode tip to the work. The coating, which in some cases consists of asbestos yarn impregnated with silicate compounds, forms a slag covering the weld which flakes off more or less in cooling. The slag must be carefully removed at each stage when the weld calls for successive layers. The voltage required with metal electrodes is much lower than with the carbon electrode process and either alternating or direct current may be used, although in nearly all cases the latter is used as manipulation is then easier and the rate of depositing the metal is quicker, the electrode as before stated being made positive to the work. The arc formed is very short, $\frac{1}{4}$ inch or less, and it is found to be very sensitive to pressure variation so that skill and great care are required in the manipulation of the electrode.

The current required is relatively small, but a voltage sufficient to maintain the small arc, say, 60 to 100 volts, is necessary, although in special cases a slightly higher pressure may be used; generally speaking it is advisable to keep the pressure as low as is possible. The current may be from 20 to 225 amperes depending on the nature of the work. No general rules can be laid down, and one can only be guided in the main by instructions issued with the electrodes specially supplied by reputable makers, or experience in special cases.

It is only proper to mention that there is still a difference of opinion as to whether or not in arc-welding a flux is necessary. It is sometimes alleged that it is not required with metal electrodes and desirable with carbon electrodes since it enters into combination with any carbon which may be projected in the direction of the weld and prevents it combining with the metal. It is also maintained that a flux is necessary to increase the fluidity of the metal. It is argued too that welding by means of the carbon arc without a flux results in the formation of a crater of boiling metal, which readily absorbs oxygen from the atmosphere; also that a weld which has absorbed oxygen will always be weak, because the oxygen will react and combine with the carbon in the metal and with the metal itself, and the metal at the junction becomes porous. This merely illustates the diversity of opinion on the subject in the face of which it is difficult to pass judgment; the question is further complicated by the fact that there is no marked agreement as to the best composition of the flux or flux-forming coating when used, and also because an excessive current in the arc may bring about a condition in the weld which is very similar to that caused, say, by the use of a carbon electrode without a flux.

It can however be said that the coated metal electrode process is now firmly established for repair and constructional work.

It should also be mentioned, that all coatings applied to metal electrodes are not necessarily liquid flux-forming. In what is known as the gaseous flux process the metal electrode is covered with a fire-proof sleeve of non-conducting material, so that as the metal is removed by the arc, the sleeve projects beyond the end of the rod and forms a guide for the molten welding material, the sleeve itself falling away automatically. This sleeve prevents the metal from oxidation and reduces heat losses. A great deal of satisfactory commercial work has been carried out with this process in the repairing of mercantile boilers, &c. and to build up worn propeller shafts, crank shafts and wagon axles.

A well-known coated electrode process is that known as the Quasi-Arc process, the special feature of which appears to consist in the introduction between an impregnated asbestos coating (chiefly of ferrous silicate) and the rod, of a fine aluminium wire, which represents in bulk about 2 per cent. of the electrode itself. It is claimed that the effect of adding the aluminium is that a strong reducing action is brought about, the metal having a strong affinity for oxygen at the welding temperature. The asbestos coating itself also acts as a reducing agent and forms a slag which covers the weld and it is claimed prevents oxidation. This slag is either removed by hammering or by means of a stiff brush when the metal has cooled. Either single phase alternating or direct current can be employed, the electrode forming the positive pole in the latter case. In working, the tip of the electrode is brought into contact normal with the work and an arc is formed. The electrode is then dropped to an angle and the arc is destroyed owing to the covering passing into an igneous state, and, as a secondary conductor maintaining electrical connection between the work and the metallic core of the electrode. The action once started, the electrode melts at a uniform rate so long as it remains in contact with the work and leaves a seam of metal which, if the operation has been correctly carried out, is fused into the work. The covering material of the electrode acts as a slag and spreads over the surface of the weld as it is formed. The length of the arc varies between $\frac{1}{8}''$ and $\frac{1}{4}''$ according to the size of the electrode used. The aim, when working, is to keep the point of the electrode just in the molten slag. The size of the electrodes varies from 14 to 4 S.W.G., the electrodes being of high quality mild steel, *i.e.*, free from impurities. For reinforcing work carbon steel electrodes are used, and in some special cases manganese steel electrodes. The current varies from 20 to 25 amperes with 14 S.W.G. electrodes to 150–175 amperes with 4 S.W.G. electrodes. The size of the electrodes depends generally on the amount of metal to be deposited, but in the case of work liable to distortion, overheating by the use of unduly large electrodes must be avoided.

The electrode is held in a holder of which there are two types in general use. One is a pincer-shaped holder which is usually grooved to take these different gauge electrodes, and the other has a fairly large hole through which the electrode is placed and held by a tongue piece operated by the grip of the operator. The holder is connected to the electric circuit.

The characteristic of the wire which is used for the metal electrodes is a very important matter, and dead soft iron or steel wires have been found satisfactory for the purpose in their respective spheres. It would appear that uniform mechanical treatment in manufacture and careful annealing are required to give the best results. A good composition for an electrode for welding steel plates is approximately :—Carbon ·18 per cent., Silicon ·08 per cent., Manganese ·50 per cent., Sulphur and Phosphorus ·05 per cent., each as a maximum.

Experiments have been carried out at times to determine the nature and properties of the metal deposited by arc-welding and a careful study of the results gives valuable indications of the possibilities and limitations of these processes. Although there is an opinion that the properties of the metal of an arc weld are affected materially by the adjacent metal by reason of the interpenetration of the two, it is more generally considered that the change of properties of the added metal induced by the fusion is of fundamental importance and should form the basis of any study of arc-welding.

In these experiments blocks of arc fused metal for test were built up on the end of a section of a plate of mild steel. When a block of sufficient size had been formed, it, together with the portion of the steel plate immediately beneath, was sawn off from the remainder of the steel plate. The specimens for test were then turned entirely out of the arc-fused metal.

In one such series of experiments that were carefully carried out, two types of electrodes were used as the material to be fused. These differed considerably in composition and were chosen as representative of a " pure " iron and a low carbon steel. The electrodes were in various sizes and were used both in the bare condition and after coating with a representative oxidising and refractory mixture.

The general results from this series of experiments showed that the effect of fusion under welding conditions was to render the two materials used for the electrodes more nearly the same in composition after fusion. The loss of carbon, silicon and manganese was very marked in each case. The coating used in these particular cases appears to have had but little influence, if any, in preventing the oxidation of the carbon and other elements. But an important change that was observed was an increase in the nitrogen taken up by the fused iron increases somewhat as the current density increases.

Quite recently the presence of nitrogen in iron or steel has been given serious consideration, but analysing for this element is a difficult matter. It has, however, been proved in actual cases that this element was not only present in amounts up to 0·15 to 0·2 per cent., but was a most important factor in causing "cold-shortness." As little as 0·06 per cent. nitrogen will considerably reduce the elongation in a 0·2 per cent, carbon steel. Under ordinary conditions of fusion nitrogen would appear to have little effect on iron, but under the conditions of exposure to the electric arc the gas molecule is broken up and the nitrogen atom readily combines with the molten iron and iron vapours. The oxygen and nitrogen content of the fused metal can be kept at a minimum by using as short an arc as possible with the smallest current to maintain the arc and fuse and transfer the metal. Excessive current appears to increase both the oxygen and nitrogen content to a point where the deposited metal may be excessively brittle. It is considered that the portion of the nitrogen enters into solution with the ferrite causes the brittleness and not the free nitrogen.

Attempts have been made to improve the ductility of the weld by adding various de-nitrogenizing elements in the electrode but none have been entirely successful due to the fact that any such element possessing desirable affinities in this direction is rapidly attacked and otherwise combined during its passage through the arc. This question, however, requires further investigation.

Returning to the experiments on arc-fused metal referred to, tensile tests of the electrodes and of samples of the arc-fused metal are interesting. The results obtained over a wide range were fairly consistent and indicate a general deterioration in the deposited metal as compared with that of the electrode.

The results showed (1) a general similarity of the properties of the deposited metal from both iron and steel electrodes, (2) a reduction in tensile strength and (3) a very marked falling off in the reduction of area of fracture. Also all fractures of the specimens when minutely examined gave evidence of interior flaws, the metal appearing to contain a considerable number of cavities and oxide inclusions and generally it was concluded that with the best of precautions it is not at present possible to fuse and deposit the metal without imperfections.

In any consideration of electric-arc welding, it should constantly be borne in mind that the weld metal is simply metal which has been melted and has then solidified *in situ*. The weld is essentially a casting, though the conditions for its production are very different from those ordinarily employed in the making of castings. The physical properties of a weld or of any casting depend upon the grain, solidity and chemical composition;

the conditions under which a weld is made, however, are generally such as to affect these factors unfavourably and to an uncertain extent. The grain is usually coarse due to the method of cooling, and for best effect in this direction the metal should be deposited in relatively thin layers.

The metal in any case certainly loses many of the properties it possesses when in the wrought form and hence it is not to be expected that a fusion weld by any process whatever will have all the properties that metal of the same composition would have when in the forged or rolled condition. A knowledge of the characteristic properties of the arc-fused metal is therefore of fundamental importance in the study of the strength and reliability of the electric arc weld.

It must always be borne in mind during welding operations that the fact that metal is melted and allowed to run into a joint does not indicate that fusion of the metals will take place. A real weld can only be made when the metals to be welded are in a liquid state with the slag and oxide floating on top.

Another point to appreciate when applying a welding process, either for constructional, repair or reinforcing work, is that there is not, at least at present, any reliable method of testing the soundness of a weld after it has been completed, and therefore careless work may be turned out which is difficult or impossible to detect. In engineering structures, it is nearly always possible by rigid tests of the materials used and with ordinary careful workmanship, to determine whether the structure will be suitable for the stresses it has to bear, and the fact that unreliability may be present in a weld that appears satisfactory renders it all the more necessary that in any case its use should be carefully considered.

The possibilities of the application of an X-ray process to examine welds is being investigated, but the research is not sufficiently advanced to enable a definite opinion to be formed as to its ultimate value.

One other consideration in welding must not be lost sight of. Apart from the differences between the metal deposited and that of the work, the metal in the neighbourhood of the weld undergoes a change of structure owing to the over-heating which takes place. This heating may have a deleterious effect on the metal. It can be minimised by using as small an arc as is consistent with obtaining fusion at the surface and depositing the metal rapidly but even so, the effect depends to a great extent on the skill of the operator. In principle electric welding is simple, but in practice it requires a very skilled and conscientious operation to produce the best results. Slag inclusions are a common source of weakness and are due mainly to poor workmanship. One layer is put over another without proper cleaning or the pool of metal is not kept molten long enough to float off the slag formed during the deposition of the electrode.

If the operator uses too small a current or holds the electrode too far from the work, the melting of the edges of the work may not have been properly effected, so that there is not adequate adhesion between them and the added metal, and the small cracks thus remaining will in time lead to trouble. An excess of current may cause " bad " metal to be deposited or bubbles of gas may form in the weld and reduce its strength, or the metal may be burnt by keeping the arc too long in one particular spot.

Having discussed the welding processes in general it is interesting to consider in more detail the application to particular metals or alloys where its use is largely adopted.

Welding Cast Steel.—The physical properties of cast steel, neglecting the effect of heat treatment, are mainly governed by the kind and amount of the several constituent elements, technically known as "impurities" (carbon, silicon, manganese, sulphur, &c.) in the metal. There is at the present time a lack of reliable information regarding the effect on weldability produced by the presence of these various impurities. It is known, however, that a steel containing ·5 per cent. or more carbon is subject to burning at a much lower temperature than low carbon steels. As far as has been observed, the chief controlling element in steel, as regards the effect on weldability, appears to be carbon.

The requirements during a welding process are the addition of a certain amount of cast steel of a given composition, so that, if it is known how the metal of the casting as well as the metal to be added will behave through the temperature range of the welding process, the nature of the completed work may be approximately determined. The rate of cooling which is dependent on the shape of the casting and on the manipulation of the arc, may be different in different localities of the same weld, with a corresponding difference in character of the metal in different sections.

The process is frequently used for filling blow-holes in steel castings, a quite legitimate and useful application if the blow-holes occur at position where an intact surface is the main requirement rather than the thickness of metal to withstand stress. Such positions are, *e.g.*, at the face of a flange or on the seating of a valve box. The blow-hole should, however, be carefully cleaned out before the process is commenced as it has been frequently observed that segregates of impurities exist at such positions.

In welding up a crack, the crack is usually opened out in the form of a " V " as shown in Fig. 1, and the width of the " V " should be sufficiently wide to allow the welding electrode to be properly applied. The welding must always be done on clean metal, the presence of oxide, dirt or grease on the surface inter fering seriously with the welding. The crack should preferably be opened out by easy chipping to lessen the strain on the surface. If the crack has been opened out by a flame, blue oxide may be present, and this must be removed by further chipping or sand blast.

Welding of Mild Steel Plates.—The metallurgical problems met in the welding of steel plates are similar to those met with in the welding of cast steel only so far as the character of the metal in the weld is concerned. Sheet or plate metal is, however, a product which has passed through a process which improves its quality beyond that of cast steel, viz., the mechanical treatment in the rolls. The result of this mechanical treatment is compactness of the structure with a resultant increase in toughness. The metal in the weld, which will in general have the characteristics of cast steel, will therefore not have the toughness and ability to resist the tendency to crack in bending that is possessed by the rolled metal. This consideration is of great importance when the question arises of welding cracks in boilers and other structures subject to stress, and requires very careful attention. A boiler, for example, is a structure in which each part is designed to stand known stresses confirmed by theory and experiment. The material in the first case is subjected to a stringent series of tests and rejected if it does not comply with them. The effect of the introduction of a generally inferior metal attending the use of a welding process must therefore be carefully weighed in all its bearings when repairs to such parts are contemplated.

In this connection the following circular issued by the Board of Trade a short time ago is of interest :—

" The repairing of the boilers of passenger steamers by the electric or oxy-acetylene welding processes has been tentatively in operation for a considerable period; and in view of the experience gained, the Surveyors are informed that, provided the work is carried out to their satisfaction by experienced workmen, these processes may be employed, within limits, for repairing cracks in furnaces, combustion chambers, and end plates of boilers, and in the same parts for re-enforcing the landing edges of leaky rivetted seams which have become reduced by repeated chipping and caulking.

" In some old furnaces which have been repaired by the above processes, it has been found that, after a few months' working, cracks have again developed at parts adjacent to those welded; probably owing to the original material of the furnace having become fatigued and worn out by long and severe usage. In dealing with old furnaces, therefore, this fact should be taken into consideration.

" It has also been brought to the notice of the Board of Trade that a shell plate of a cylindrical marine boiler cracked recently through a solid part where some surface welding had been done by the electrical process two years ago. The welding had extended for a length of about 12 inches along the outside caulking edge of one of the middle circumferential seams at the bottom of the boiler, the leaky edge of the seam and the adjoining shell plate having been covered (soldered) by metal deposited by this process in the usual way. The shell plate was 1-5/32 in. thick, and the crack, which followed the line of surface welding, extended in a circumferential direction for a distance of 2 feet 9 inches, the welded part being situated midway along the crack.

"For the present, it is not proposed to prohibit, within limits, the re-inforcing of the circumferential seams of boiler shells if the end plates are well stayed, but no welding should be done to these parts by any process which may cause local heating over an appreciable area of the plate.

"In no circumstances should any part of a boiler of a passenger vessel be welded if wholly in tension under working conditions, such as a stay or the shell plate at a longitudinal seam, the failure of which by cracking at the welded part might lead to disastrous results.

"In any case in which the proposed repairs to the boilers of passenger vessels by either of the above processes are of an uncommon or unusually extensive character, the particulars should be submitted for the Board's consideration and approval.

"After repairs by welding have been completed, the parts at or adjacent to the welds should in all cases be well hammer-tested and, unless the welding is of a trifling character, a hydraulic test of not less than one and a half times the working pressure should be applied to the boiler after the hammer-testing has been effected."

As has been noted under cast steel, the properties of steel plate depend upon the kind and amount of the several "impurities" contained in the metal. Mild steel made by the open-hearth process and low in carbon, sulphur and phosphorus would appear to give the best results as regards weldability.

In some cases where experiments have been carried out, the carbon would appear to have been the chief controlling factor in determining the weldable properties of the steel, as although flanging and working of the material have been carried out satisfactorily, difficulty has been experienced with welding when the carbon content exceeded a certain limit. In other cases the sulphur would appear to have had a marked effect as with a comparatively high percentage of this constituent boiling and blistering of the metal takes place.

No definite figures can be quoted for the limiting values of the various constituents as the question is so much dependent on the process adopted and the care taken in the operation. From what has been said the necessity for knowing beforehand in any particular case the quality of the material can, however, be appreciated if a successful weld is to be effected.

Two kinds of electrodes are in general use for plate welding, viz., Norway or Swedish iron (or equivalent) and low-carbon steel wire. The iron wire under good conditions gives metal in the weld of a tensile strength of about 22 tons per sq. inch, while the steel wire may give a slightly higher figure. The iron electrode may be melted more rapidly than a steel electrode, and probably has less tendency to burn the steel. In general, however, it is more difficult to weld with iron electrodes than with steel. To get the best results it is advisable to use as low a current density in any case as is consistent with a usable arc.

In some experiments that have been carried out with welded steel plates, it has been found that there is little or no difference between the moduli of elasticity of the weld and that of the plating. but if tested to destruction the ultimate extension is much less in the case of welded pieces than in the plain plate, *e.g.*, the extension of about 29 per cent. in a length of 8 inches of plain plate would be reduced in a welded plate to from 8 to 12 per cent. These figures while of interest have normally little bearing upon practical questions, since in no case should the permissible stress exceed the elastic limit. Welding, however, would appear to have a marked effect on the capability of the structure to withstand alternating stresses. Experiment has shown that welded bars or plates will always fail at the weld when subjected to such stresses even if the test be so arranged that the welded part is only subject to stresses as low as 3/5 that of the unwelded part. Nor are welded specimens capable of being bent without fracture over the prescribed radius usually specified for steel plates or bars, *e.g.*, if 180° is specified for the original plate, it is unusual to produce a weld in such metal that will enable the plate to be bent more than 90° with a ¼-inch plate or above 30° where the thickness is 1 inch, although this figure may have been sensibly exceeded in special cases.

The reinforcing process has been used in mercantile practice in connection with boiler work, not so much from the strength-giving point of view as to restore material wasted by corrosive effects which may have weakened the plates at external seams, or erosive effects at manhole door orifices, &c., and so delay the corrosive or erosive action extending to dangerous amounts.

As illustrating some of the points discussed, the case may be quoted of an unsatisfactory repair to the front plate of the steam drum of a water-tube boiler in which a crack had developed extending from the main feed orifice through a stud-hole to within ½ inch of the edge of the manhole flange. The remainder of the manhole flange being under compressive strain under the test conditions limited the extent of this crack. The crack was vee-ed out on both sides of the plate, and welded up, the general appearance of the weld being satisfactory, and the re-drilled stud hole showing good material. A ¾-inch riveted patch, was also fitted. On testing the boiler subsequently to the repair, the crack again developed at the working pressure, and when the pressure was raised to 300 lbs. this new crack extended to the stud hole, and again within ½ inch of the edge of the manhole flange.

This plate was forwarded to the Admiralty Engineering Laboratory for an examination of the structure of the metal at the weld to be made. The chemical analysis of the original

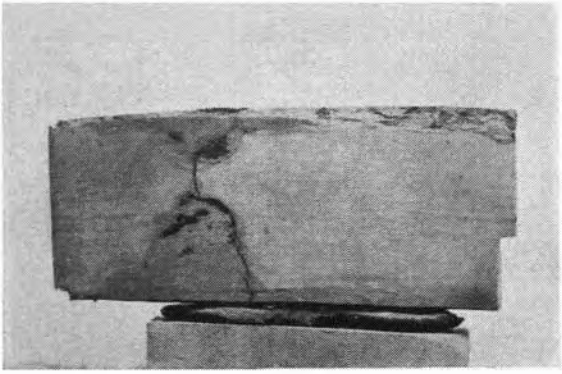
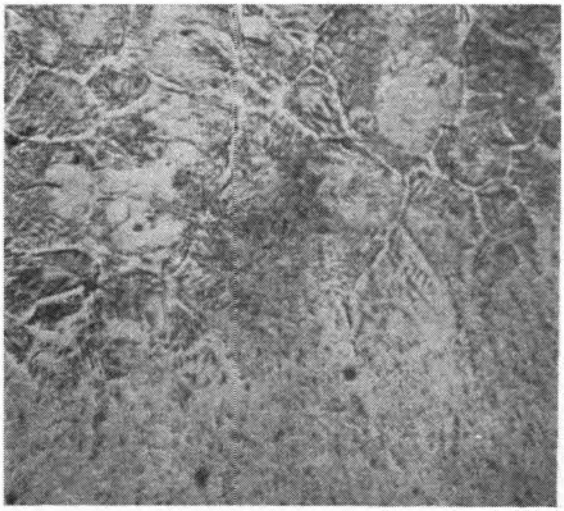


Fig. 1.

Fig. 2.

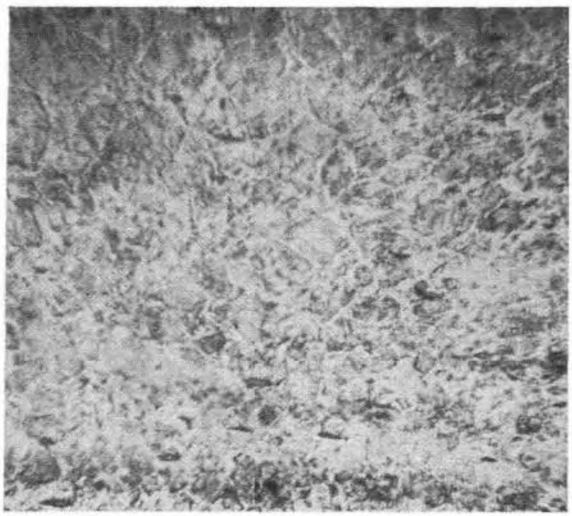


a. Weld Metal →

b. Fused Steel →

c. Overheated Steel. →

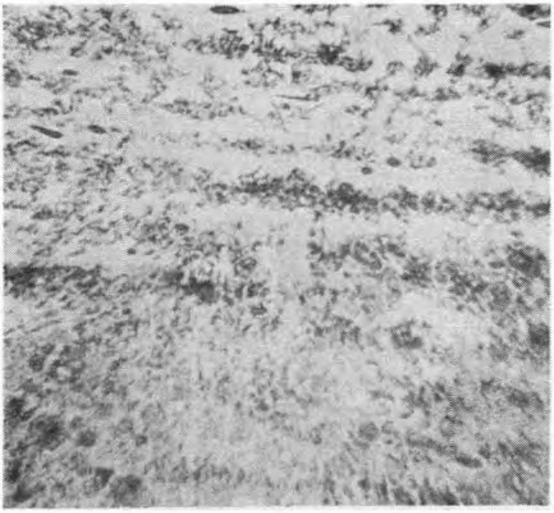
FIG. 3.



c. Overheated Steel. →

d. Annealed Steel. →

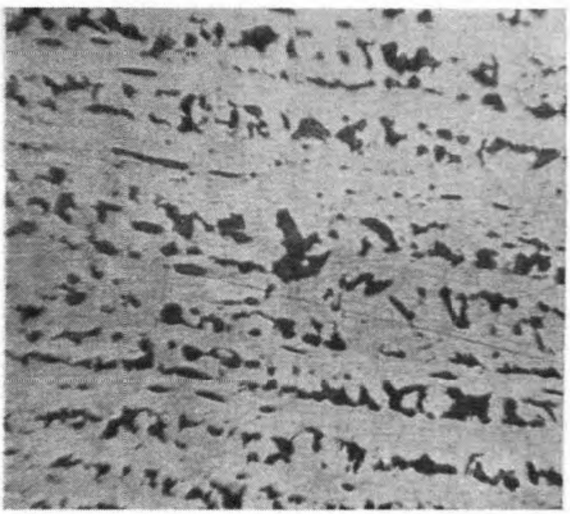
FIG. 4.



← *d* Annealed Steel.

← *e*. Steel not heated above critical points.

Fig. 5.



← *f*. Unaltered Steel below e.

Fig. 6.

steel of the plate showed the following composition as regards "impurities":—

Carbon	·22	per cent.
Silicon	·16	" "
Sulphur	·022	" "
Phosphorus	·067	" "
Manganese	·51	" "

The phosphorus constituent is slightly above average, but the steel can be assumed as of normal good quality and showed a maximum tensile stress of 26½ tons both near the weld and at a remote point. It was not possible, owing to the shape of the end plate, to take a test piece to include steel likely to have been seriously affected by the welding operation.

Fig. 1 of the Plate shows a rough section across the crack, indicating the path of the crack through the plate, the character of the weld and the extent of the metal added by the welding. The welding is seen to be defective in places, the junction between the original steel and the new metal being imperfect. The second crack appears to have originated from the first crack, passing thence partly along the imperfect junction just referred to, and partly through the new metal added by welding.

Figure 2 shows the structure noticed in parts of the root of the groove cut in the steel along the path of the original crack as a preliminary to welding. In addition to revealing that a corner of this groove has not been filled with metal, it also shows that the steel plate at this point has not been heated in welding to a sufficient degree to remove the distortion of the steel due to the work of the tool. Under these conditions it would not be possible to effect a good weld of the remains of the original crack and this crack would therefore remain as an internal flaw in the plate.

The Figures 3 to 6 are interesting as illustrating the changes between the unaltered steel and the new metal added; these sections were taken across a part of the weld, where the junction between the steel and new metal was satisfactory. The various structures will be observed to merge gradually into one another.

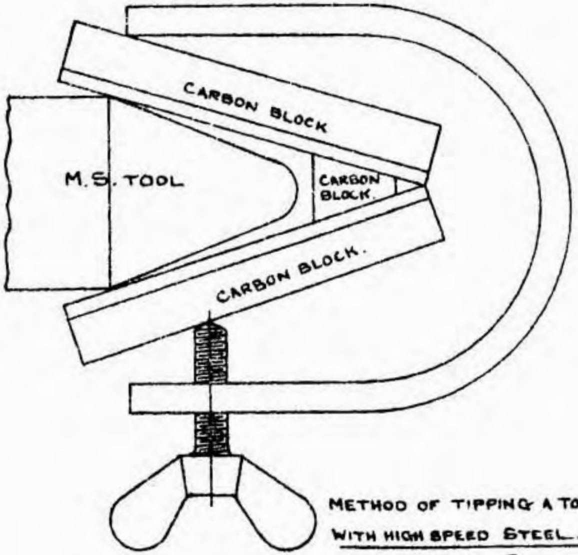
Figure 3 shows the added metal merging gradually into the steel overheated by the welding operation. Figure 4 shows overheated steel passing into steel annealed by the heat of welding. Fig. 5 shows annealed steel passing into steel which has not been raised to the annealing temperature causing the granular appearance of the pearlite and films of carbide of iron between ferrite crystals. Fig. 6 shows the banded arrangement of ferrite and pearlite which is the general structure for this class of steel.

Welding of Steel Forgings.—The application of the electric arc-welding process to steel forgings is in general similar to its application to boiler plate and structural work. This is due, of course, to the fact the forgings belong to the same classification, namely, metal which has had mechanical treatment. The metal added during the welding process is cast metal and has a lower degree of elasticity than the metal in the forging. This must again be clearly emphasised and appreciated. It is very common to talk of "reinforcing" worn shafts, &c. by this process, especially where grooving, corrosion and general wear of journals has been experienced. The process is very useful for restoring working surfaces, but it cannot be assumed that the shaft has necessarily been reinforced from the strength point of view.

The stresses and strains for which a shaft is especially designed to resist assume a homogeneous material of which the shaft is made, and generally the maximum stresses occur at the external surfaces. It is therefore usual to recognise this limitation and to be on the safe side, to reckon the strength of the shaft on the size before reinforcing. When reinforcing work is carried out on a worn shaft, the new metal should be deposited in strips parallel to the shaft, the surface of which has been previously cleaned, and each strip thus deposited should be carefully cleaned of slag before the next is added. It is also advisable to deposit layers on opposite sides of the shaft as shown in Fig. 2, the layers being deposited in the order 1, 2, 3, &c. By carrying out the process in this manner, distortion of the shaft will be minimised or prevented.

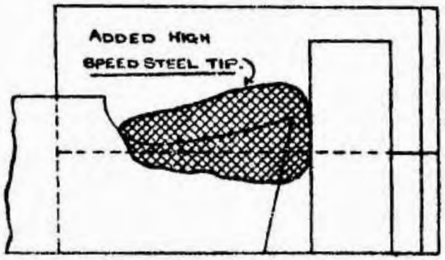
Welding of Cast Iron.—The molecular construction of cast-iron renders it particularly sensitive to the effects of expansion and contraction and considerable experience and judgment is required to make satisfactory welds on this metal. It would appear that welding only takes place within a small range of a definite temperature depending on the quality of the particular variety of cast-iron. The tendency of the metal to strain in certain directions must be minimised by the application of the heat at the right positions and in the correct sequence. It is advisable to pre-heat the casting to black or dull red so as to avoid chilling of the deposited metal and to distribute the contraction stresses over the body of the casting and not concentrate them at the weld itself. The heat at which best results are obtained is about 500° C., the point at which the casting changes from a black to a dull red heat. In some cases where pre-heating is not possible or convenient the job should be placed in sand to cool slowly after completion of the work with a view to minimising the contraction stresses.

In any case the welding of cast-iron details subjected to stress must be approached with great caution, the character of the metal itself having an important effect on its weldability. Good grey iron, high in silicon and low in phosphorus, welds the best. Special electrodes have of late years been put on the market for the welding of cast-iron, these electrodes containing rather a large percentage of silicon with a low manganese content. In the welding operation the silicon content is reduced, leaving a deposit which is practically ordinary grey cast-iron. The metal in the weld then possesses a coefficient of expansion approximately similar to that of the



METHOD OF TIPPING A TOOL WITH HIGH SPEED STEEL.

FIGURE 3.



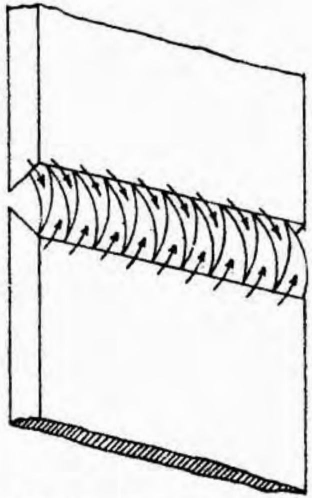


DIAGRAM OF WELD SHOWING DIRECTION OF POINT OF ELECTRODE.

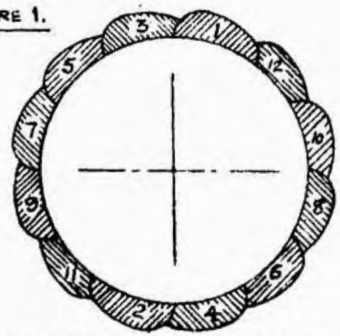
THIN METAL

MODERATE TO THICK METAL

THICK METAL WHEN BOTH SIDES ARE ACCESSIBLE FOR WELDING

METHODS OF VEEING.

FIGURE 1.



METHOD OF REINFORCING A SHAFT. FIGURE 2.

bulk metal and local strain is thereby reduced. The tensile strength of the weld may be rather low and this consideration must be borne in mind in connection with the function of the particular detail being welded.

For light parts castings, such, for example, as crank-cases, which may have cracked under impact or other conditions of mal-usage or perhaps to internal casting strains as distinct from working strains, welding may be permissible when a question of oil or water-tightness only is involved. In such cases it is not always necessary to " vee " the casting as the metal can be deposited over the crack and adjacent surfaces, this operation being carried out on both sides of the casting if accessible. If the thickness of metal permits, the welding can be assisted by " stitching," *i.e.*, fitting steel studs at either side of the fracture and welding over these studs which then serve as a sounder foundation for the weld-metal.

Satisfactory results have been obtained in the dockyards in the welding of cast-iron details subjected to low stresses besides ordinary steel work by using mild steel electrodes coated with sailmakers' twine soaked in a saturated solution of borax closely wound round the wire, the electrodes being kept in the solution till required and used in the wet state. Aluminium filings dusted on the electrodes in the solution and smeared over them just prior to use assisted in giving a weld free from blow-holes and which admitted of easy machining. A small diameter electrode and as low a current as practicable is found desirable with this metal.

As previously referred to, the repair by welding of the heavily damaged cylinders of a number of the German liners interned in the U.S.A. during the war, threw into prominence the possibilities of the process applied to heavy cast-iron details. In many cases this welding was done without pre-heating or " stitching." The process found most successful was not a true welding of cast-iron to cast-iron as generally understood. In welding together two cast-iron edges a layer of steel was first welded to each and then these steel layers were welded to each other. This was because of the great difficulty of immediately welding two cast-iron parts, but the welding of a steel piece to cast-iron was simpler although still requiring considerable care.

Even with the best of care and experienced operators it was sometimes found that on laying on the welding metal it might be porous in spots. These spots had necessarily to be closed up before another layer of metal was attempted. A caulking tool was therefore run along each layer which, beside closing up these spots, also discovered any hard or brittle metal, and this caulking or an equivalent hammering process is now generally recognised as conducive to better results in all welding work. If the metal appears hard in a particular locality, but is not disturbed by the caulking tool, it is advisable to chip it out before the next layer is applied. Ruling out a subsequent destruction test, this is the best way at present to ensure that a weld is reasonably good.

Welding of Alloy Steels.—As regards the special alloy steels, a nickel steel containing 3 to $3\frac{1}{2}$ per cent. nickel, which is in fairly common use in engineering practice, is found under certain conditions to be susceptible of welding, but the effect of chromium appears to increase considerably the difficulty of welding. So many combinations of "impurities" in a large number of varying proportions are met with in practice, that it is impossible to give information on relative weldability in each case.

In all special steels, as compared with the commoner commercial varieties, the difficulties are much increased and the question in each case should be made the subject of special investigation if welding should appear desirable or necessary. In particular, it would appear that the presence of a very small amount of arsenic in steels makes welding almost impossible. It must be borne in mind that, as a general principle, the special alloy steels are used for engineering details subjected to very high stresses and undergo during manufacture special heat treatment to enable the full value of the alloy to be realised. The operation of welding therefore which would generally deposit an inferior metal and weaken the alloy in the neighbourhood of the weld is at present only of importance in its application to these steels, for the "reinforcement" of bearing surfaces, &c.

An interesting and useful application of the weld process is seen in the tipping of machine tools with high-speed cutting steel. The electrodes used for this purpose are of high-speed steel coated in the ordinary way, and supplied by firms making a speciality of these electrodes. The metal can be deposited on a shank of mild steel and the deposited metal ground to shape on an emery wheel. Carbon blocks are held in position by a clamp, as shown in Fig. 3, and the deposited metal is allowed to flow over the sides and end of the tool. It can then be ground without touching the mild steel. Whilst the metal is still molten it has been found advantageous to make an arc with a carbon electrode for a short period. On completion of the deposit the tool is quenched in oil.

Welding of Non-ferrous Metals.—All these metals, viz., copper, the bronzes and brasses, and aluminium, to mention the more important, fuse at temperatures so much below that of the electric arc, that they require even more care and skill in the operation of welding than the ferrous metals. Resistance welding would appear better suited to these metals although as an example, copper has been welded successfully with the carbon-arc process and some measure of success has attended attempts to weld copper by using copper electrodes. Welds in brass having a high percentage of zinc are apt to be porous, as the zinc volatilizes at a comparatively low temperature. Similarly the tin affects the welding of bronze. Aluminium requires careful treatment on account of its tendency to oxidise at a lower temperature than its melting point.

Generally speaking, there is a very short temperature range between the welding and fusion points of the non-ferrous metals, and the rapidity with which the metals oxidise adds to the difficulty of carrying out successful welding operations. Moreover, even with resistance welding, the current required is very heavy owing to these metals being relatively good conductors.

At present the application of electric welding to the non-ferrous metals is somewhat limited.

Cyc-Arc System.

The processes dealt with up to the present have referred to the welding together of two similar or practically similar metals, but this system is a method of welding two dissimilar metals, such as brass and steel. It is now in process of development, being the subject of recent patents. It has been used by the Admiralty for small work such as the welding of brass studs to bulkheads for securing clips for electric cables &c. The weld is effected by making the bulkhead or plate the negative pole, and the stud holder, the positive pole. The current is passed and an arc formed between the poles, thus raising them to a fusing temperature. The arc is governed in respect to the time it is working and the distance of the stud from the bulkhead. This distance is very small, about 1/16th inch, and is set by an adjusting screw to give the exact length of arc, whilst the time of the arc is controlled by an electric timing device. The stud-holder is held in place on the bulkhead or plate by two electro-magnets, the circuit for which is an auxiliary one to the main circuit and is separately controlled by a switch. In addition there is a solenoid which permits the stud to be brought to the bulkhead at the moment the metals are fused. This energising of the solenoid "strikes the arc" and is controlled by the electrical timing device, the weld being obtained practically instantaneously. In some cases the function of forcing the stud into place on the bulkhead is carried out by air pressure in lieu of the electrical means stated above. The voltage used varies from about 60 to 100, and the normal current range is from 200 to 500 amps. according to the size of stud to be welded. No flux or building-up metal is used.

The apparatus will successfully weld naval brass or manganese bronze studs up to ½ inch diameter on to brass, manganese bronze, iron or steel of practically any thickness and also on to galvanised iron or steel. It is possible also to weld studs to cast iron, but the results are not entirely satisfactory at present.

The welds obtained with this process are very strong, the studs showing a greater strength at the weld under tension than in the studs themselves. This is considered due to : (*a*) absence of oxide in the weld; (*b*) extremely local heating in the region of the weld; (*c*) penetration (in each direction) of the metals to be welded, *e.g.*, in the case of a weld of brass on mild steel a micro-section showed: (1) no oxide; (2) on the steel side of the weld the heating had produced structural changes which persisted for a depth of only ·05 inch from the weld. Adjoining the weld was a solid solution formation containing fine cracks which had filled with brass. Below ·05 inch from the weld the structure was normal. On the brass side of the weld the brass showed a layer of about ·01 inch thick which had been partly melted and having a fine-grained confused structure. Below this the normal structure of the brass was found.

Although with this system of welding the weld is found to be stronger than the stud for a single direct load, still, under alternating stress, the weld is found to be the weakest position as in other systems.

Testing of Welds.

The necessity for testing welded work as far as is practicable need hardly be emphasised. Not only should samples of the weld in any particular case be treated, if possible, but it has been considered of importance to carry out tests on samples of the electrodes supplied. There are at present no general standardised tests laid down for welds made with electrodes under test, but the methods adopted in one of the dockyards are of interest.

(a) *Tensile and Bending Tests.*—Butt-welds are made on samples of the plate, these welds being about 20 inches in length. Strips are cut from the plates to include the joint and these strips subjected to the usual tensile and bending tests. If the junction has been made on a Vee-ed plate the bending tests comprise those which tend to further open or close the Vee. Sample welds are made with the plates in various positions, *i.e.*, in horizontal and vertical planes, &c., according to the manner in which the welds will be made in the actual case. In some cases the tests are repeated, the pieces being annealed after welding.

(b) *Built-up Test Pieces.*—A one-inch plate has a piece about 2 ft. long and 4 in. wide cut off. This gap is filled up with a metal deposited by the electrodes. Two test pieces 1 in. square are cut from this metal sufficiently long to get a tensile test piece with 8 in. stretching length. This is tested for tensile strength, elongation and modulus of elasticity.

A similar piece is built up and subjected to a forging test.

(c) *Vibratory Impact Test.*—A butt-weld 30 in. long is made in $\frac{5}{8}$-in. plate, the plate being afterwards machined on both sides to a thickness of $\frac{3}{8}$ in. and cut into strips for testing, each strip being $2\frac{1}{2}$ in. wide. The testing machine grips a test piece at the weld in a vice and alternating blows are given to the opposite end of the test bar, the number of blows before breakage being noted by a counting device.

The complete series of tests referred to above is usually made on welding done both at 60 volts and at 110 volts. The tensile tests obtained with variously welded samples have been fairly consistent over a very large range of tests with different thicknesses of plates and in various directions of welding, the majority of the tests giving a breaking test in the weld exceeding 20 tons to the square inch, figures as high as 27 tons having been reached in special cases. The plates under test were the ordinary 26-30 tons mild steel. The bending tests show a wide variation in their results, depending chiefly on the direction of application of the bending. Although the load necessary to fracture when tending to open the Vee approaches fairly closely that carried when closing it, the angle bent through in the former case is much lower and indicates perhaps a greater liability to failure under repeated or vibratory stresses.

In conclusion, it will be appreciated that various special electrical apparatus is required for the application of welding operations, but it is not intended to describe this. For work on ships motor-generators are placed at convenient positions in the yard, portable resistances and controls being taken to the ship on which it is required to carry out operations by welding and the necessary connections made by flexible leads. In the shops, permanent systems are fitted for carrying out such work as can be transported to the shop or for small items as can be done at the benches.