LECTURE

WELDED STRUCTURES — THEIR GROWING IMPORTANCE IN ENGINEERING ENTERPRISES.

By DANIEL CLARK.

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In engineering advancement during the past decade no phase has contributed more than fusion welding. When introduced in the early years of the present century, development was naturally slow, but cumulative experience and improved technique have enormously increased the tempo to which the exigencies of the present international insanity have contributed greatly. The speed of development has, in a large measure, been made possible by the immense amount of research which has taken place all over the world, not only by those producing equipment in the shape of welding rods, electrical plant, etc., but also by metallurgists and engineers in divers spheres.

Preceding fusion welding by gas or electric current, the union of wrought iron and steel was performed by smithing or power hammering. This process consists of heating the material to incipient fusion, cleaning the surfaces, then piecing the parts together by blows from a heavy sledge or power hammer.

The efficiency of mechanical welding of iron or steel in this manner is governed very largely by the carbon content of the metal. The lower the carbon the better and more perfect the joint.

Alloy steels cannot be successfully dealt with in this way and, in so far as plain carbon steels are concerned, .25% of that element just about represents the border line between carbon steels that can and cannot be satisfactorily smith welded. It has often been stated that the purer the iron or steel the better the weld. This is not strictly true, because wrought iron, which welds as perfectly as any steel, is both visually and microscopically dirty, and full of entangled slaggy matter. As a matter of fact, the slag it contains actually performs the same function as a coated electrode by floating the oxides away from the surfaces being contacted.

With the advent of fusion welding, however, smith or hammer welding is gradually falling into desuetude, and, like the coke-fired crucible process for making steel, may soon belong to the past.
It is my purpose to-night to deal briefly with the undernoted aspects of the subject we are discussing, and view them mainly from a metallurgical standpoint:—

1. Thermit Fusion Welding.
2. Electric Resistance Welding.
4. Arc Welding.
5. The Metallurgy of Welding.
7. Relief of Weld Stress.
8. The Economics of Welding.

1. Thermit Fusion Welding.

In Thermit welding it is well known that the necessary heat is generated by the chemical reduction of a metallic oxide with metallic aluminium finely divided when brought to a high temperature by ignition. This method is particularly useful for joining large parts in situ, and to all intents and purposes is a steel-making process. The weld metal can be melted in a matter of seconds only, in which short time it reaches the astonishingly high temperature of 2750° C., as against approximately 1600° C. for open hearth or electric steel by the normal processes. When this superheated metal is brought into contact with the preheated sections to be amalgamated, complete fusion is obtained. Moreover, since welding by this means is a single stage operation, residual stress is at a minimum compared with the gas or arc processes, where each new layer is superimposed upon the rapidly cooling preceding layers.

This process is also capable of being used for cast iron repairs as well as steel, but welding of cast iron is not undertaken when the length of the weld exceeds the section by more than eight times.

The chemical reaction resulting from the use of Thermit was discovered at the beginning of the present century, and is represented by the following equation:

$$\text{Fe}_2\text{O}_3 + 2 \text{Al} = 2\text{Fe} + \text{Al}_2\text{O}_3 + 197,000 \text{ Calories}.$$  

2. Electric Resistance Welding.

The first application I witnessed of this was in Sheffield more than twenty years ago, where it was being successfully employed for the butt welding of high-speed tool tips to mild steel shanks.

By this method, the two ends to be butted are rapidly heated under mechanical pressure to a plastic condition by means of
an alternating electric current of high amperage and low voltage. Among other applications of butt welding are the joining of new sections to old railway and tramway rails.

It has been computed that the strength of an electric resistance welded joint is about 93% of the original metal.

In resistance spot welding, generally applied to thin plates, two electrodes are mechanically pressed against the plates to be united, the diameter of the spots approximating that of the ends of the electrodes. Experiments have shown that plates spot welded bear about twice the load of the rivetted, whilst an additional advantage is that there is no structural damage to the steel, such as takes place in the act of punching or rivetting, nor does the section suffer the reduction in thickness around the edges of the holes involved in punching.

This process of spot welding, however, is disadvantageous when applied to stainless steel, because the damage to the surfaces spotted detrimentally affects resistance to corrosion, to overcome which the parts would require to be reheated treated and polished. The Budd Manufacturing Company of Philadelphia have, however, cleverly overcome this by introducing a method called “shot welding,” whereby the maximum heat is applied to the internal faces, not the external. By this means they have successfully built up struts from cold rolled sections, and thus effected considerable reductions in weight. The cold rolled sections supplied have a tensile stress of about 60 tons per square inch, and this method of assembly permits the use of this high strength material in thinner sections than normally employed for similar struts.

The first practical demonstration of these built-up shot-welded struts was their employment in the construction of the coaches of the Diesel Motor Train “Burlington Zephyr.” Not only were the structural members of stainless steel, but the plates for the bodies were of the same material, which eliminated the necessity for painting.

The total reductions in weight resulting from the use of high strength stainless steel throughout in the construction of this train is an important factor in enabling it to attain the high speed of 112 miles per hour. The success of this achievement cannot be overstressed, and, if in the course of time, we can perfect a process whereby stainless steel can be cheapened, we will assuredly witness one of the biggest engineering advances in all history. Think what it will mean to the shipbuilding industry alone. The introduction of high strength built-up structural stainless steel sections and the employment of welded stainless steel plates also of high strength and ductility for the
hull assembly will not only effect enormous savings in weight, but will reduce painting to what may be necessary for decorative purposes alone.

Considerable advance has also been made in the employment of welded stainless steel in aircraft construction for such purposes as wing panels, petrol tanks, etc. One method of resistance welding stainless steel sheets for this service stated to have proved satisfactory provides for the use of two electrodes spaced at the required centres on one side of the upper sheet and a copper backing-up bar on the bottom sheet. With this set up, the current passes from one electrode through the sheets, then along the copper bar to link up with the second electrode.

If the best physical and stainless properties of 18/8 stainless steel which has been extensively welded are to be recovered, and the carbon is low enough to prevent possible intergranular corrosion, the parts should be reheated to 1060/1100°C., and quickly cooled out by quenching. This ensures the carbides being in solution, thereby reducing the liability to selective corrosion. The desirability of reheating and accelerated cooling following welding will be appreciated when it is realised that heating to or slowly cooling from a high temperature to between the limits of approximately 450°C and 800°C., there is a danger of causing a precipitation of the carbides of chromium, which tend to migrate to the grain boundaries. Since this produces an enrichment of chromium in some at the expense of other areas, corrosion is liable to commence in those areas denuded of chromium when the operating conditions favour attack.

Dealing with welded aircraft structures up to approximately ¼ thick where steels other than stainless are employed, German experience covering weld crack failures over a period of years has shown the amount of sulphur and phosphorus present to be potent factors. So much so, that in the case of the largely used chrome-molybdenum steels they now specify maximum values for sulphur of .015%, phosphorus .02%, with carbon not above .27%. In so far as sulphur and phosphorus are concerned, it is difficult to believe that the percentage of these elements, within reasonable limits, of course, are vital. In all probability the difficulties will be found to be more associated with some phase of the actual steelmaking process itself, peculiar to German practice. With regard to carbon, however, the amount present would definitely influence the quality of the weld and better results would be expected to follow when limited to .27% now stipulated as a maximum.
3. **Gas Welding.**

The gases employed are oxygen combined with acetylene, town gas or hydrogen. Oxygen in conjunction with acetylene or town gas is used for high temperature work, and has a temperature of approximately 3200° C., whilst the oxy-hydrogen combination reaches a temperature of about 1440° C., and is suitable for burning in lead and alloys of low fusion points. By the latter method the joint is sometimes made by simply fusing together the two parts to be united. When steel, however, is being dealt with amalgamation is generally secured by running in a welding rod of approximately the same composition as the steel itself.

A characteristic feature of gas welding is that an oxidising, reducing or neutral flame can be secured at will. For many purposes, the neutral flame is preferable, to obtain which the acetylene and oxygen have to be in proper balance. Where, however, a slight input of carbon is desired, excess of acetylene is necessary, whilst under conditions demanding an oxidising atmosphere excess oxygen must be used.

In oxy-acetylene welding the molten metal is advantageously protected from atmospheric influence by the enveloping flame.

That gas welding is on the increase in undoubted, and what is happening in France may be taken as symptomatic of what is happening elsewhere. In a French article which appeared some time ago, it was shown gas welding had assumed almost equal importance to arc welding. In 1936 France consumed about 50 million arc welding rods. During the same period, for oxy-acetylene welding, she used 100,000 tons of calcium carbide.

4. **Arc Welding.**

As is well known, there are three methods of arc welding, viz., carbon arc, metallic arc, and atomic hydrogen. In the carbon arc process the arc is formed between a carbon or graphite electrode and the job itself. The heat of the arc fuses the base metal, and, if necessary, a filler rod is fused in. Metallic arc welding is substantially the same except that the rod serves a dual purpose, viz., that of electrode and filler. Atomic hydrogen arc welding is a process whereby an arc is struck between two tungsten electrodes in a stream of hydrogen gas. By this method the hydrogen molecules are split up into atoms, during which energy is absorbed, but in contact with the work this energy is given up as heat due to the atoms recombining to again assume molecular form. The temperature of this arc is very high, viz., 3500° C. approx., and what is a distinct advantage is that the
envelope of the hydrogen gas protects both work and electrodes from oxidation during the welding operation.

5. The Metallurgy of Welding.

In the early days of fusion welding by gas or electricity scant attention was paid to the metallurgical aspects involved in the art, and it was only when it was realised that welding was in effect a steel-making process, requiring observance of certain principles involved in heat treatment, that definite progress was made. Irregularity of results led to uncertainty and lack of confidence, so much so, that designers were grievously in doubt concerning safety factors. Gradually, however, fears are being dispelled and difficulties ironed out as a result of accumulated knowledge built up from investigation of past failures, and in recent years such has been the success obtained from welded structures in many fields that the future seems very bright indeed for this, the newest method of assembling structures.

In gas welding it has already been stated that the outer envelope of the flame protects the molten metal from atmospheric gases which permits the use of bare wire and secure fair results, but are welding has no such initial advantage. This disability has probably been a blessing in disguise, because it brought into use the coated electrode, the gradual and intelligent development of which has brought a great improvement in welding and given it considerable impetus.

In the manufacture of steel by the open hearth and electric arc processes, the metal is protected from atmospheric influence by a covering of slag, which in effect is what happens when using a flux-coated electrode. During welding the metal drops from the electrode in nodules, each of which represents a considerable ratio of surface to volume, and because of lack of insulation, these nodules are open to direct attack from atmospheric gases, mainly oxygen. When it is realised that the temperature of molten steel deposited either by gas or electric welding is very considerably higher than is obtained or indeed desirable in the open hearth or electric processes, and that the capacity of steel for absorbing oxygen, nitrogen or hydrogen increases as the temperature, it will be appreciated how important is the protection afforded by the fluxes forming the coverings of coated electrodes.

In an investigation made abroad on comparisons between work done by bare and coated electrodes, it was clearly shown that weld metal produced by bare wire exhibits on etching numerous gas holes, while that from a specially prepared fluxed electrode coated with a mixture of cellulose, ferro-manganese,
silicon flour, kaolin and sodium silicate, shows considerable freedom from such defects. (See Figure I.)

Examination under the microscope at 100 magnifications is equally conclusive, the section from the bare wire sample clearly showing the line of demarcation between the weld area and the parent metal, whilst in the case of coated wire the two areas merge into an almost homogeneous whole, with the junction barely distinguishable. (See Figure II.)

It need hardly be pointed out that the definite character of the junction at the welded area in the bare wire sample constitutes a generic weakness, and when sufficiently stressed, rupture would be practically certain to take place at that point, and in all probability follow the path of the joint or in close proximity to it. Figure III, which is an unetched sample at a magnification of 1000, shows gas holes and shrinkage cracks characteristic of a bare wire weld.

Nevertheless, despite the case that has been made out for covered weld rods, bare wire may be used quite successfully for many purposes, such, for example, as mild steel plates up to about \( \frac{1}{2} \) in. thick where a certain amount of ductility can be safely sacrificed.

The question of shrinkage and stress produced in welding are matters receiving increasing attention by research workers all over the world, and there seems no doubt that it is the amount of light shed on these problems that will determine the rate of future progress, particularly in connection with the higher grade high tensile steels. Internal cracks are liable to be set up due to cooling stresses, their incidence and direction being determined by the location of any shrinkage cavities that may be present.

Another important phase in connection with the widening applications of structural welding is that of fatigue. In the sphere of shipbuilding naval architects cannot afford to take undue risks, but our knowledge of this aspect has been so enlarged that before long welded joints will completely supercede rivetted in the construction of all classes of ships. An outstanding research on this problem is that contained in a paper read some time ago before the Institute of Naval Architects in London by Professor Haigh and T. S. Robertson. After testing various types of joint, they concluded that "the limiting alternating fatigue strengths for electric butt welds in boiler plates and in general structural work are approximately 0 + or — 11 and 0 + or — 6 tons per square inch respectively, while the corresponding figures for fillet welded lap joints with
shallow double joggles or deep single joggles are \( 0^+ \) or \( -4 \) and \( 0^+ \) or \( -2 \) tons per square inch, which are both probably in excess of the corresponding values for rivetted joints of ordinary qualities such as have served, and served well, in shipbuilding practice extending over several generations."

The limiting range of pulsating stress from zero upwards is stated to be almost 10 tons per square inch on ordinary welding. Higher values are obtained occasionally, yet seldom consistently, but the figures quoted are substantially better than can be expected in rivetted joints. Fatigue failure generally originates on welded structures at the edge of the parent metal due to the change in the micro structure caused by the intense heat input in producing the weld. This effect, however, can be greatly minimised by an intelligent interpretation and application of the art of heat treatment.

6. Failure of Welded Structures.

A welded structural failure upon which was focused the attention of the whole engineering world was that of the all-welded bridge over the canal at Hasselt, Belgium, early in 1938.

This bridge had a span of 244 ft. 6 in., and a total dead weight of 635 tons. Collapse took place while entirely unloaded. It would appear that four other bridges of similar construction have exhibited evidence of weakness where failure on this originated, viz., the gusset flanges, at which location cracks formed. Nevertheless, it would be misleading to assume the accident to be due to faulty welding per se without incontrovertible proof, since other causes may have been operating, such as faulty or unsuitable grade of steel or unrelieved weld stress at interlocking sections. If the failure took place when the atmospheric temperature was low, as seems likely considering the season of the year, this condition would undoubtedly accentuate any inherent brittleness either due to the steel itself or welding procedure.

In so far as the parent metal is concerned, it was stated by one of the interested parties that the sulphur and phosphorus contents proved to be higher than desirable for good welding. One notable aspect of the failure was the absence of deformation anywhere, which fact one generally regards as conclusive evidence of undue brittleness. As a result of this collapse, all welded bridges in Belgium are being systematically investigated by radiological examination, but if one may hazard an opinion, I should say it would be difficult, if not indeed impossible, to draw the line between a flaw that would render a structure...
dangerous, and one providing a reasonable safety factor. I do not know how this work is being conducted, but I consider it necessary in radiological work, when the type of job permits it, to make examination on at least two planes. Unless the method of investigation faithfully portrays defects to enable their degree of seriousness to be correctly interpreted and assessed, a difficult matter on some structures, due to their shape, then we might be better without the knowledge rather than permit ourselves to be lulled into a possible sense of false security. In the production of welded boiler shells at their works on the Clyde, Babcock and Wilcox submit all welds to radiological test, but in this case the examination is simple compared with what would be encountered in many general engineering structures. Even admitting, however, that the present-day high pressure boiler shells have to withstand stresses of considerable magnitude, on which account it is necessary to ensure efficient welding, these stresses are more or less static, whereas, on a traffic bridge such as the Hasselt Bridge, they would be both static and dynamic. The need, therefore, for the highest quality welding is perhaps more necessary in a bridge structure than even in a boiler shell. It has been suggested that had this bridge been rivetted it would not have collapsed. While this may be so, the failure should rather be regarded as one of the penalties we have to pay for progress, and when the lessons of this experience have been applied, there is no doubt that welded bridge structures will in future supersede rivetted in increasing measure.

7. Relief of Weld Stress.

There is, perhaps, no phase of welding exceeding in importance that of stress relief, and it is not overstating the case in the slightest to assert that its future development will largely be governed by the attention paid to this phase of the art.

In any welded structure stresses are produced by the selective heating of the parts being united, the magnitude of which are determined not only by the actual area being welded, but also by the thickness of the parts themselves. Such stresses can be relieved fairly effectively, if not completely, by resting, but, as this may in extreme cases take months, it is obviously impractical except in remotely isolated instances. The most effective method of minimising strain is by heating to a suitable temperature, constituting what is known as a stress relieving treatment.

While it is desirable, for metallurgical reasons, to heat the complete structure, this is not always possible. In such cases, even with fully heat-treated alloy steels, there are considerable advantages to be obtained by running over with an oxy-acetylene
or oxy-coal gas torch, an area enclosing two or three inches on each side of the joint. The temperature to employ is dictated by the composition and physical characteristics of the steel, but generally a temperature of approximately 600° C. is ideal, i.e., just visibly red in the dark. It should be clearly understood, however, that this treatment is purely and simply designed to relieve stress, and in a measure temper the hard zone, but it does not dissipate the coarse-grained structure which may be produced at the joint itself. To overcome this more or less brittle condition in cases demanding development of the highest properties requires a much higher temperature, say approximately 850° C., which treatment in a carbon steel over .35% carbon is best followed by a reheating to about 600° C. or in an alloy steel other than stainless to a temperature not exceeding the original tempering temperature. It should be observed, however, that temperatures in excess of 800° C. produce scaling and possible warping, the degree depending upon time and the method of heating. It will, therefore, be evident that for certain purposes these disabilities may constitute a definite barrier.

In a paper read by W. G. Theisinger in the United States an investigation to determine the stresses set up in welding steel plates was described.

One experiment consisted of hand welding two plates, 36 in. x 12 in. x \( \frac{1}{8} \) in., depositing several beads, and in another case machine welding two similar plates, depositing a single bead.

After welding, small tapered holes were drilled into both surfaces of the plate. These were made 2\( \frac{1}{4} \) in. apart in four series of lines across the weld. The distance between the holes on both sides of the plate was measured by a strain gauge reading to 0.0001 in., and the mean of each pair of readings recorded. The plates were then cut up into strips transversely to the weld, each measuring 24 in. x 3 in., and carrying two rows of holes on each of its surfaces. The distance between holes were again measured, and the mean figures noted for each pair.

The difference between the two sets of recorded readings showed the changes in length in units of 0.0075 in., which, based on the modulus of elasticity, represents a stress of 400 lbs. per square inch. The results were compared by means of graphs. Both plates were then stress-relieved by heating to 620° C., holding for 30 minutes at that temperature, after which measurements were again taken.

Prior to the heat treatment, a maximum residual stress of 20.5 tons per square inch was calculated at the middle of the weld, and the stress determined at the same point after the
heat treatment was only 1.8 tons per square inch. These experiments demonstrate clearly the high residual stress induced by welding and how it may be reduced to almost zero by suitable heat treatment.

Before leaving this phase, it is perhaps well to point out that when welding high carbon or alloy steels of air-hardening properties, it is highly desirable, and indeed necessary, as a preliminary step, to preheat the edges to be butted. This precaution will reduce the tendency to crack formation at, or adjacent to, the weld. Such a procedure is also essential when welding together two pieces dissimilar in thickness, otherwise a weak weld may result, due to differential cooling. Another danger likely to arise when welding two unequally sectioned parts not preheated, is that the extra heat necessary to raise the heavier section from atmospheric temperature to fusion point may cause undue burning of the lesser one.

8. The Economics of Welding.

In steel, chemical, shipbuilding, bridge building plants, and indeed in all general engineering, savings of considerable magnitude in the aggregate are being made by a wise adaptation of welding.

For purpose of maintenance alone, welding is indispensable in any modern steel works. Spindle wobblers, rollers for run-out tables, mill rolls and innumerable other parts of any steel works equipment can be quickly repaired or even extensively altered by welding. In so far as mill rolls are concerned, there are cases on record where a section or sections have been called for at short notice for which no rolls were available, nor would the expense of new ones be justified. Old rolls have been resurrected from the scrap heap, new passes cut, and built up by welding.

In the chemical industry welding has long since passed the experimental stage, and its utilisation in lieu of rivetting is now commonplace. Vessels for certain chemical processes are more advantageously produced by welding than rivetting, because unbroken inner surfaces can be obtained which leave no points for lodgment of material likely either to affect the efficiency of the chemical reactions or form starting points for corrosion. Vessels operating under pressures in excess of 600 lb. per square inch are now successfully and economically fabricated by welding, and, although in the early days, when the welding was done by hand, they were viewed with an understandable suspicion, the introduction of machine welding has
so increased the efficiency of such work that welded vessels are proving superior to rivetted units, and are preferred.

Both gas and electric welding are employed for the manifold uses of the chemical engineer, but it has been found that in contact with certain chemical solutions gas welding is unsuitable because subject to corrosive attack by the liquor, whereas electrically welded joints are immune. This attack is in all probability due to impurities introduced by the gases. On the other hand, where no such corrosive influences are at play, gas welding has proved perfectly satisfactory.

For purposes such as tubular heaters in the chemical industry resistance butt welding has proved particularly advantageous. By this method the electrodes form the clamps holding the two pipes against one another. Current is supplied from a transformer, the secondary windings of which are tapped at points providing up to about eight volts.

In the sphere of shipbuilding welding has made understandably slow progress, but sufficient experience has now been obtained, indicating very clearly the considerable savings that can be effected compared with rivetting. Perhaps the first ship of importance where welding substituted rivetting was on the German pocket battleship "Deutschland." The weight saved by the elimination of rivets in construction was used to augment her armament, thus making her a most formidable ship of war relative to displacement.

Until 1935 Lloyds were proceeding very carefully in the matter of welded ships, and had only approved of it as an experiment on some small ships and barges. It does appear, however, that these initial trials have been so successful that the welding of hulls is gradually being extended to larger units built under their rules and supervision.

In Germany, before the present war, where the need for economy was greater than in either Britain or America, a passenger ship of about 24,000 tons and some oil tankers to 15,000 tons dead weight capacity were assembled by electric welding. In the case of the passenger ship, the saving in weight amounted to no less than 1300 tons, equal to about 14% of the total weight of the hull. The economy in rivets was stated to be something like 1,600,000, and of steel for the bulkheads, tanks, decks and deck-houses over 400 tons. In an oil tanker of 15,000 tons dead weight it has been assessed that the total weight of the hull can be reduced by about 20% by the introduction of welding throughout.
Despite the failure of the Hasselt Bridge, in Belgium, already referred to, it is unquestionable that welded bridges are gradually replacing rivetted, and although so far such bridges have been comparatively small, there seems no doubt that as a result of the experience now gained, we will gradually witness larger and yet larger units being erected. Just what the limit will be may depend upon the compensations made for expansion and contraction. It is conceivable that a welded bridge will be more rigid than a rivetted one unless in the latter case the rivets are driven home absolutely tight hydraulically, a condition which despite contrary opinion, must produce a more or less fatigued condition of the rivet. On the other hand, if left a little on the loose side, which should be done except where watertight conditions are necessary, the structure will be less rigid, and therefore more accommodating to volume changes induced by variations in atmospheric temperature. The increase in the number of welded bridges at present completed and under construction is unquestionably due to the economies accruing from this method of construction.

In constructing the framework of a new railway station at Duisburg, in Germany, a straight comparison was made of the cost of rivetted and welding framing. The first rivetted frames constructed were 19.4 tons each in weight, whilst welded frames subsequently made for exactly the same purpose were only 14.3 tons each, a saving in weight of 5.1 tons, equalling 26.3%. Another and not unimportant feature of the comparison is that the welded frames are reported to have a distinctly better appearance than those assembled by rivetting, so that aesthetically, as well as economically, the advantage is with the welded structure.

9. **The Future of Welding.**

Even the most conservative and therefore partisan spirit of other types of construction cannot do otherwise than agree that, great as has been the development of welded structures in recent years, the future holds tremendous and almost limitless possibilities.

In the sphere of mechanical and electrical plant the scope is ever widening, and increasingly do we find castings and forgings which, by reason of complication in design, present manufacturing difficulties, being replaced by fabricated welded structures with completely satisfactory results. In steam generating plant the introduction of welding has not only revolutionised design in certain types of boilers, such as the Lamont, Velox, Sulzer Monotube, etc., but for repair work also it has proved effective
in extending the life of many units, such, for example, as the welding of new furnaces to the back tube plate in Scotch boilers and the cutting out of wasted plates, and butt welding replacements in the combustion chambers.

Sir Wm. Larke in 1938, in an inaugural address as president of the British Institute of Welding, said that: "In the case of dynamically loaded structures the application of welding in the manufacture of bed plates, entablatures, stator frames, armature hubs, rotors for electric generators, motors, turbo blowers, and similar structures has facilitated the development of units formerly produced as castings or forgings." For the propelling machinery in marine installations, where weight reduction without loss of rigidity is a most important factor, the greatest savings have been obtained in the fabrication of bed plates and engine frames in mild steel by means of welding. The application of welding to high pressure pipe joints has, in some instances, provided steam-tight joints where all other methods have failed.

Further evidence of welding development is the fact that dissimilar metals can now be united so that composite structures may be fabricated and components chosen as required to suit corrosion or heat resistance, strength and magnetic or non-magnetic properties.

Perhaps one of the most interesting adaptations of welding in recent years is that of the all-welded steel dwellinghouse in the United States. During the last war the Scottish firm of G. and S. Weir, famous for pumping machinery, introduced in Scotland mass-produced houses constructed from rolled steel plates, bolted together on site, and made ready for occupancy within 48 hours. One disadvantage, however, was the expansion and contraction that took place, due to seasonal changes of temperature. This has now been overcome to some extent in the American plan by eliminating all right-angled corners and having them well rounded, thus permitting designers to introduce internal linings such as plaster, etc., serving not only as insulation, but also enabling the decorative artist to exploit his art. In lieu of assembly on site, they can be welded in the factory and transported complete, if desired. Fig. 5 shows one such design, costing complete something like £1100 Australian currency.

Welded buildings, giving uninterrupted floor space by the elimination of pillars, have been constructed in England. One erected in London has an unobstructed floor area of no less than 52,000 square feet. The same is true in the United States, where
this method of construction is now incorporated even in the tallest structures. The building regulations of the cities of New York and Chicago permit working stresses of butt welds up to nine tons per square inch in tension. The London County Council fix the limit at eight tons. If one may indulge in the pastime of peering into the future, it seems indubitable that in the field of building construction alone welding will be adopted in ever increasing measure, the speed and extent of which will be governed by the degree of co-operation exercised by engineers, architects, welding technicians and metallurgists.

Reference has already been made to welding in the construction and fabrication of bridges. Due, no doubt, to the more pressing need for economy before the present war, greater progress was reported in the European countries in this sphere than anywhere else in the world. In 1938 the number of welded bridges in Europe with spans up to 350 feet was in excess of 700, and whilst the progress in Great Britain and America was not perhaps so rapid, it is reasonable to assume that there also all welded bridge structures are gradually superseding rivetted.

Turning now to shipbuilding, it is here that we may witness a more spectacular development than in any other phase of structural engineering. It is perhaps natural that Lloyd’s made a very slow approach to welded ship structures, because it must be remembered that one branch of this vast organisation represents possibly the greatest insurance group in the world, and on that account their technicians are not prepared, or indeed permitted, to adopt new ideas or developments until amply proved beyond all shadow of doubt. To commence with, welded barges for canal use were designed and their performances noted by the Lloyd’s staff. From that modest beginning the trials were extended to embrace interior fittings and bulkheads of sea-going ships, and prior to the war welding was permitted to a limited extent on the hull itself. In America similar caution was observed, but it was in that country that the largest all-welded ship, completed to the end of 1938, was built, viz., the ‘‘J. W. van Dyke,’’ a turbo-electric driven oil tanker of 18,500 tons dead weight, 522 feet long, with a beam of 70 feet and depth of 40 feet. Up to the end of 1937 56 all-welded vessels under 260 feet in length were in course of construction, and the following year many large units were under way.

It will scarcely be disputed that the greatest test of welding in shipbuilding is its employment for the hulls of tankers, which must be oil-tight. In this connection the following extract from a report presented to the American Society of Naval
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Architects respecting the performances of a small United States oil tanker is interesting: "When, therefore, one finds a tanker which has not leaked a drop over a period of three years, despite several groundings and collisions, and on which the only work to be done at the regular dry docking periods was the application of one or two coats of paint, it looks, to a tanker operator at least, like a big step in advance in the art of shipbuilding."

In naval construction the British Admiralty have sponsored a considerable amount of research work, and shown commendable enterprise. As evidence of the efficiency welding has attained in His Majesty's ships, you will recall the un-rehearsed test which took place in the H.M.S. "Hunter" a few years ago somewhere in the Bay of Biscay, when a violent internal explosion occurred with entirely satisfactory results to the welded parts.

The Admiralty's growing confidence in welding as a means of assembly is such that about 80% of the famous aircraft carrier "Ark Royal," of approximately 23,000 tons, was welded. Carrying the experiment a stage further, the sloop H.M.S. "Seagull" represents an entirely all-welded job, and on the performance of this ship the future of welding in shipbuilding for naval purposes, at any rate, will largely depend. In the large passenger ships "Queen Elizabeth," "Mauretania" and the "Dominion Monarch," the newest big ship placed on the Australian run, a considerable amount of welding has been done, but none, I believe, on the actual hull structure.

A very cursory examination of a ship's hull, assembled as at the present day by rivetting, reveals at once the tremendous drag offered to wind and water by rivet heads alone. When to this is added the eddy currents which form behind each of the hundreds of lapped joints, particularly below the water line, it will be realised how great is their cumulative effect in retarding speed.

Butt welding the plates and smoothing off all joints will effect not only a reduction in friction, but such a saving in weight that less power will be required for a given speed. Just how soon welded hulls will completely supersede rivetting for all classes and types of ships will depend not only upon the efficiency of the operators and the degree of supervision exercised, but also upon how far shipbuilders are prepared to go in ensuring all welds being suitably stress relieved.

There was never a time in history when shipbuilding has been of greater importance than to-day, and it may be assumed
that progressive organisations are seizing the opportunities offered of extending their experiments in welding and gathering valuable experience.

Important as are savings in weight and reduction in friction to ships, they are still more so on the modern all-metal aeroplane. A method of producing effective welds on non-ferrous sheets so extensively used in plane construction, and capable of being placed on a production basis, has not yet been found, hence the continued employment of rivetting, with all its attendant disadvantages and weaknesses. If, however, in lieu of white alloys, there is a complete change over to stainless steel, not only will there be saving in weight by taking advantage of its greater strength, but the all-welded aeroplane becomes nearer accomplishment.

As in all new developments, the scope of welding and the position it will occupy in engineering enterprises will be largely governed by the amount of research undertaken, and signs are everywhere evident that interested bodies are co-operating in this work to the fullest extent. When one examines a modern all-metal aeroplane, and realises the effect on its speed of the many thousands of rivets employed in assembly, it can be understood how important a part welding would play, and it is safe to predict that the aircraft of the future will develop into an all-welded job.

REFERENCES.


ADDENDUM.

EXPERIMENTAL WELDING OF TEST BARS.

With the object of determining the quality of welds obtainable from bare and fluxed electrodes, the following investigations were carried out on rolled plates:—

Three grades of steel were selected—
1. Mild Steel, in rolled condition.
2. High Carbon Steel, in normalised condition.
3. Nickel Chrome Steel, in oil-quenched and tempered condition.
WELDED STRUCTURES.

One test bar from each grade was retained in the above condition for the purpose of comparative tensile tests after the following welds were carried out on other bars:—

1. **Mild Steel.**
   (a) Electric weld with bare wire.
   (b) Electric weld with fluxed wire.
   (c) Oxy weld with bare wire.

2. **High Carbon Steel.**
   (a) Electric weld with bare wire.
   (b) Electric weld with fluxed wire.

3. **Nickel Chrome Steel.**
   (a) Electric weld with bare wire.
   (b) Electric weld with fluxed wire.
   (c) Oxy weld with bare wire.

Tensile tests were prepared which produced the following results:

<table>
<thead>
<tr>
<th></th>
<th>Ult. Stress</th>
<th>Elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>tons per sq. inch</td>
<td>on 2 in.</td>
</tr>
<tr>
<td><strong>1. Mild Steel—Unwelded</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) Electric weld, bare wire</td>
<td>30.30</td>
<td>10.0%</td>
</tr>
<tr>
<td>(b) Electric weld, fluxed wire</td>
<td>26.69</td>
<td>42.0%</td>
</tr>
<tr>
<td>(c) Oxy weld, bare wire</td>
<td>17.43</td>
<td>25.5%</td>
</tr>
<tr>
<td><strong>2. High Carbon—Unwelded</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) Electric weld, bare wire</td>
<td>48.3</td>
<td>3.0%</td>
</tr>
<tr>
<td>(b) Electric weld, fluxed wire</td>
<td>11.07</td>
<td>23.0%</td>
</tr>
<tr>
<td><strong>3. Nickel Chrome—Unwelded</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) Electric weld, bare wire</td>
<td>61.8</td>
<td>11.5%</td>
</tr>
<tr>
<td>(b) Electric weld, fluxed wire</td>
<td>18.9</td>
<td>3.0%</td>
</tr>
<tr>
<td>(c) Oxy weld, bare wire</td>
<td>22.78</td>
<td>2.5%</td>
</tr>
</tbody>
</table>

**Microscopic Examination.**

Sections showing the weld were taken and examined under the microscope at 100 magnifications.

**Mild Steel**—The three welds—two electric and one oxy—all show a fairly extensive thermally disturbed layer at the weld junction.

**Fig. 6—Electric weld, fluxed wire**—
Weld very dirty, grain size of the parent metal rather large.
Fig. 7—Electric weld, bare wire—
Weld very dirty, grain size of the parent metal smaller than Fig. 6.

Fig. 8—Oxy weld, bare wire—
Some large inclusions present in weld.
Grain size large, due to extensive heating in effecting this weld.

High Carbon.
Fig. 9—Electric weld, fluxed wire—
Weld good, grain size of weld and parent metal very small.

Fig. 10—Electric weld, bare wire—
Weld good, grain size of parent metal medium.

Fig. 11—Oxy weld, bare wire—
Weld rather dirty, numerous gas holes. Grain size large, heating has again been excessive.

Nickel Chrome.
Fig. 12—Oxy weld, bare wire—
Weld good, effect of welding has produced a martensitic structure in the original bar.

Fig. 13—As above. Tempered at 600° C.—
The effect of tempering is clearly evident from the spheroidised structure. Weld metal shows tendency to form dendrites.

Fig. 14—Electric weld, bare wire—
Weld good, grain size of weld and parent metal small. Slight tendency to form martensite.

All the foregoing welds were performed by an average operative without any special instructions. The physical test results are interesting, and reveal the high efficiency attainable when dealing with mild steel. It is apparent, however, that by ordinary methods, in the case of the higher-strength, high carbon and nickel chrome steels, there is a marked falling off in properties irrespective of the type or grade of electrodes used. These deficiencies can, however, be overcome by investigation directed towards effecting an improvement in technique not only respecting the actual welding operation itself, but in preparation for it and the subsequent treatment.

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