The Origins and History of Metal Joining Processes

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THE ORIGINS AND HISTORY OF METAL JOINING PROCESSES

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A C K N O W L E D G E M E N T S

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Patrick O'Neill

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P R E F A C E

The purpose of this paper is to show the development of metal joining processes. Part I deals with early metal joining processes, those processes known as soldering, forge welding, casting in various metals, hammer welding, which were the most commonly used up to the latter part of the nineteenth century. The scope of this section is very broad and covers more than 2,500 years, circ 700 B.C. to circ. 1800. The examples described were all found in Ireland, and whereas the particular technology being described may have been in use elsewhere in the world before it's introduction here, the exact timescale of any discovery in this section is not that important, because the progress of metal joining technologies was rather slow, principally because of the primitive methods used and of the imperical technical knowledge available. The latter part of this section deals very briefly with developments from the 15th to the 19th century. It is not dealt with in more depth because, I feel, it is already covered adequately in other texts dealing with the period, indeed there are many fine examples still in use today, such as cast iron railway bridges, wrought iron gates and railings both inside and outside churches and public buildings. Part II of this paper deals with the introduction of arc welding and some of it's many branches and variations. The effects of the introduction and development of this process of joining metal has been a major influence on how we view our lives. It has made it's impact through industry, by providing a means by which a multitude of domestic and capital products could be mass-produced. On the domestic front, such products as electric toasters, stainless steel sinks, cookers, fridges, scales and kitchen utensils, etc. It has had a very significant effect on industrial production rates of capital equipment in such areas as shipping, transportation, communications and has made possible the development of such products as the concorde, the space shuttle, and many more. Welding as we know it today did not just happen, it was developed from it's small beginnings, less than 100 years ago, to what has become a major industry today, where it has changed the way in which, for instance, a designer will conceive a new product he is designing where metal components are concerned. He can view his product as one continuous item, which can be broken down into the necessary number of components for ease of production and reassembled as one continuous item at the assembly stage.

Bearing these and other effects of this process in mind, I proceeded to investigate the origins and early development in it's experimental stage and also where possible, its early use as an industrial tool. Where possible, I have used interviews and personal recollections by actual inventors of particular processes, or early users of particular processes as a means of discussing the invention and/or it's early application. There is a glossary of technical terms and definitions included to help any reader who may be unfamiliar with some of these terms.

1. EARLY METHODS OF WELDING AND JOINING METALS

I Late Bronze Age

Welding, which is one of the newer metalworking trades, can trace its historic development back to ancient times. Some of the earliest examples available come from the late Bronze Age. These are small circular gold boxes apparently joined by the pressure welding of laped flanges at the edge of two dome shaped sphere segments, to a cylinderical centre strip piece. These boxes were made approximately 700 B.C., and examples are on exhibit at the National Museum of Ireland in Dublin. The function of these boxes is not clear, as once they were made, they became a sealed unit and could not be opened. See figs. 1, 2 and 3, which show a top, side and bottom view of one of these boxes.

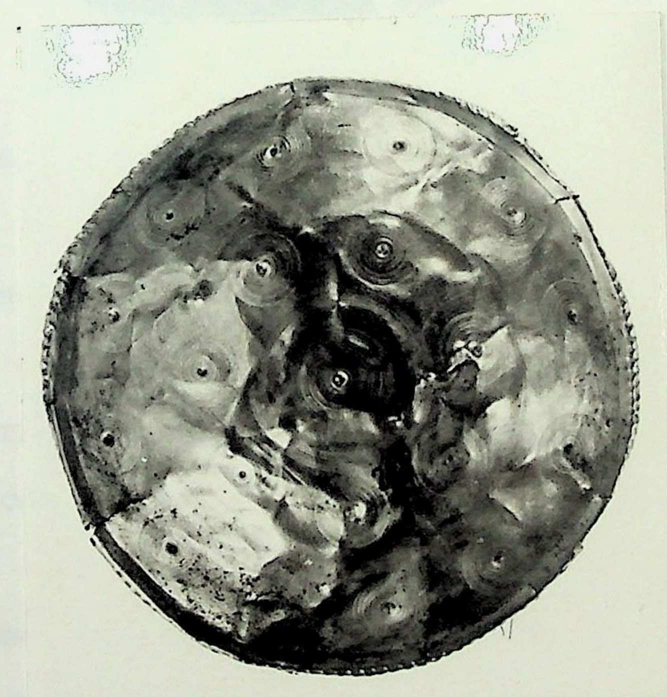


Fig. 1. Top view of Gold Box from National Museum of Ireland (I.M.I.) 700 B.C.

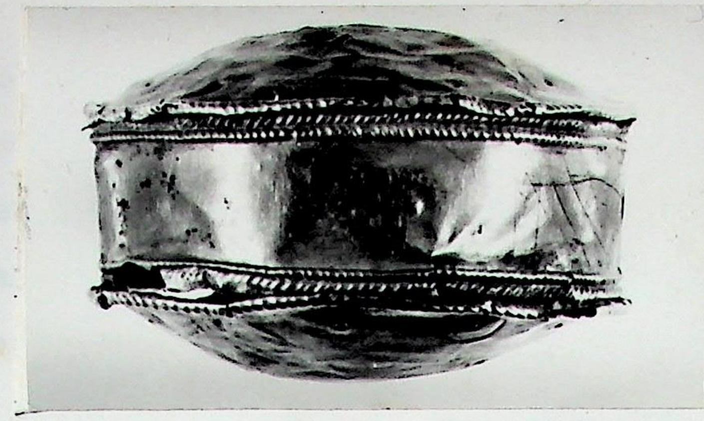


Fig. 2. Side view of Gold Box from N.M.I. 700 B.C.

Fig. 3. Bottom view of Gold Box from N.M.I. 700 B.C.

Found in a reclaimed bog at Ballinclemesig, Near Ballyheigue, Co. Kerry. The lid and base are decorated with a pattern of concentric circles, each with a central conical boss.

Also, from the same period (700 B.C.) we have a pair of gold lock rings. (See Fig. 4.) These gapped conical ornaments, thought to have been used for holding hair in place, are examples of intricate and skillful workmanship. "They are constructed of four main pieces: a central split tube, two gapped conical faceplates and a circular binding strip. The central tube is slit vertically and the cut edges folded back; the top and bottom curve outward around a supporting wire to grip the folded edges of the faceplate.

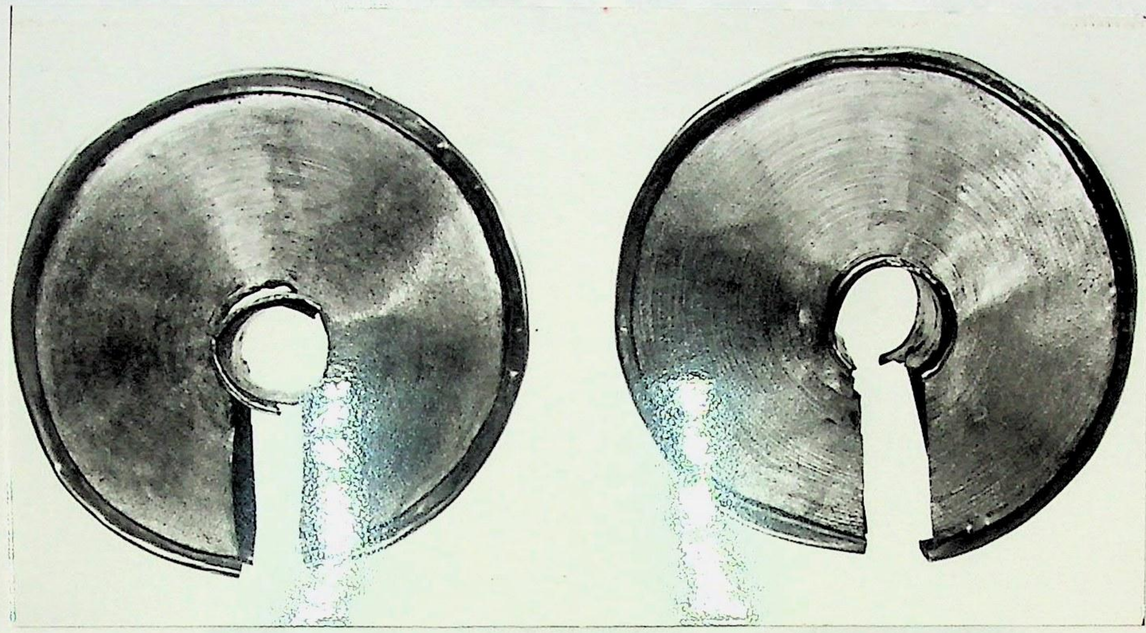


Fig. 4. Showing plan view of gold lock rings. N.M.I.

These tubes are decorated with horizontal double rows of small punched bosses for gripping the hair. Each faceplate is built up of threadlike wires (approximately three per millimeter) soldered together. The work is so fine that the closely spaced circles appear to have been incised on sheet gold, but the wires can be seen on both outer and inner surfaces. On the outside, excess solder has been cleaned away from the grooves between the wires; on the inside droplets of solder can still be seen. There are some indications that the wire itself was made by twisting a narrow strip cut from the edge of a thin plate. The surrounding binding strip is a split gold tube held in position by inserting the splayed-out edges of the plates between it's rolled-in edges. One of the ornaments still retains reinforcing wire within the tube."[1] These were found with two gold bracelets, a gold collar and an example of the group termed fibulae. It is interesting to note that, though presumably from the same workshop and made at the same time, one contains 22% silver, 9.6% copper and 1.5% tin, while the other has 15% silver, 11.5% copper, 31% tin and 0.5% lead. One pendant is 9.8cm in diamater and 5.2cm wide at the centre, the other is 9.8cm in diameter and 5cm wide. These were found in Gorteenreagh near Feakle, Co. Clare. (see Fig. 5.

Fig. 5. Showing gold lock rings (Dowris Phase) circa 700 B.C.

Many items of bronze have been found from this and earlier periods. One example is a dagger which dates from 1,200

B.C. and was cast from bronze in a one or two piece stone mould. It would have been rough cast in stone firstly and then finished off by hammering excess flashing away and forming the blade edges. Down a central tapering ridge is an incised V shaped design. The purpose of this ridge is to give the blade added strength. (See Fig. 6.) "Very few Irish copper/bronze objects were made by hammering alone and it is probable that metal-working, when introduced to Ireland", (about 2,000 B.C.), "had already proceeded beyond the purely experimental stage. Objects were cast at first in open stone moulds but soon two-valve moulds were being made. Many are composed of fine grained sandstones, but it is a mark of the expertise and the enquiring nature of the Irish craftsman, that in order to get the finest material possible for his moulds, he used aplite, a stone which is found bedded relatively deeply in the granite formations" [2] Another example similarly made but dating from 1,800 B.C. is a spearhead, (See Fig. 7.) It has four holes at the shaft end which were probably used to secure it to its shaft. This argues for a superb knowledge of the environment and for a very close communion then between man and nature. "Stone for moulds was, from about the middle of the Bronze Age onwards, that is, from about 1,000 B.C., supplemented by clay and expecially when hollow casting became common in the cire perdue or waste wax process".[3] An example of hollow casting using a clay core is shown in Fig. 8. This is a detail of a trumpet or horn from the late Bronze Age 600 - 700 B.C. It shows a joint on the neck of the trumpet/horn which would have been cast in shorter lengths

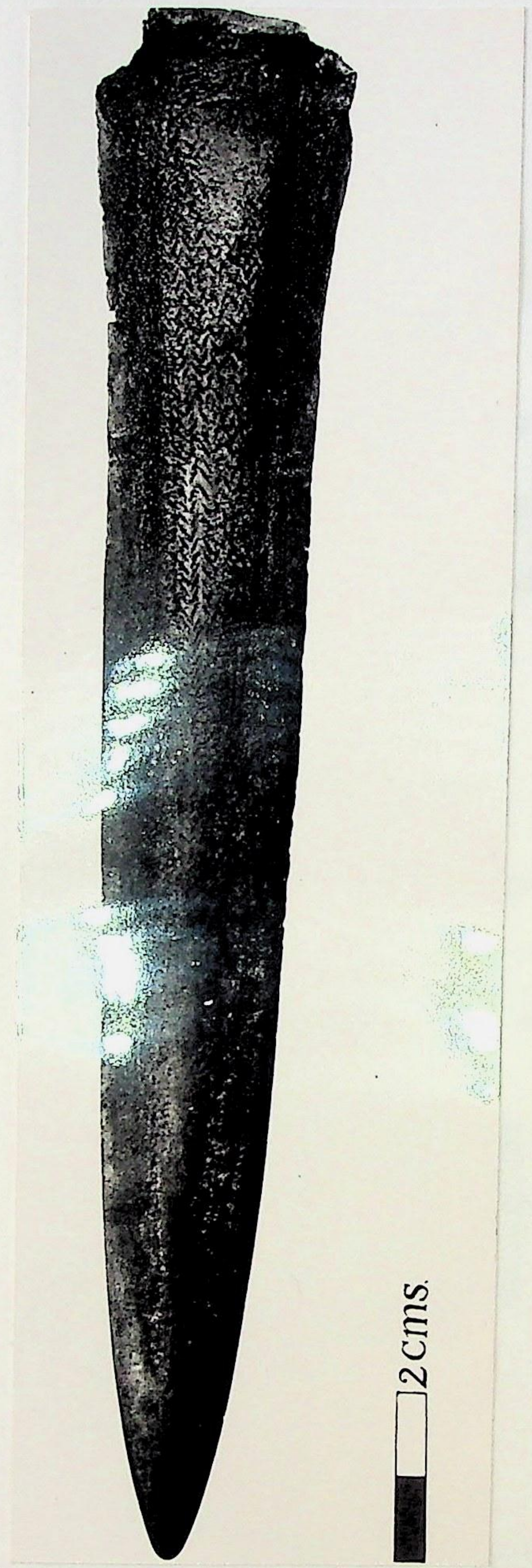


Fig. 6.

Knife 1,200 B.C.

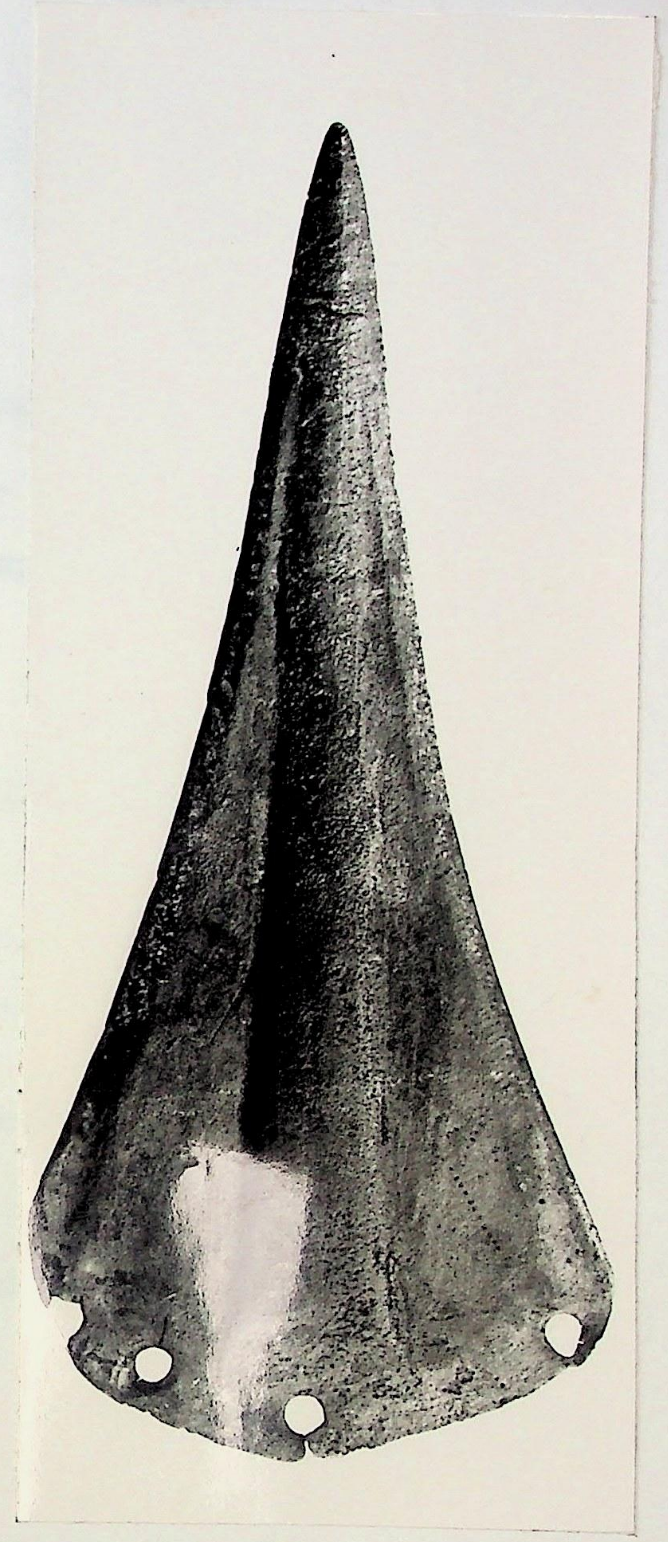


Fig. 7.

Spearhead 1,800 B.C.

due to the complexity of making a single core, which would run along the entire length of the horn. The construction of this joint as an alternative is very complex in itself and further demonstrates the level of skill reached at this time. The joint was prepared as follows: Firstly, the two sections to be joined were cleaned and aligned to check dimensions Fig. 8.A.

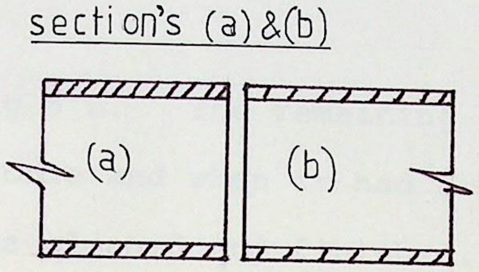


Fig. 8 A

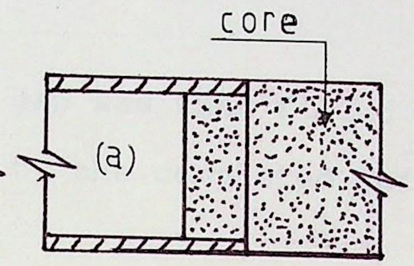


Fig. 8 B

Then a core of suitable dimensions was made up and matched to section (a) as in Fig. 8 B. Around this was then cast the main part of the joint (c) as in Fig. 8 C. When the component had set the core was

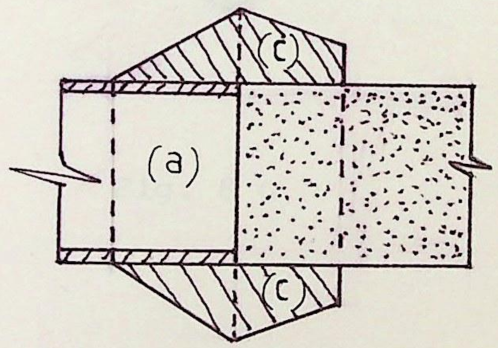


Fig. 8 C

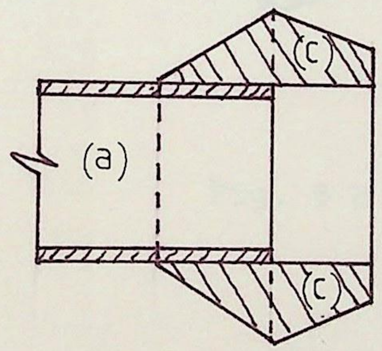


Fig. 8 D

removed and section (a) looked like Fig. 8 D. Meanwhile section (b) received a plug, as per Fig. 8 E, into which the second part of the joint was poured Fig 8 F. After this set, the plug was discarded and Section (a) and (b) were joined as in

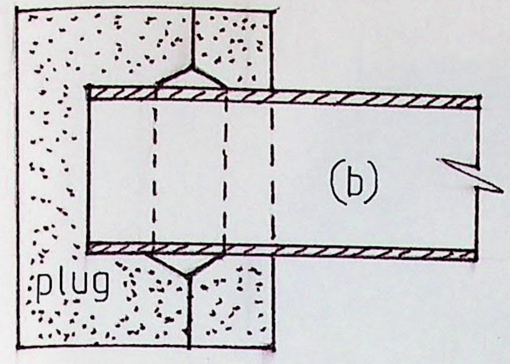


Fig. 8 E

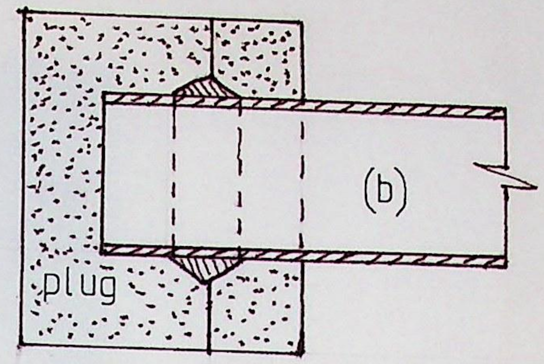


Fig. 8 F

Fig 8 G. The remaining gap was then filled with molten bronze and when it had set, the completed joint Fig 8 H was cleaned and finished.

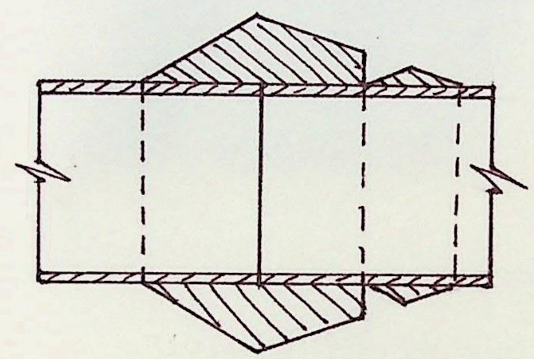


Fig. 8 G

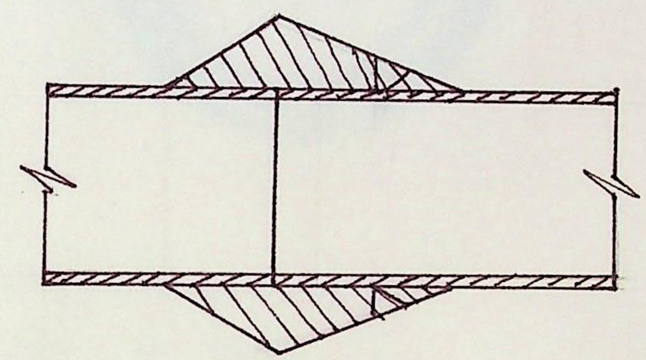


Fig. 8 H

Fig 8. Detail of horn/trumpet joint.

Late Bronze Age 600 - 700 B.C.

Fig. 9 Bronze Axehead 750 B.C.

The above socketed bronze axehead (Fig. 9) is made from a clay mould and is of the late Bronze Age, circa 750 B.C. It's lack of artistic embellishment would indicate a utilitarian, rather than decorative, use. The loop at the top was probably used to help secure it to it's handle. "The bronze smiths of the time were, it would appear, so familiar with their raw materials and with measuring quantities, that, by varying the proportions of tin or arsenic of antimony, they were able at will to change the degree of hardness of alloy and to vary, for aesthetic purposes, its final colour from, say, the harsh red of a vibrant copper to the shining gold of a tin-rich bronze". [4]

II. The Iron Age

The Iron Age commencing in Ireland perhaps about 300 B.C., or so, was a period of new techniques. There is no reason to suppose that there was any marked change in the social structure of the people or in their manner of living. The means of production had certainly improved because the raw material for iron, the new metal, was available over large parts of the country and soon, the blacksmith became a person of great importance within the community as a whole. Many everyday objects were produced by these smiths at relatively low cost. Examples of this type of product are shown in (Fig. 10). These are two wood saws made of iron, approximately 700-800 A.D. They would have been hammer forged from rough ingots of iron. The saw teeth would have been relatively soft and in need of frequent reshaping and sharpening.

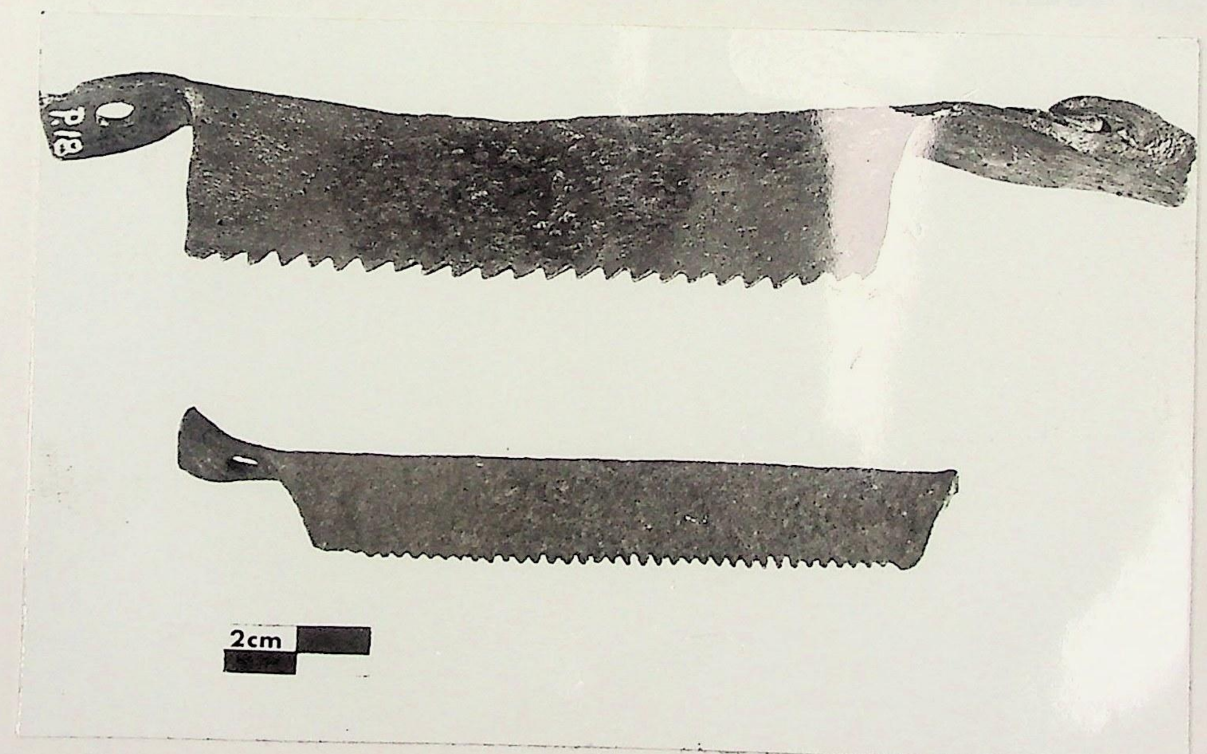


Fig. 10 Iron wood saws circa 700-800 A.D.

III. The Middle Ages

During the Middle Ages the art of blacksmitting was developed to a high degree and many items of iron were produced which were welded by hammering. This development was going on, on a global level and in fact any development in Ireland only tended to reflect developments imported from Europe. Welded sword blades were developed during the Middle Ages, and the most famous of these being produced by the Arab armouries at Damascus, Syria. The process of carbonization of iron to produce hard steel was known but the resultant steel was very brittle. The welding technique, of interlayering relatively soft and tough iron with high-carbon material, followed by hammer forging, produced a strong, tough blade. Many such items from this period have been found in Ireland, although not necessarily made here. Three such examples follow and are briefly described.

Fig. 11. Axehead. Forge welded in iron with silver inlay.

Fig. 12. Viking Sword 900 A.D. Forge welded with silver inlay. The blade was forged by interlayering soft and tough irons to give a hard yet flexible finish.

Fig. 13. Iron axe bearded type.
Forge welded 1,300 A.D.

By the end of the 14th. centuary, the methods of joining metals were (1) either to cast a metal joint over two components by methods like or similar to those described for Figure 8, (2) to forge weld pieces of iron together (3) to solder pieces of metal together, although soldering was not of much use where large components were concerned, as this method provided a relatively weak joint, as no actual fusion between the two parent metals occurred and (4) the use of rivets.

Man developed these methods of metal joining over the next couple of hundred years. The major contribution being the introduction and extensive use of cast iron. Whereas this was a major achievement in economic terms, because it provided a relatively cheap material for the construction, engineering and mining industries. The range, type and quantity of products produced by cast iron is vast and well documented in texts dealing with the industrial revolution. As no fundamental change in the method of joining metals occurred with the introduction of cast iron, I do not propose to deal with it in this paper.

Up until the invention of arc welding and gas welding, towards the end of the eighteenth century, the methods of joining metals were as follows:

1. To cast separate components of a product together i.e. cast iron structures.

2. The use of rivets to join plates together i.e. cast iron structures.

3. To use lead or solder as a means of joining dissimilar metals i.e. cast iron to wrought iron.

4. To join separate wrought iron components by using forge welding as a medium.

5. To cast a joint around two separate components. Whereas these methods are quite effective, it is only with the introduction of electric and gas welding that a basic change in the method of joining metals and as a consequence, a change in the method of design of products occurred.

2. HISTORY OF MODERN WELDING PROCESSES

I PRELIMINARY NOTES ON THE HISTORY OF ELECTRIC AND GAS WELDING.

In the development of welding it is well to remember some significant dates, with a brief description of relevant events which occurred. This should also serve as an introduction to some of the terminology used in this section, with which some readers may not be familiar.

"1774 Discovery of oxygen. Prientley working in England, Scheele in Sweden. About the same time Lavoisier made his contribution to the Theory of combustion which as far as welding was concerned

1837 was crowned with the discovery of acetylene by Edmund Davy in 1837.

The Germans claim that Lichtenberg, writing to

1782 a friend J.A. H. Reimanius in 1782, says in his letter:-

' Presently I have arranged the characteristics of artificial electricity in another way which until now only the electric arc (lighting) could do. That is, I melted a watch spring and the blade of an English penknife in such a way that a part of the watch spring and the knife edge joined together'.

It would appear that Lichtenberg was the first welder.

1806-1809 Sir Humphry Davy discovered that an arc could be created and maintained between two terminals of a high potential electric circuit.

1841 J.P. Joule discovered the relationship between heat, current and resistance (H = 1^2 RtK) and by
1857 made the first resistance weld in England. This was by direct current there being no contact resistance.

1887 Elihu Thomson described experiments to the Franklin Institute in Philadelphia. He described how he passed current of high potential through the fine windings of an induction coil and received current of low potential. He observed that the ends of the wires from the course winding had joined together and this suggested a means for joining metals.

1883-1885 Elihu Thomson worked on experimental resistance welding machines.

1886 Thomson applied for first resistance welding patent.

1888 He founded Thomson Electric Welding Co.

1889 C. C. Coffin took out a patent on flash butt welding.

1890 Coffin's patents on spot welding using copper electrodes.

1897 First patent on projection welding.

1881 Auguste de Meritens first fused the heat of an arc between the workpiece and a single carbon electrode. He connected the positive side of the circuit to a plate which supported the work while the carbon electrode served as the negative pole, and with this he joined together parts of lead storage battery plates.

1885 Benardos and Olewski (Russia) saw the potential in de Meritens' discovery and they obtained a patent using a single carbon electrode tool.

1887 Benardos proved that the carbon arc could be used for joining ferrous metals and successfully demonstrated this as a repair method.

1889 C. C. Coffin improved upon Benardos' method by using a twin electrode process which not only melted the filler metal but also supplied sufficient heat to cause extended fusion of the base metal.

1889 Slavianoff worked out a similar repair process - an arc casting process for filling holes, cracks and defects in castings.

1907 Kjellberg began his work on electrode coatings. His patent application claimed the 'application of a heavier electrode coating which resulted in a simple and practical method of welding whereby the welding of joints on the lower side of objects can be easily effected' and he also claimed that the coating material could be formulated so that it 'effects mechanical or chemical changes'. Oscar Kjellberg was the founder of the firm of ESAB Ltd., and from the beginning ESAB electrodes have always carried the designation OK after the initials of the founder.

About the same time an analytical chemist and consultant, A.P. Strohmenger whilst working for two clients became involved in experiments on arc welding being carried out by an engineer called Slaughter. Strohmenger analysed the wash coatings on some of these electrodes and suggested to Slaughter that he might try wrapping the welding wire with some blue asbestos which he happened to have on his bench, the property of the Cape Asbestos Co. (also a client). The result was an instant success, more so since the arc would run on a.c. whereas the wash-coated wires would not. Strohmenger showed his new process to Professor Sylvanus P. Thomson of London University, who expressed the opinion that the arc was not a normal metallic arc and christened the process Quasi-arc.

1912 Further Kjellberg patents which described more specifically the electrode materials, coating, minerals for slag formation and various ferroalloys, all of which were claimed to have some effect on weld properties. Welds were superior to those made from base electrodes.

1927 Solid electrodes made by A. O. Smith for its own use.

1929 Made commercially by Lincoln Electric Co.

1930 Iron powder, cellulose and titanium were finding greater use in creating materials while use of silicate asbectos, fluorspar and lime was declining.

late 1920s-1930 Metallic arc welding growing fast. Greater thought given to designing structures for welding, e.g. ships, tanks, buildings, pipelines, bridges and other structures were welded successfully.

1931 Welding codes were adopted for all-welded power boilers and unfired pressure vessels.

In the same year a report, which established the safe stress limits in steel structures, was approved. Although ovygen had been discovered in 1774 and acetylene in 1837 nothing emerged until

1884 Wroblewski and Olszewski discovered a means for liquefying air.

1890 Oxygen produced by electroysis of water.

1893 Dr Carl von Linde worked out the technical details on equipment for producing liquid air - the source for commercial quantities of oxygen.

1892 Thomas L. Willson in Spray, North Carolina, performed some experiments in which he heated lime and carbon in an electric furnace. The product of this reaction was a hard substance from which gas evolved when immersed in water. The substance proved to be calcium carbide and the gas acetylene.

1895 Le Chaterlier described to the French Academy of Sciences how he obtained a flame temperature of 6000 to 7000^{O}F by the combustion of acetylene with oxygen.

1901 Fouche and Picard in France designed a suitable torch which drew acetylene from a cylinder under pressure of 15 p.s.i.

1903 Fouche developed another torch for use with a low-pressure acetylene generator.

1904 Calcium carbide production was high enough to satisfy the acetylene requirements of industry but oxygen production was lacking.

1907 This deficiency in oxygen production was overcome when Linde Air Products Co., built the first commercial plant in America.

1895 C. Vautin whilst experimenting with methods for reducing metals from their oxides, found that a cold mixture of metallic oxide and powder aluminium, when ignited, would supply enough heat to propagate the reaction throughout the mixture. A single reaction lasted about 30 seconds and gave rise to a temperature of more than 5000°F. This was the beginning of thermit welding. As the result of which Dr Hans Goldschmidt applied Vautin's process in a practical way by welding together iron bars.

1902 Goldschmidt obtained a patent and introduced it to the USA and it proved effective for repairing rails, ship rudders, mine equipment and other objects.

1934 Submerged arc welding, which permitted the use of high current densities, first used commercially at the Consolidated Steel Co., Los Angeles. Since this time, submerged arc welding and inert-gas processes have assumed greater importance. It is interesting to note that the idea of using an inert gas for weld protection goes back to 1980 when CO_2 was proposed.

1920	Hobart and Devers studied the effects of various gases on an electric arc and reported that helium and argon were satisfactory for weld protection.
1930	Basic patents for welding with helium or argon as a shielding gas using a refractory electrode were granted to Hobart and Devers but this process was not commercially taken up until
1940	when Northrop Aircraft Inc., used the process for joining magnesium and magnesium-alloy assemblies.
1948	Feeding of a continuous consumable rod into a blanket of inert gas had been considered for many years but it was not until 1948 was a practical method developed by Air Reduction Sales Co." [5]

II Arc Welding Early History

From the preceding list of events we can extract the more relevant ones and deal with these in more detail. The first noteworthy event was the work done by Sir Humphry Davy in 1808. "An advance of great importance was the introduction of the electric carbon arc, which was exhibited in experimental form in 1808 by Sir Humphry Davy. Davy used a large battery to provide current for his demonstration, since no means of mechanically generating electricity had yet been developed. In principal an "arc" of current across the gap between two rods of carbon heated the tip of the positive carbon to brilliant incandescence. As the carbon rod gradually vaporized they had to be continually adjusted to maintain a constant gap. The use of carbon arc was not practical until some 50 years later, when adequate generating sources were developed." [6]

The first practical use of the electric carbon arc effect was developed by the Paris Opera, who made use of it to develop the effect of - a beam of sunlight - as early as 1846. By 1860, the Paris Opera had also developed a lighting machine, a rainbow projector and a luminous fountain. Most important, the company made the earliest spotlight, a carbon arc and reflector housed in a hood, which included a lens and a shutter.

It was not until 1885, almost 80 years after the Davy experiment that Nikolas Von Benardos and Stanislav

Olewski, both Russians, patented the first process for arc welding. It is not known what part S. Olewski played in the invention, although his name is on the patent. The essential features of the invention were formulated as follows, in Patent No. 11982:-

"'The subject of the invention is a method of joining and separating metals by the action of an electric current, and is called the "Elektrogefest" method. The method was based on the direct use of a Voltaic arc between the point at which the metal is to be treated, this metal being one of the electrodes, and the holder, containing the other electrode connected to the appropriate pole of the electric current, when this holder is brought up to the metal. The following operations can be performed with this method: components can be joined together, metals can be separated and cut into components, metal can be drilled or holes and spaces made in it, and layers of metal can be deposited'.

Sometimes the 'Elektrogefest' method is identified with welding with a carbon electrode; this is incorrect. The patent states that the electrode can be made of carbon or other conducting substances. The technological part of the invention is worked out in extreme detail, and this is confirmed by the drawings which were appended to the application (Fig.15). Drawings 1 and 2 are electrode holders; 3, 4 and 5 are semi-automatic machine with a shielding glass, a stopwatch and a toothed rack for making interrupted welds, and smooth rails for continuous welding; 6 is a frame with rails; 7 is a work bench; 8 - 15 are examples of interrupted spot joints and continuous joints; 16 and 17 are examples of cutting; 18 and 19 depict metal

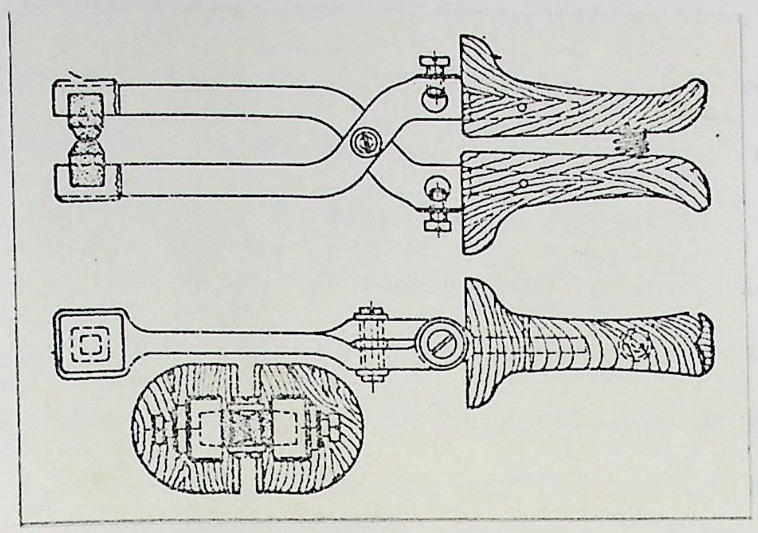


Fig.14. Spot welding pliers.

deposition; 20-22 are welded structures made of corrugated iron; 23 is a corrugated iron block filled with resin or cement, to be used as a component part for engineering structures; 24 shows the deposition of lettering; 25 is armour plating for ships. Quite obviously, this invention was well thought out, thoroughly checked, and the result of prolonged hard work.

N.N. Benardos also invented other methods of electric welding, most of which were not put into use until our times. Among them are: gas-shielded arc welding (several variations), the indirect action welding arc between two or more electrodes, under-water arc cutting, automatic carbon arc welding machines, and automatic machines for metal arc welding (several systems); magnetic control of the arc and magnetic welding tables, also welding with the electrode inclined; spot and seam welding (several methods). Figure 14 shows the manual pliers for spot welding invented by Benardos; arc welding with molten filler metal, a method developed in our times; arc welding electrodes made of wide range of materials (carbon, metal and composite) and of many shapes (rods, discs and tubular electrodes, including cored electrodes), and welding fluxes; a.c. arc welding, the spiral welding of tubes, arc welding with the welds peened or pressed, and the heat treatment of metals using the arc for heating; dip and furnace brazing, the casting and surfacing of metals; electric casting and incandescent brazing, the hydroelectric melting and heating of metals to white heat, electric brazing torches (several original designs) and a method of electric brazing for sheet metal".[7]

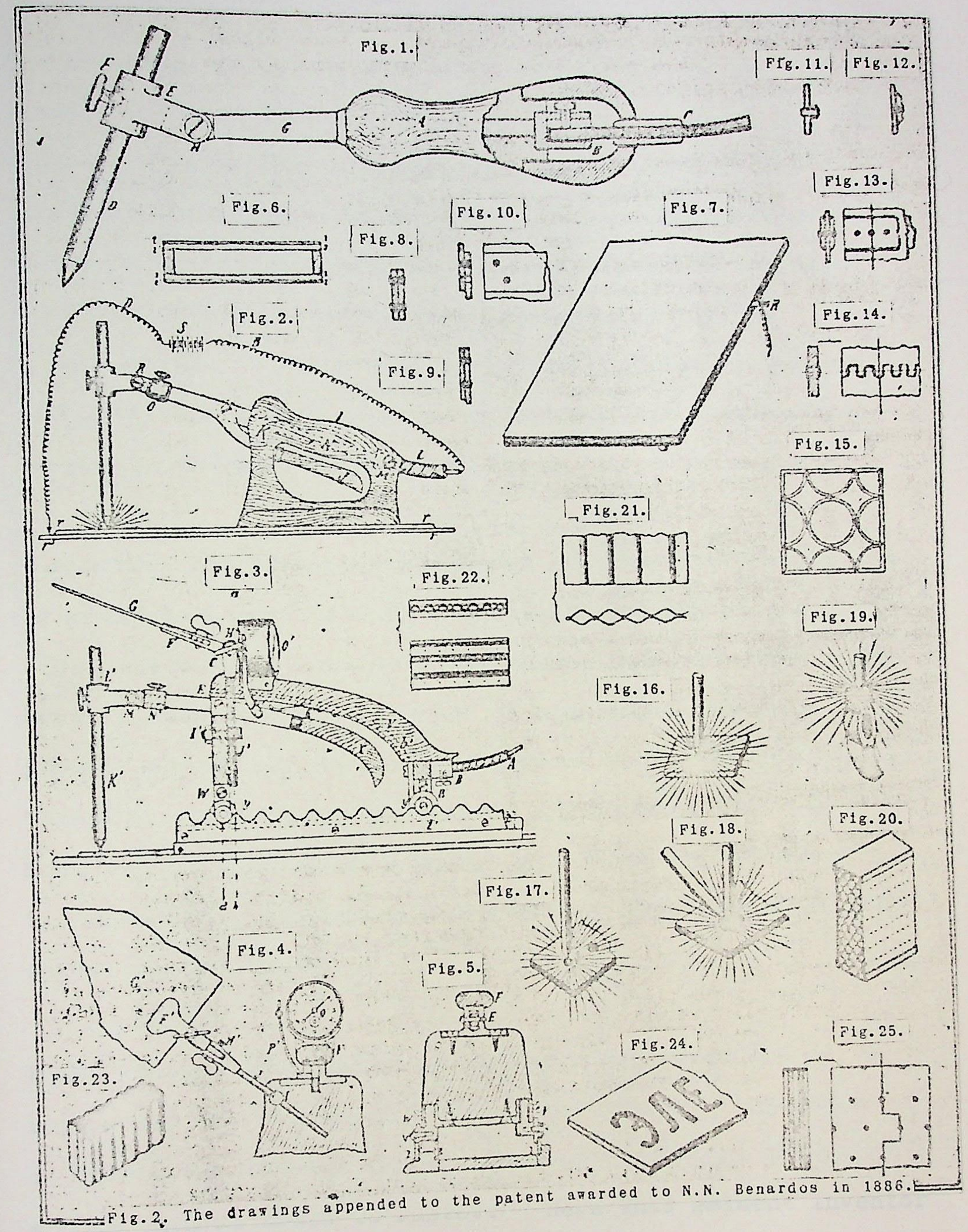


Fig. 15. The drawings appended to the patent awarded to N.N. Benardos in 1886.

From the range and scope of work produced on the subject by Benardos, it would be correct to say that he was the Founder of most modern welding processes. He was not as successful with his personal finances. In fact, his greatest invention, arc welding fell into the hands of a group of businessmen, and he was actually precluded from developing this invention further and putting it to practical use. Even these businessmen, however, proved too small for such a task and quite soon the venture died in Russia and was taken up in Europe.

"Benardos' financial circumstances continued to deteriorate. He could no longer live in St. Petersburg, and in the late 1890's he moved to the town of Fastov, close to Kiev. We have no records of this period of his life. Extreme poverty forced the inventor to appeal to the Russian Technical Society for assistance; in October, 1902, this Society adopted a resolution to appeal to the Government for material assistance for Benardos. The results of this appeal are not known.

Heavy labour, constant privation and lead poisoning undermined the health of Nikolai Nikolaevich. He lived in Moscow for about a year, undergoing treatment in hospital and he then returned to Fastov. Here this eminent inventor died on 8 (21) September, 1905, at the age of 63, and was buried in the parish cementery. His death passed practically unnoticed during the stormy period of the First Russian Revolution."[8]

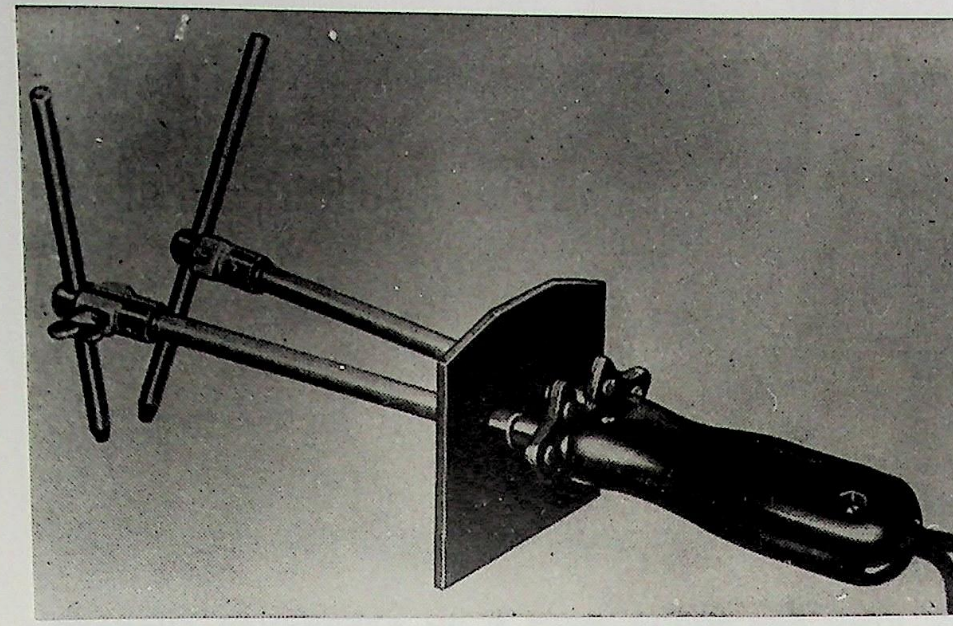


Fig. 15A   Multiple-Arc Welding Gun.

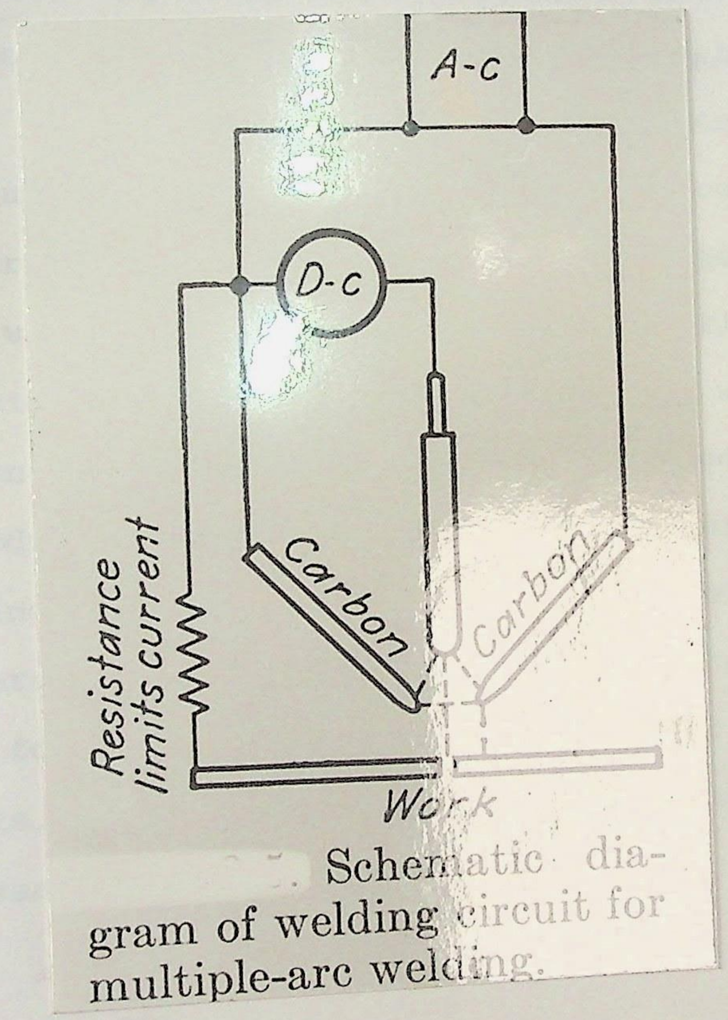


Fig. 15B   Schematic diagram of welding circuit for Multiple-arc welding.

The above example of a multiple-arc welding gun is the modern day equivalent of Benardos' system. There is very little difference between both systems, although carbon-arc only has a limited use nowadays.

III Arc Welding - Development

Modern fusion welding processes are an outgrowth of the need to obtain a continuous joint on large steel plates. Riveting had been shown to have disadvantages, especially for an enclosed container such as a boiler. Gas welding, arc welding and resistance welding all appeared at the end of the 19th. century. The first real attempt to adopt welding processes on a wide scale was made during World War One. By 1916, the oxyacetylene process was well developed and the welding techniques employed then are still used. The main improvements since then have been in equipment and safety. Arc welding using consumable electrodes was also introduced in this period but the bare wires initially used produced brittle welds. A solution was found by wrapping the bare wire with asbestos and an entwined aluminium wire. The modern electrode introduced in 1907, consists of a bare wire with complex coating of minerals and metals. Arc welding was not universally used until World War Two, when the urgent need for rapid means of construction for shipping, power plants, transportation and structures, spurred the necessary development work.

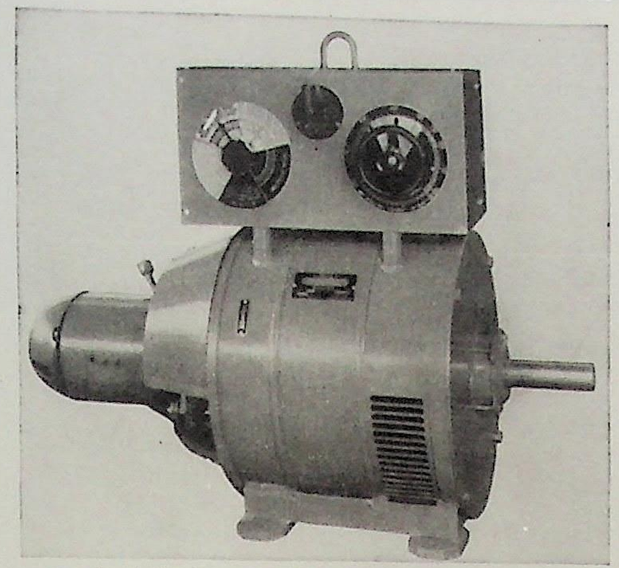


Fig. 4-1. Generator for belt drive or direct connection. (*Courtesy of The Lincoln Electric Company.*)

Fig. 16. D.C. Generator with variable voltage characteristics.

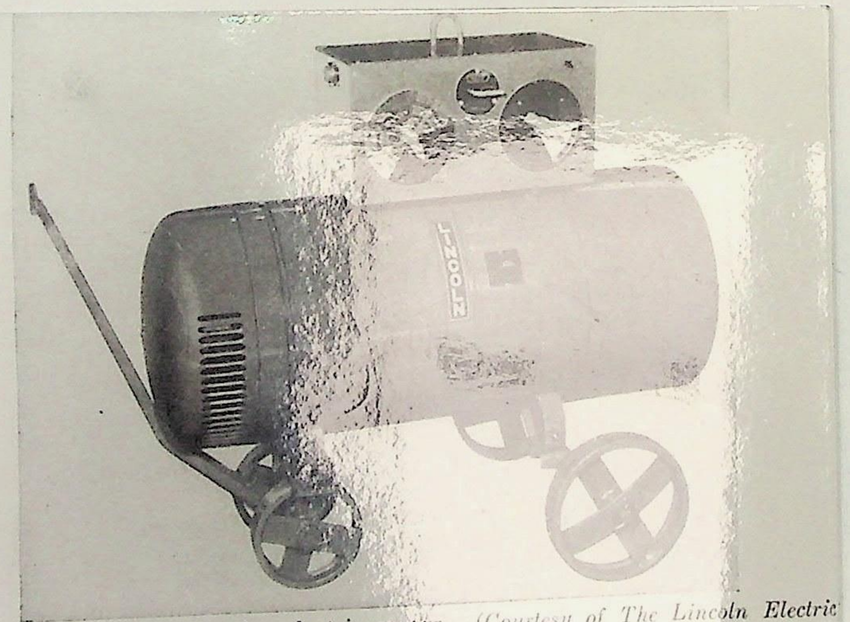


Fig. 4-2. Generator driven by electric motor. (*Courtesy of The Lincoln Electric Company.*)

Fig. 17. Portable Generator driven by electric motor.

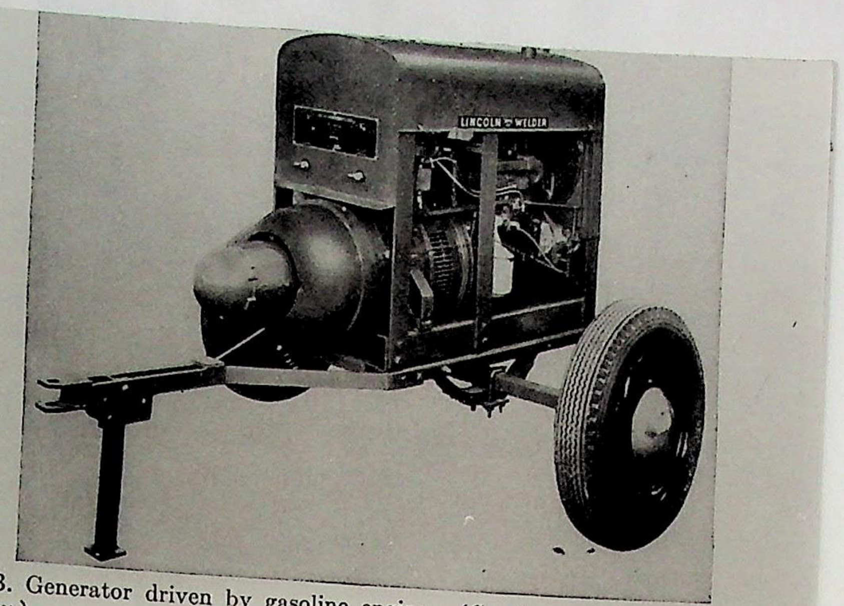


Fig. 4-3. Generator driven by gasoline engine. *(Courtesy of The Lincoln Electric Company.)*

Fig. 18 Portable Generator driven by gasoline engine.

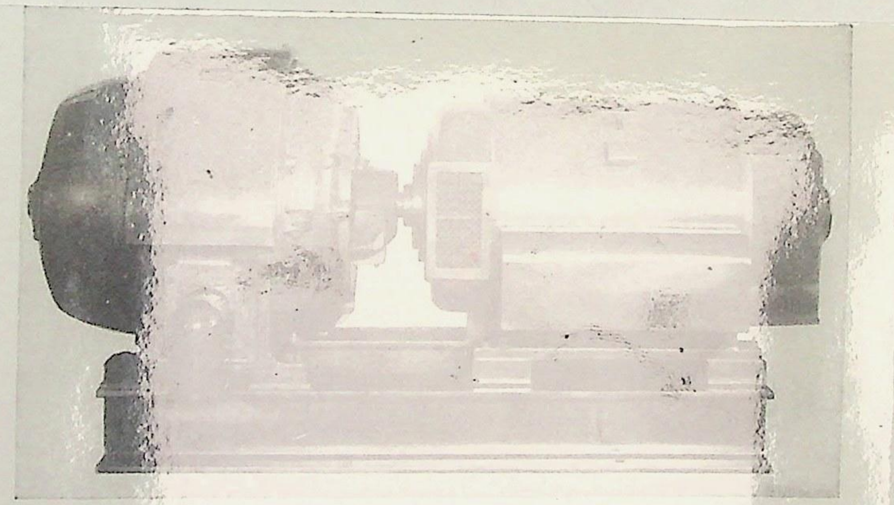


Fig. 4-4. Typical multiple-operator d-c arc-welding set. *(Courtesy of General Electric Company.)*

Fig. 19 Stationary multiple-operator d-c arc-welding set.

IV Arc Welding - Historical Account

In order to describe the type of work carried out by the arc welding process during the period when it was first used as an alternative to the older systems i.e. riveting etc., there follows an extract from an article entitled "Fifty Years Since the Establishment of the First University Welding Laboratory", by N.M. Kunitsyn who was a Russian welder, and discusses his experiences between 1925 and 1929.

"In those days the power sources for the welding arc were exclusively direct-current machines, modified to produce welding characteristics. Schemes with independent excitation and self-excitation were employed. At that time the total stock of welding machines numbered ten units. The use of direct-current machines was absolutely necessary, bearing in mind that welding was nearly always effected with 'bare wire', not made purposely and without any covering. Electrodes with chalk covering, mixed using an aqueous solution of sodium silicate, were sometimes used for the stabilisation of arc burning. Special covered electrodes appeared later, and at first they were purchased from abroad. The quality of welding achieved using electrodes without coverings, or with chalk covering, seems remarkable today, in view of the fact that no serious cases of failure of structures welded with such electrodes were recovered.

The welder's trade was extremely privileged at that time. Welders had a number of privileges - they received a special milk allowance, worked a six-hour shift, received additional leave, and received better wages than in other trades.

A fairly large group of students of the GDU formed around V.P. Vologdin (Shket, Savitskii, Kislovskii, Markov, Borisov, etc.), and they decided to specialise in welding. It should be pointed out that the ability to instil enthusiasm and to unite a body of helpers around himself was a basic trait of V.P. Vologdin's character. He was an extremely charming and amiable person. Although he was an eminent scientist and theoretician, he had nevertheless fully mastered arc welding techniques, and he could not only talk and explain, he could also give a practical demonstration of the art of welding. He effected a number of interesting welding jobs personally; in particular, he fabricated the first all-welded steam boiler of the traction engine type. Many received his personal instruction in the art of controlling the welding arc. The authority of 'Petrovich', as he was affectionately referred to by his welders, was absolute and deserved. All students controlled the welding arc excellently, and they were often employed in the execution of many important welding operations. They also undertook many engineering tasks involving welding, and they participated in the design of welded structures, and in the design and modification of welding machines. This group, headed by V.P. Vologdin, organised welding production at Dal'zavod, where the core of our oldest electric welders was formed. The first, and excellent electric welding operatives, were Fonarev, Silin, Bidnyi (who died tragically during the repair of the steamship 'Yana'), the brothers Shadrin, and the brothers Golubev. Many operations, both at Dal'zavod and elsewhere, were managed by V.P. Vologdin's chief assistants - Kostyaev and Tirman (an expert in oxygas welding and cutting). I.S. Dimitriev and G.K. Tatur joined in this work somewhat later.

The development of welding at Dal'zavod was greatly encouraged by the Works Director Koval', the machine shop manager Pavlov, the foundry manager Eroshkin, the manager of the boilermaking shop Ped'ko, his deputy Bazalii, foreman Volkov, and many others. With their help, Dal'zavod became the place where many, at that time unique, welding operations were accomplished at the dawn of electric welding.

It is of course impossible to describe all the welding work undertaken at that time. At first, purely repair work predominated, but then more and more operations connected with the installation of new structures and articles by means of welding were undertaken.

We will give just a few examples of the repair work undertaken at that time using electric arc welding in which the present author took part.

In 1926 it became necessary as a matter of urgency to replace our winter personnel on the island of Vrangelya. It was at the end of the summer, there was just enough time for the passage to the island, and a suitable vessel was yet to be prepared. The ice-breaker 'Nadezhnyi' was urgently placed in dry dock - it had been laid up for several years before this, and conversion to the gunboat 'Krasnyi Oktyabr' was commenced. In addition to numerous other repair jobs, it was necessary to replace more than a million old rivets in the hull. For the most part, the plating had to be retained. The method usually employed at that time for removing old rivets was to drill them out using a pneumatic drill. A team of two drillers and two people for knocking out was capable of drilling out and removing not more than 80 rivets in an eight-hour shift of arduous work. If drilling was inaccurate, the none-too-easy task of knocking out was even more difficult, and re-drilling was necessary. It was possible to increase the number of drilling teams to some extent, but even then it would not have been possible to reach any deadline. Then, at the suggestion of the welders, headed by V.P. Vologdin, the rivet heads were melted out using a carbon arc. The technique is very simple. The welder uses the arc to burn away some of the paint in the region of the rivets, and after this the outline of the rivet head can clearly be seen. Melting of the conical body of the rivet head begins. Because the arc naturally tends towards the more heated place, its thermal action is concentrated in the mass of the rivet, without affecting and melting the rivet hole. The rivet, without its head, and also heated, can be knocked out by one man using a hand punch with no great effort. Whereas the men employed for knocking out lagged behind when drilling was used, in electric melting it was the welder who could not keep up, even though he was able to burn out at least 240 rivets in his six-hour shift. The welders quickly mastered the technique of melting-out rivets, and their work was always of good quality. Clever and timely application of the electric arc had helped to solve this repair problem. The 'Krasnyi

Oktyabr' set out on time and completed its important task. The method of the melting-out of rivets was employed on numerous other occasions, in particular for dismantling the large, obsolete ship 'Pechenga'.

The messenger ship PS-10 had had an accident with a steam boiler. Local bulging into the firebox had occurred as a result of severe overheating by the hot coal in both drums of the fireboxes of a fire-tube boiler. At that time there were few frontier-guard vessels, and each of them had to be strictly operational.

It was necessary to replace the damaged sheet-steel drums inside the boiler, and this cannot be done without first removing nearly all the fire tubes. At a meeting, the boilermen determined a repair time of just a few weeks. I remember that they called me and asked whether the repair could be effected using welding, and how long it would take. I first studied the actual nature of the fault (the vessel was already standing near the factory berth). The bulge on the drums (four drums in each firebod) was about 30-35mm. The area of the bulges was roughly 300 by 400 mm. The drums had wall thicknesses of 12mm. I said that I could do the work, and without knowing the time limit set by the boilermen, I said it would take less than twenty-four hours, provided that I could appoint a team of boilermakers headed by Kuberskii, who was a real expert. My declaration was met with considerable doubt by all those present. However, the conditions were accepted, the team was selected, and at 5 o'clock on the same day we started the work. The water was drained from the boiler, which was still hot, the two bottom rows of fire tubes were removed, and both bulges were cut out using oxygen. Meanwhile, patches had been prepared, and welding in was begun. The entire job, skilfully organised by Kuberskii, was completed by 10 o'clock in the morning, i.e. in just 17 hours. The boiler was tested, and accepted in respect of all the regulations, and steam was raised in it. Everything had been done extraordinarily quickly; the PS-10 was again capable of fulfilling its tasks, as if no serious accident had occurred.

Of course, the above is not an isolated example. The popularity of electric welding increased rapidly because of its astonishing ability to reduce repair times. A variety of repairs were effected, for the reclamation of worn shafts and the blades of screw propellers by building-up, for building-up the edges of the plates of riveted steam boilers, to increase their thickness, and for other operations using building-up. The method of submerging a vessel to repair its underwater part without docking was employed for the first time (the tanker 'Neftesindikat SSSR, and others).

One day in 1927, Dal'zavod was approached by the management of the English cargo steamer 'Willesden', which had recently completed work with Soviet freight. The firebox of one of its four boilers was damaged. Repair of the box by welding had already been carried out in Singapore, but without success. The order was accepted, and I was again entrusted with the work. The vessel was berthed 2-2.5 miles from the Works. The work was performed in situ, by transporting a welding machine. The degree of technical difficulty was not beyond our usual capabilities, and therefore completion of this work, after the lack of success in Singapore, was a matter of prestige. The work was effected successfully. The clients invariably expressed their satisfaction to Dal'zavod for the welding work on subsequent voyages.

As already mentioned, the GDU and Dal'zavod were the first to fabricate all-welded boilers, including fitting the fire tubes by welding instead of roller-expanding. Sebsequent replacement of tubes was also accomplished by welding. At that time this represented a considerable achievement. In general, this period was typified by the use of welding in place of riveting. Among other work in this direction, mention must be made of the use of welding to make oil storage tanks of about 7 metres in height and diameter. To make the tanks, only final assembly and welding were carried out on site in field conditions. As much welding as possible was completed in the workshops: the half-bottoms and half-tops, and all the vertical seams of the banks - except the last, closing band. The bands were rolled up, and everything was loaded onto flat tracks, within the railway size limits, and despatched to the place of installation. For the first time V.P. Vologdin employed a method for the assembly and welding of tanks in which the tank was assembled on its bottom from top to bottom, starting with the top cover, then the upper and subsequent bands, and ending by welding the bottom band to the bottom. This employed only four hoists, suspended on four colums dug in around the tank, and a minimum of people. Many tanks were built in this way.

Bold and successful solutions were found for the very important problems of mechanisation of loading work in the transit section of the port of Vladivostok. More than half a kilometre of various welded transporters for trans-shipment of bagged and piece cargoes, and also oilcake, was fabricated in the workshops of the GDU. A large volume of work was undertaken for the production of metal supports for these transporters, old rails being utilised for these supports. At that time this was convincing evidence of the advantages of welding, which could be used for joining rods in structural assemblies of limitless complexity. Numerous structures of the bridge and roof type were made also, the first tubular girder assemblies were designed, and techniques were developed for testing welded lattice structures.

The end of the 1920s saw the first Soviet production of all-welded sea vessels. The welding of a series of sea launches was started in the summer of 1928 (their length was about 16 metres). During the course of their construction, even before they were put into service, an accident confirmed the great reliability of the hull welds. One of the launches with the hull completed was being lowered into the water. At that time this operation was accomplished using a floating crane. While it was being lowered, the bow rope broke and the vessel's bow struck the water from a height of more than two metres (the stern rope did not break). As the vessel floated up rapidly the left bow section struck a pier girder and a dent 80-100mm deep formed. All the seams in the region of the dent remained sound. If a riveted hull had sustained such damage it would have been necessary to re-rivet all the riveted joints. In this case the dent was not even straightened out - a patch was simple fitted and welded flush with the hull." [9]

V. Arc Welding Electrodes.

As has already been stated early arc-welding involved the use of bare steel rods as electrodes. Manual bare wire welding, as it was known, was employed for almost half a century but it is now virtually unused. Considerable skill was required to strike and maintain an arc and because the operation was done in air the deposited metal was seriously contaminated with oxygen and nitrogen. This effected the impact properties adversely. Not long after the introduction of the bare-wire metal-arc process attempts were made to overcome these difficulties by coating the electrodes. These attempts may have been prompted by the fact that from the earliest days the importance of the surface of the electrode wire was recognized. Although described as 'bare' the wire used for welding frequently received a lime wash during wire drawing which resulted in the surface of the wire having a thin film of rust and lime. Although of negligible thickness this film led to a marked improvement in arcing properties. Kjellberg introduced the first flux-coated electrode in 1907 and clearly understood that the coating could have other functions than merely that of stabilizing the arc.

Since their introduction at the turn of the century, metal-arc electrodes have been the subject of continuous development. In spite of competition from other, more recently developed methods of welding, the metal-arc process, in which electrodes in the form of short lengths of flux-covered rod are held by hand, has become the most widely used welding process.

recently developed methods of welding, the metal-arc process, in which electrodes in the form of short lengths of flux-covered rod are held by hand, has become the most widely used welding process.

This section includes some diagrams which, although not directly related to the subject matter, should help the reader visualize the content.

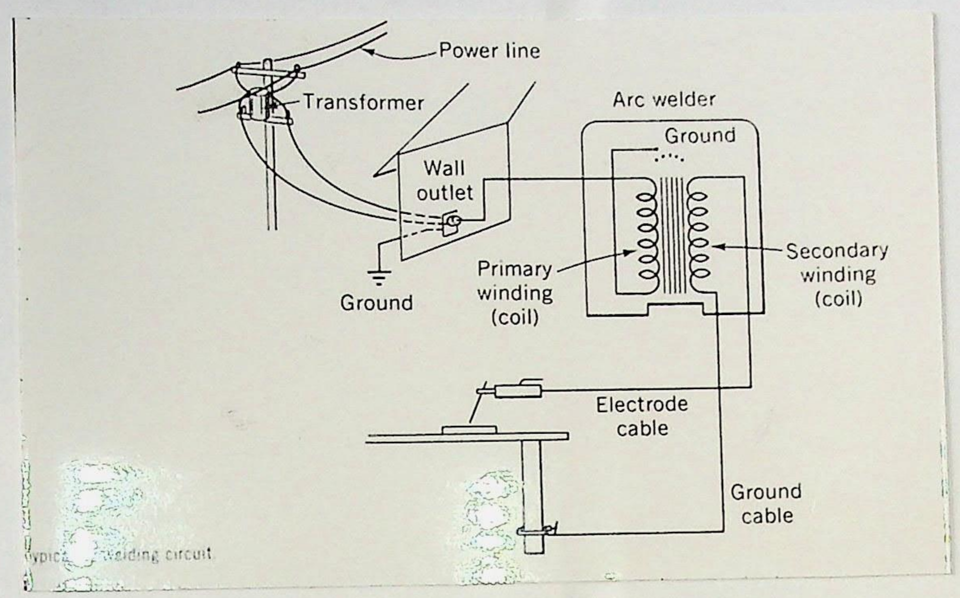
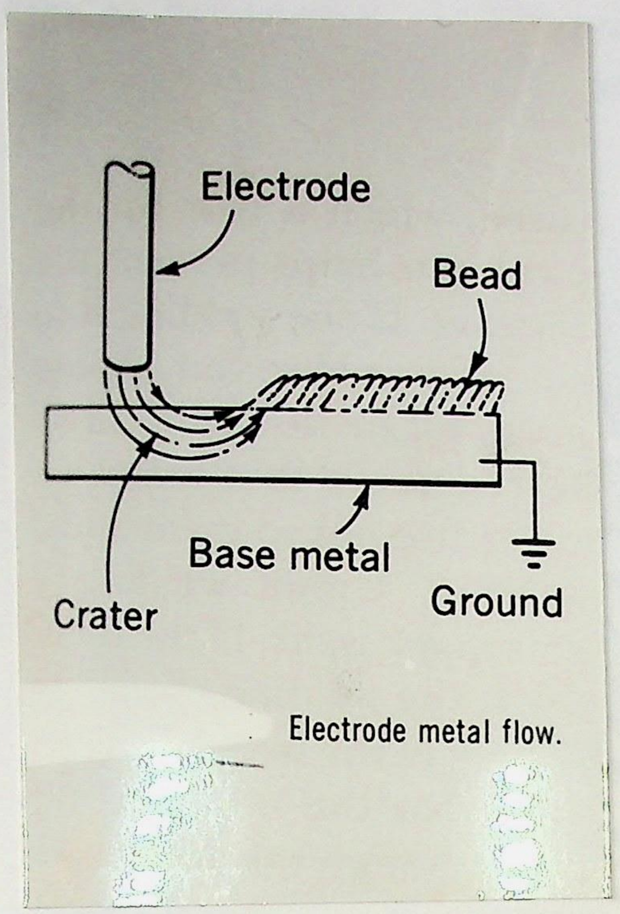
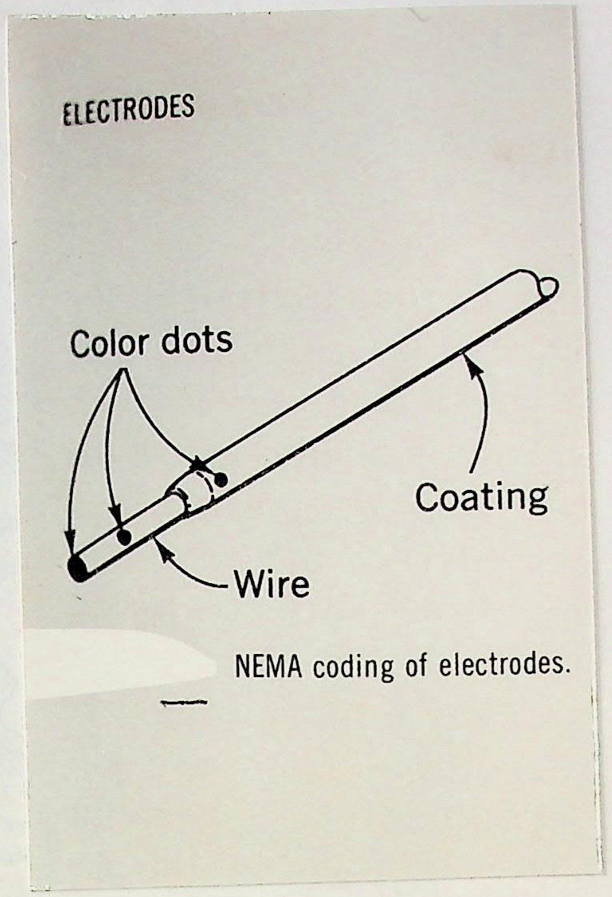


Fig. 20 Typical ac welding circuit.

"In 1903 electrodes were produced with acid type coatings, namely mineral silicates, rutile and cellulose. Weld metal hydrogen values 10-25mls/100 grams. In 1907 Kjellberg began his work on electrode coatings. His patent claimed the 'application of a heavier electrode coating which resulted in a simple and practical method of welding whereby the welding of joints on the lower side of objects can be easily effected' and he also claimed that the coating material could be formulated so that it 'effects mechanical or chemical changes'. Oscar Kjellberg was the founder of the firm of ESAB Ltd., and from the beginning ESAB electrodes have always carried the designation OK, the initials of the founder.



Electrode metal flow.



NEMA coding of electrodes.

Fig 21. Electrode metal flow

Fig. 21. NEMA coding of electrodes.

About the same time, an analytical chemist and consultant, A.P. Strohmenger, whilst working for two clients became involved in experiments on arc welding being carried out by an engineer called Slaughter. Strohmenger analysed the wash coatings on some of the electrodes and suggested to Slaughter that he might try wrapping the welding wire with some blue asbestos which he happened to have on his bench. This was the property of Cope Asbestos Co (also a client). The result was an instant success, more so since the arc would run on A.C. whereas the wash-coated wires would not. Strohmenger showed his new invention to Professor Sylvanus P. Thomson of London University who expressed the view that the arc was not a normal metallic arc and christened the process Quasi-arc. As soon as Strohmenger and his engineering friends discovered the advantages of using this Quasi-arc electrode, steps were taken to patent it.

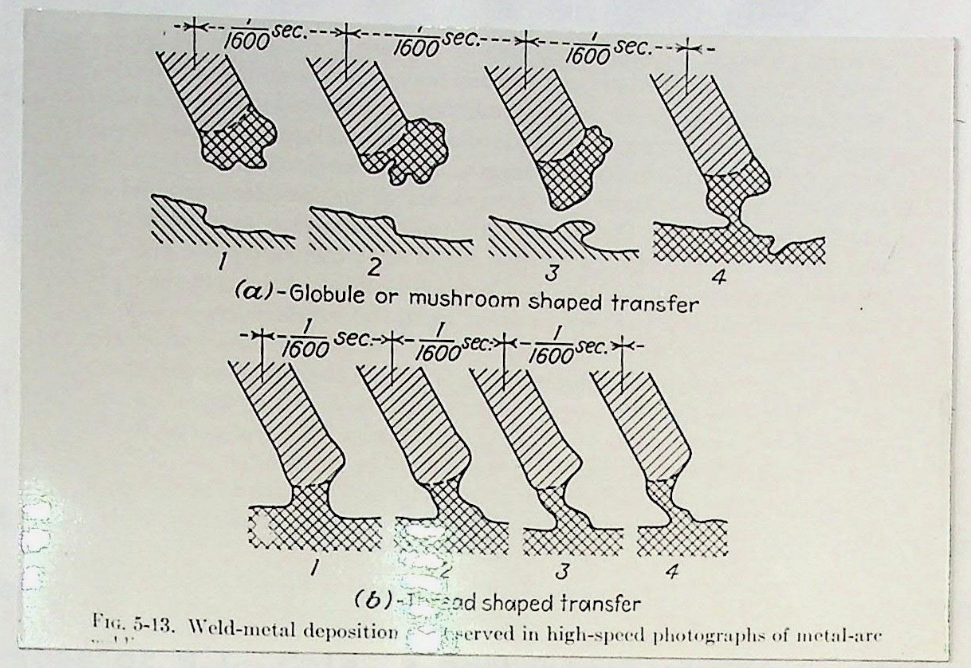


Fig. 22 Weld -metal deposition as observed in high-speed photographs of metal-arc.

In 1911 electrodes wound with blue asbestos were used with great success by Slaughter and other contractors on both tramway and minor ship repairs in the London docks, but this company was mainly interested in contracting work as welders whereas Stohmenger enlisted the help of a firm of Chartered Accountants of whom a Mr. C.H. Champness was the principal director and on his advice formed the Quasi-Arc Co. Ltd., later absorbed by the British Oxygen Co.

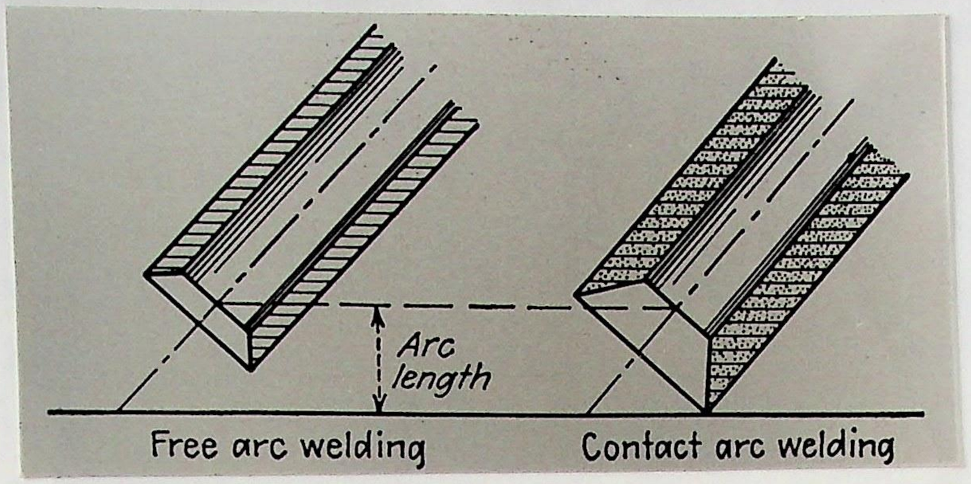


Fig. 23. Free Arc Welding and Contact Arc Welding

In the early days when Strohmenger and Champness were recruiting staff for the new company they enlisted the services of W.L. Cole, a mechanical engineer, who was the head of a small business in Mile End. This man, at one time when ship-building was carried out on the Thames, had been very active in carrying out subsidiary work on small craft. About the time of the founding of the Quasi-Arc Co. in 1912 work had fallen off and had been mostly concerned with miscellaneous construction of machines in various works in the East End of London. Cole was glad to give his attention to the design and manufacture of machines for making Quasi-arc electrodes which were operated in the first place in his Mile End works.

Although the early activities of the company seemed to have been local to London and the South of England, soon representatives and travelling Sales Engineers were appointed and the sale of electrodes increased rapidly.

Every welder who had previously used bare Swedish iron wire as an electrode for arc welding immediately recognised the ease of striking an arc with a Quasi-Arc electrode and every engineer was delighted at the clean bright appearance of the weld metal as soon as the fused slag had been chipped off.

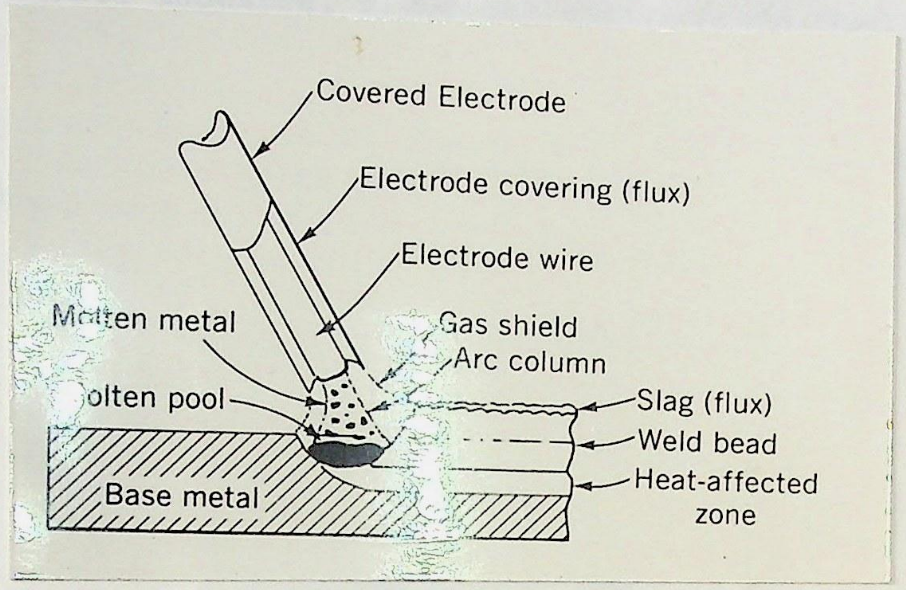


Fig. 24 Schematic diagram of arc-welding process.

By the time war has been declared in 1914 the Quasi-Arc Co. was well established and the term "Quasi-Arc" welding was generally used for all work carried out with blue asbestos covered electrodes.

In 1911 further Kjellberg patents appeared which described more specifically the electrode materials, coating, minerals for slag formation and various ferroalloys, all of which were claimed to have some effect on weld properties. Welds were superior to those made by base electrodes.

In 1927 solid electrodes were made by the A.O. Smith Co. for its own use, but in 1929 they were made commercially by Lincoln Electric Co.

By 1930, iron powder, cellulose and titanium were finding greater use in creating materials whilst the use of silicate asbestos, fluorspar and lime was declining.

1938 saw the development of basic lime coated electrodes depositing weld metal with potentially low hydrogen values of <10mls/100grams.

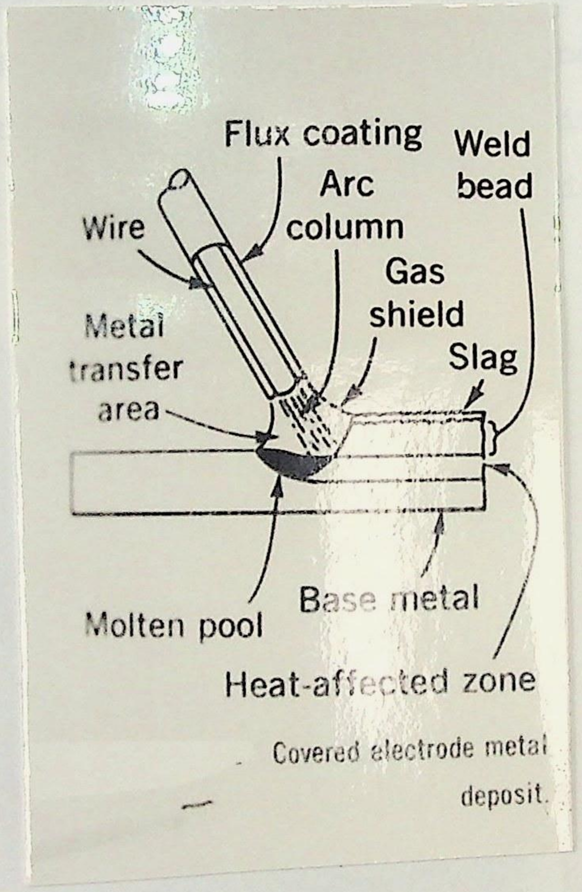


Fig. 25 Covered electrode metal deposit.

1940 saw the development of alloy type electrodes for welding stainless steels and hard facing.

In 1942 there was further development of basic low hydrogen electrodes for welding low alloy high strength hardenable steels.

Acid rutile-iron powder 'touch' type electrodes were developed in 1952 and by 1960 there were further developments in the high efficiency iron powder type.

1962 saw the introduction of zircon iron powder basic coated electrodes and in 1965 a composite double coated basic low hydrogen electrode was introduced. By 1970 there was developed basic coated electrodes depositing weld metal of high fracture toughness with values of 200J at 10°C and ductible to brittle transition temperatures of -70°C.

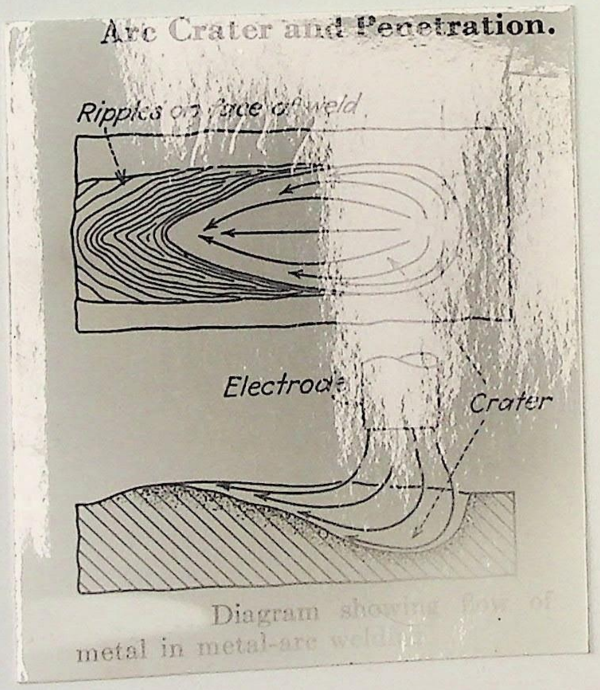


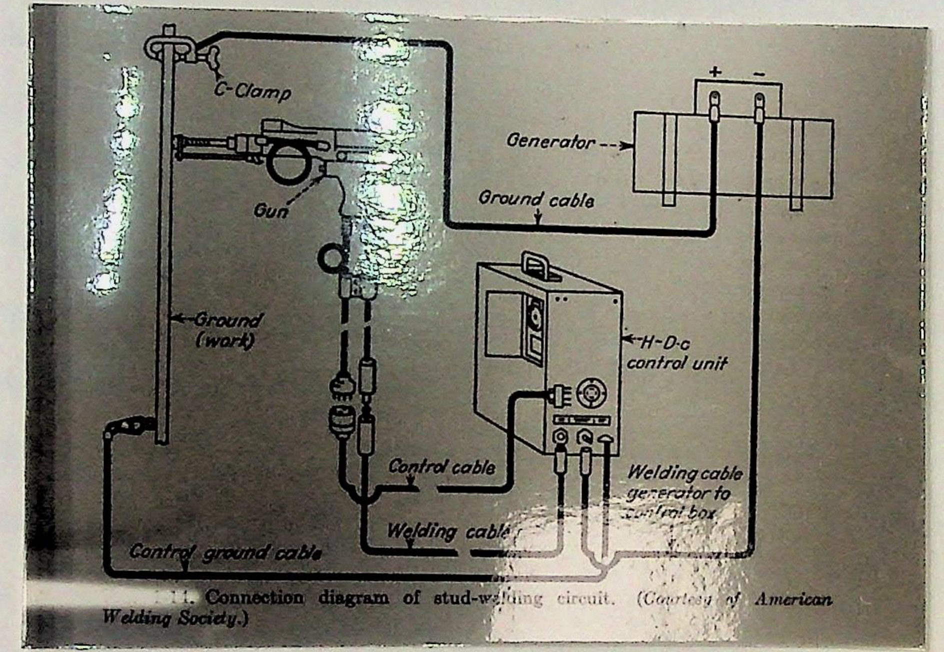
Fig. 26 Diagram showing flow of metal in metal-arc welding.

The use of welding electrodes has made an important contribution to engineering technology since 1903. They have been produced for and successfully used on all weldable ferrous alloys including some of low inherent weldability e.g. 11-14% manganese steel and carbon manganese and low alloy steels with a CE in excess of 0.5%.

Welding electrodes still account for at least 50% of all welded fabrication throughout the world. In most industrial countries it is between 70 and 90%. A complete range currently lists about 80 electrode types of which 38 are basic coated types." [10]

VI Stud Welding

Stud welding is an arc-welding process which, in many respects, resembles manual arc-welding. The equipment required for stud welding consists principally of a stud-welding gun, a control unit or device to control time of current flow, a source of d-c welding current and studs and ceramic ferrules. See Fig 27 below.



... Connection diagram of stud-welding circuit. (Courtesy of American Welding Society.)

Fig 27. showing basic stud-welding circuit.

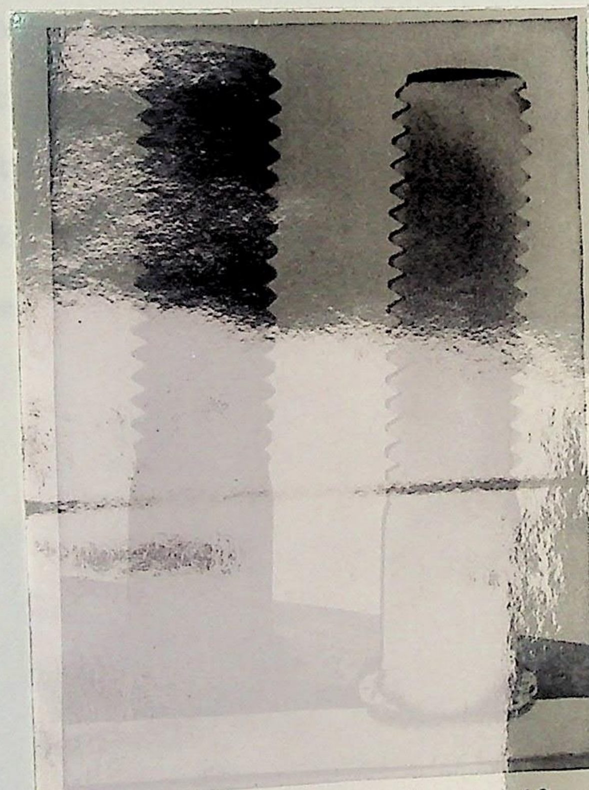
There follows now extracts from an interview conducted by "Metal Contruction" in January 1973, with Mr. Harold Martin, the inventor of the stud welding process during the 1914-1918 World War and later developed the process in the 1939-1945 War. Mr Martin was appointed experimental assistant electrical engineer at Portsmouth Dockyard, by the Admiralty in 1915 and as such the process was developed as a means of saving the time and energy required to drill and tap studs, particularly into ship's plates. These studs were used to attach machinery etc., to the inside of the ship's hull and if the hull had to be penetrated in order to allow the old type stud to be fixed, the structure could be damaged.

"A lot of the work was done on the structures of the ships themselves. We could see it offered big advantages because of the possibilities of avoiding drilling and tapping, with certain, or at any rate potential, damage to the ship's structure." [11]

"We had to clamp many things on warships such as cross-bars and many attachments for which it was most desirable to avoid the drilling of corresponding holes. If you can made a sound, strong and watertight attachment without any drilling or tapping that is obviously a big advantage - so that's what we did." [12]

At first, ordinary bolts were welded on by hand, but was not very satisfactory. Then they started using the bolt itself as an electrode.

"The bolt itself was used, with an electric current to create an arc. We held the end of the bolt in contact with the ship. The bolt had a slightly coned end and we soon had a stud-welder fully developed. By pressing a button at the controller, the main circuit was closed between the bolt and the plate, and then the stud-welder reacted and lifted the stud from the plate, thereby forming an arc. That arc was maintained for a given time and while the arc was running, molten metal was being deposited on the plate opposite the stud end. After maintaining that arc for a reasonable period - which was altered to suit varying conditions - the melted end of the stud was returned into the molten crater, so to speak, and the crater built up around the edge of the stud. The circuit was then automatically opened and the stud was firmly welded and with a reinforcing filled round the edge in contact with the plate." 13



Typical stud weld. (*Courtesy of Nelson Stud Welding Div. of*

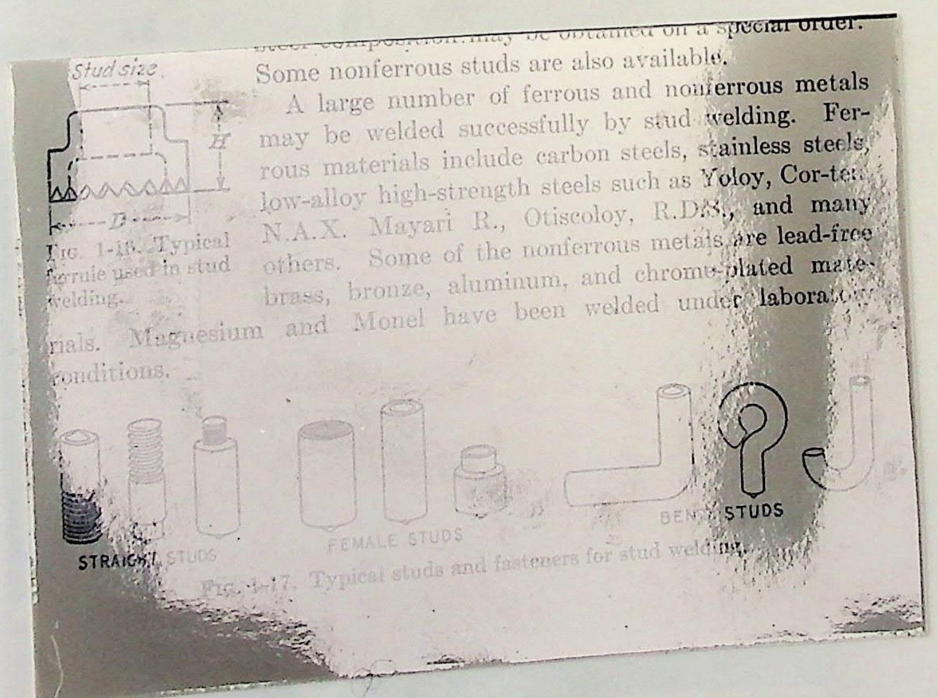
Fig 28. Section through typical stud weld.

During the interval between the Wars Mr. Martin continued to work on improving the stud-welding system by trying different material combinations.

"I could see the potential value of welding and particularly of stud welding. You see the brass-to-steel joint is very much a ship job and there were other combinations of interest in other fields. One of the first applications was to hold cables to ship bulkheads by means of bolts which were stud-welded into place - and there were a great many such welds made in a very short time." [14]

During the Second World War high tensile steel studs were developed for use on tanks and destroyers.

"In 1937, I was appointed Electrical Engineering Manager at Chatham dockyard and right at the beginning of the last war, in 1939 or 40, somebody came along concerned with Army tanks because rivet heads were flying off when they were hit, and they thought stud welding would be suitable." [15]


steel composition may be obtained on a special order. Some nonferrous studs are also available.

A large number of ferrous and nonferrous metals may be welded successfully by stud welding. Ferrous materials include carbon steels, stainless steels, low-alloy high-strength steels such as Yoloy, Cor-ten, N.A.X. Mayari R., Otiscoloy, R.D.S., and many others. Some of the nonferrous metals are lead-free brass, bronze, aluminum, and chrome-plated materials. Magnesium and Monel have been welded under laboratory conditions.

Fig. 1-16. Typical ferrule used in stud welding.

Fig. 1-17. Typical studs and fasteners for stud welding.

Fig. 29 Typical types of studs presently available.

"Oh, yes and it was the same on destroyers. I remember the problems we had when we had to fix heavy conductors for degaussing against magnetic mines. One Sunday morning we went to the yard where we were experimenting with big studs to fix these bars for bonding. The fixing of studs to the armour plate on these Chatham destroyers came out alright but they were not always successful. On this Sunday we found that very big studs wouldn't stay on when they were hit with a hammer, which was the standard test, and therefore, we cross-questioned the fellow who was doing the welding. I asked what he was dipping the studs into and he said: 'Oh! I have put them in that tin can over there'. Then we found it contained urine and this lead to the idea of coating the end of the stud. We tried this and subsequently we found out why this was effective. It was the application of this observation that helped to solve the tank problem and also the armour on ships. It was one of the keys to the complete success of stud welding." [16]

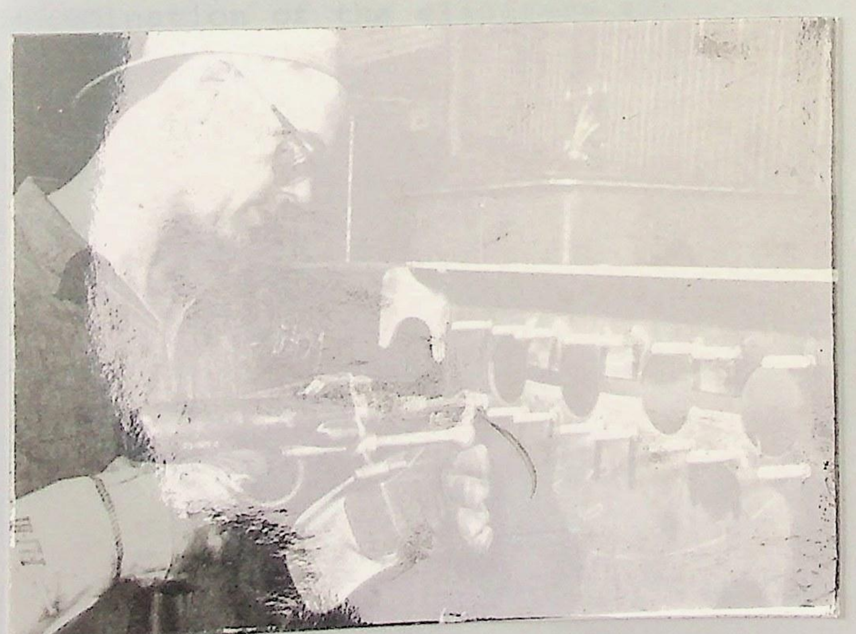


Fig. 30 Typical stud welding application.

VII. Gas Shielded Arc Welding.

The idea of using a gaseous shielding medium to protect both the electric arc and weld from contamination by the atmosphere is almost as old as the covered electrode. Roberts and Van Nuys in 1919, and others several years later, considered the problem and a variety of gases were proposed from the inert gases to hydrogen and hydrocarbons. In the 1930's the interest began to centre on the inert gases but it was not until 1940 that experiments were begun at the Northrop Aircraft Co., of U.S.A. with the deliberate intention of developing a practical inert-gas welding method. The metal to be welded was melted by an arc struck from a tungsten electrode, in an atmosphere of the inert non-atomic gas helium.

The original apparatus comprised the simple tungsten electrode torch and a d.c. generator. Arc starting was by brushing the electrode on the work but this led to contamination of the electrode and a high-frequency spark generator was added to the equipment so that an arc could be struck from the electrode without touching it on the work. At first both electrode negative and electrode positive polarity were used, although the negative polarity was favoured because less heat was generated at the tungsten electrode, which remained relatively cool.

With the desire to weld thicker material, welding currents were increased to over 100A and it was no longer possible to use the electrode positive polarity because the tungsten electrode became so hot that molten tungsten dropped off into the weld pool. The higher welding currents also necessitated water cooling of the body of the torch because of the increased amount of heat conducted back along the electrode.

By 1944 it was recognized that electrode polarity was of greater significance than had appeared at first. Up to that time the inert-gas arc process had been used principally on thin-gauge magnesium and stainless steel, but attempts had also been made to weld aluminium with which was found necessary to employ a flux. It was observed, however, that oxide removal could be accomplished by the arc itself on electrode positive d.c. or in a.c. welding, thus making a flux unnecessary. Unless a certain minimum open circuit voltage was available when welding aluminium with a.c. the oxide film was not broken down so that the a.c. was rectified and welding was impossible. By 1946, however, it had been found that the spark ionizer could be made to stabilize the a.c. arc. Gradually a preference emerged for argon over helium in manual welding, largely as a result of the smaller change in arc voltage with arc length when welding with argon. This made the process less critical from the welder's point of view.

Once a start had been made to the welding of aluminium by the inert-gas tungsten-arc method there began a period of rapid development because of the new range of applications opened up. Although limited for several years to welding sheet material at less than 150 A, there was now a demand to go to higher currents. Metal gas nozzles were replaced by ceramic ones, these in turn being replaced by water-cooled metal nozzles when it was found that the ceramic nozzles had a limited life. The water-cooled torch body and power lead was now essential to give lightness and flexibility to the torch and because the high-frequency ioniser was left on continuously,great attention had to be paid to the insulation.

Although the high-frequency ionizer stabilized the arc, it did not affect the inherent unbalance between the voltage on alternate half-cycles, which resulted in a d.c. component that tended to saturate the transformer. At first, this was overcome by applying a similar d.c. voltage, but of opposite polarity, to the circuit so that the d.c. component was balanced out. This was done with storage batteries, but subsequently it was found that large capacitors in series with the arc had the same effect.

The purity of the shielding gas was improved from 98 to over 99.95 per cent as the process developed, particularly as a result of the need for high purity gases for the welding of aluminium alloys and reactive metals. Argon, the only inert gas available outside the U.S.A. gained in popularity, even in that country, being the chief gas used for manual welding, although the higher arc voltage and, therefore, greater penetration of the helium-shielded arc was found of value in automatic welding. Both helium tungsten-arc and argon tungsten-arc techniques were rapidly applied to the welding of a range of non-ferrous metals, which had proved difficult to weld by other methods.

With aluminium, as with magnesium, the new process gave greater scope to the engineer because of the absence of flux. Previously fillet welds and other types of joints in which flux might be trapped had to be avoided because of the danger of corrosion after welding. The more concentrated heat input of the tungsten-arc welding process over gas-welding enabled welding speeds to be increased and improved the metallurgical quality of welds. Although there were many advantages to the process it was also found to have limitations. The separate addition of filler metal required the use of both the welder's hands, access to difficult joints tented to be restricted and positional welding was slow and difficult.

In 1948, however, the second important gas-shielded process made its appearance and was to prove capable of being used satisfactorily on many of the types of joint which were not ideally suited to the tungsten-arc method. In tungsten-arc welding, the electrode was non-consumable, but in the new method the electrode was in the form of the U.S.A. gained in popularity, even in that country, being the chief gas used for manual welding, although the higher arc voltage and, therefore, greater penetration of the helium-shielded arc was found of value in automatic welding. Both helium tungsten-arc and argon tungsten-arc techniques were rapidly applied to the welding of a range of non-ferrous metals, which had proved difficult to weld by other methods.

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In the first apparatus, the wire was pushed through a flexible tube to a pistol-type torch, where contact was made with the welding current conductor. Argon gas to shield the weld pool was passed through a nozzle surrounding the filler wire. Although the torch was held in the hand, the process possessed certain characteristics usually associated with automatic welding. It was the first manual process to utilize the principle of the self-adjusting arc in which the arc length is held constant during welding, irrespective of movement by the operator. An essential feature of the process, which made it possible to use both a self-adjusting arc and the flexible feed tube to the torch, was the small diameter of the electrode wire, usually about 1/16th inch. Metal was transferred axially from this wire electrode to the work in a stream of fine drops.

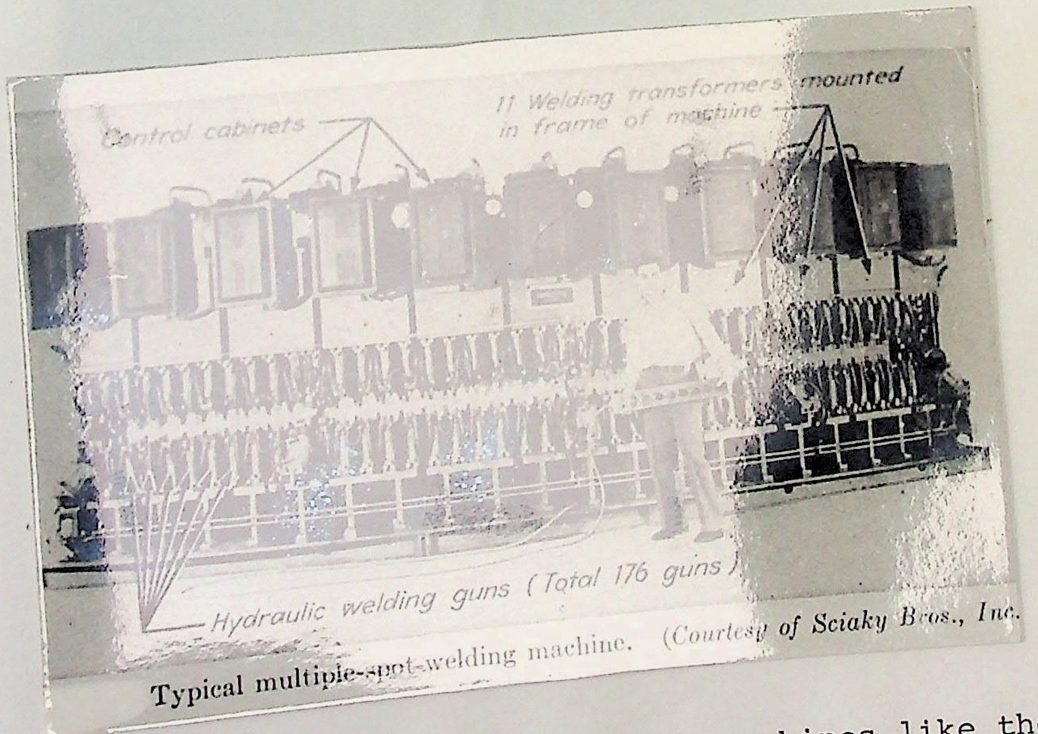
Development of the inert-gas metal-arc method in the early 1950's was closely associated with the welding of aluminium alloys, which at that time were becoming established as structural materials, in particular for ship-building where a process was needed which would weld in any position. Had the need for structures in aluminium alloys not existed in 1950, the process might well have been developed more slowly, and it was fortunate that aluminium was one of the first metals to be tried, for as it is now known, metal is transferred across the arc more satisfactorily with aluminium than with any other metal.

Following the successful use of inert-gas metal-arc welding with aluminium, attempts were made to apply the method to other non-ferrous metals and to steels. The use of argon for welding steels was not economically attractive, but after several years of research in the U.S.S.R., U.K., and U.S.A., techniques were developed which permitted the satisfactory use of carbon dioxide as a shielding gas. This gas is cheap and made the process competitive in many applications with established processes such as metal-arc.

The history of gas-shielded arc welding, from the first use of the helium tungsten-arc in the 1940's the successful use of the carbon dioxide-shielded metal-arc in the 1960's has been discussed in reasonable detail because this is possibly the best introduction to this important series of processes. The impetus behind each new development can be seen in perspective and it will have been noted that the circumstances have been extraordinarily favoured for rapid exploitation.

VIII Resistance Welding.

"The invention of resistance welding by Professor Elihu Thomson came about through a 'fortunate accident' that occurred in 1877 during a lecture at the Franklin Institute in Philadelphia. According to Stanley, Professor Thomson was using a spark coil to step up battery current to high-tension discharge in order to charge Leyden jars when he wondered what would happen if he reversed the process. Accordingly, he charged the Leyden jars from a power-driven static machine - and next passed current from the jars through a winding of fine wire to a winding consisting of heavier wire and including terminals 'held together in rather light contact'. The outcome was that the discharge of current through the fine wire winding fused or 'welded' the loose terminals of the heavy wire winding." [17]



Typical multiple-spot-welding machine. (Courtesy of Sciaky Bros., Inc.

Fig. 31 Large multiple-spot-welding machines like the one shown above were in use before 1950.

"With this experiment resistance welding was to come into being and its basic principle has never been changed. Although the experiment was conducted in 1877, Professor Thomson did not perfect resistance welding as a process until 1886. At that time he applied for two patents, one of which was a process patent and covered the butt welding or joining of two pieces of metal with equal areas. By 1898, however, the process had been utilized for spot welding."[18]

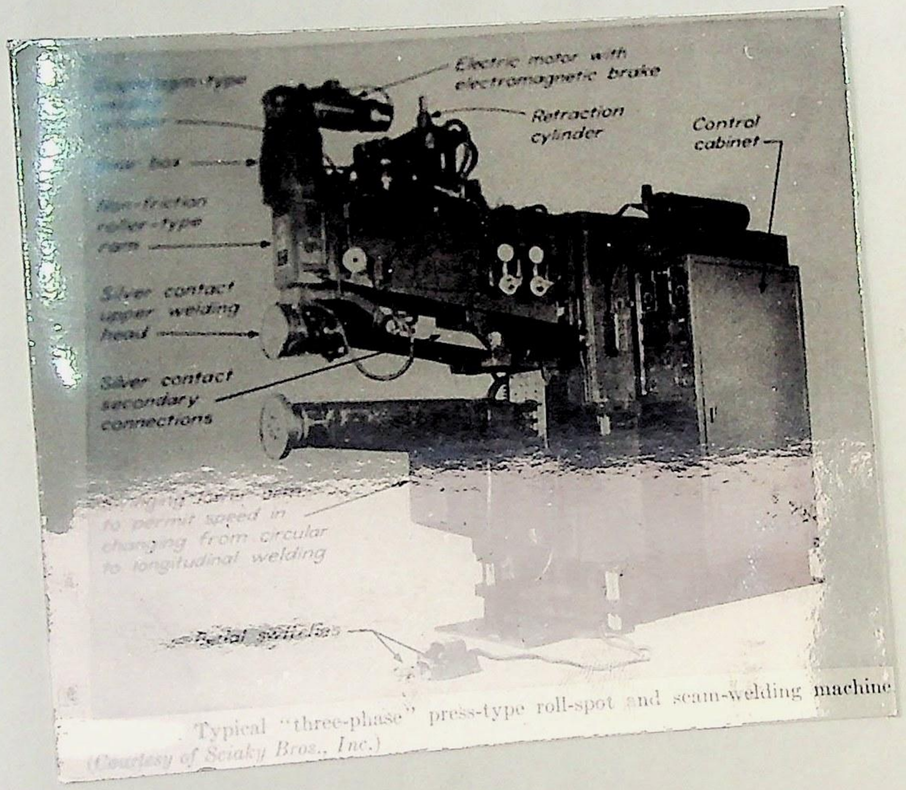
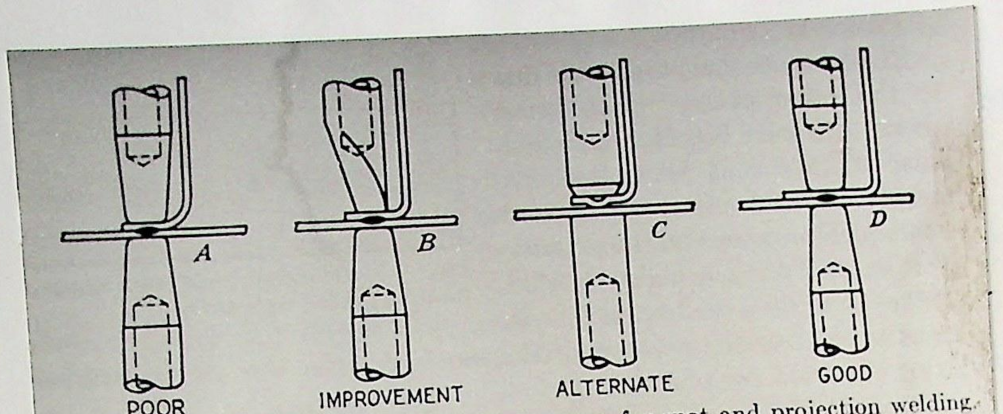


Fig. 32 Typical "three-phase" press type roll-spot and seam-welding machine.



Proper and improper electrode clearance for spot and projection welding.

Fig. 33. Detail of correct and incorrect methods of aligning electrodes for spot welding.

"Kitchen-utensil manufacturers were among early users of the process. They substituted the process for riveting and so welded handles to pans. In addition, the process was adopted by the wagon manufacturers after it was shown that the process could greatly reduce production costs. In the early days of resistance welding, however, widespread adaptation of the process was retarded in part by the fact that one company only controlled the manufacture and installation of equipment. After 1916, on the other hand, when five companies were licensed to make resistance welding equipment, application of the process for spot welding came into general use." 18

Resistance welding is one of the most used welding processes today, having many applications in the industrial and domestic markets.

IX. Oxyacetylene Process

"It is Le Chatlier a Frenchman who, in 1895 established the experimental basis for what we know today as oxyacetylene welding and cutting. In a now well-known paper delivered before the Academie des Sciences, he described how the temperature of the flame from the combustion of acetylene with oxygen produced a temperature far greater than that encountered with any other previously known gas flame. He further described how the combustion of acetylene with an equal volume of oxygen proceeds in two stages - which, today, is precisely how combustion proceeds when using modern oxyacetylene welding or cutting torches." [20]

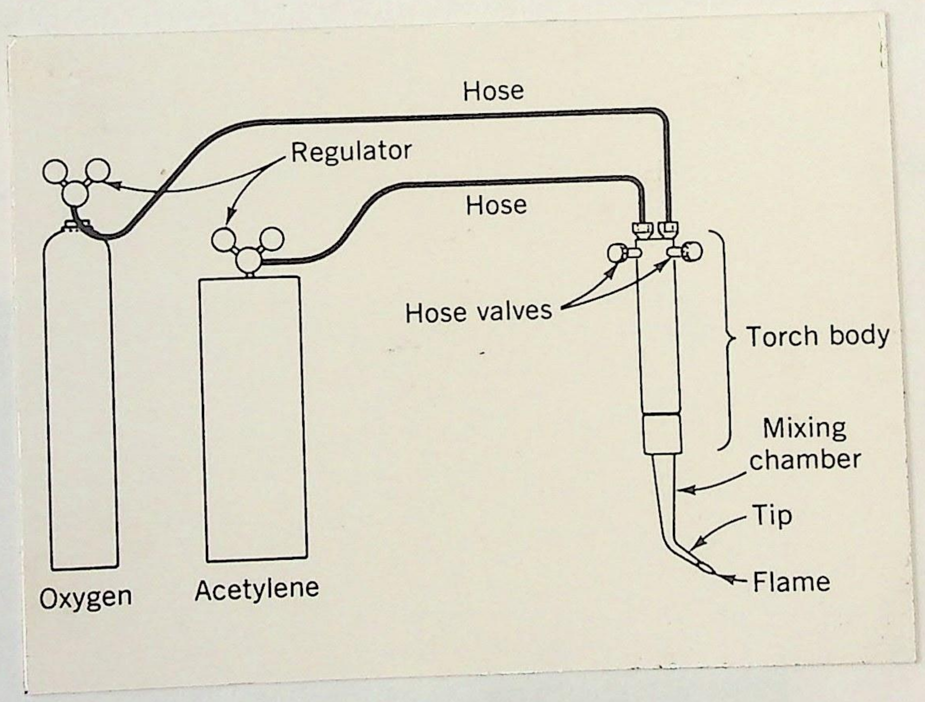


Fig. 34 Schematic drawing of oxyacetylene welding equipment.

"The work of Le Chatlier attracted the attention of others who sought to develop torches which would permit use of the oxyacetylene flame for welding. Thus torches appeared in 1901 and, by 1903, oxyacetylene welding began to be applied industrially. It is shortly afterwards - 1904 and 1905 - that torches were introduced commercially for cutting".[21]

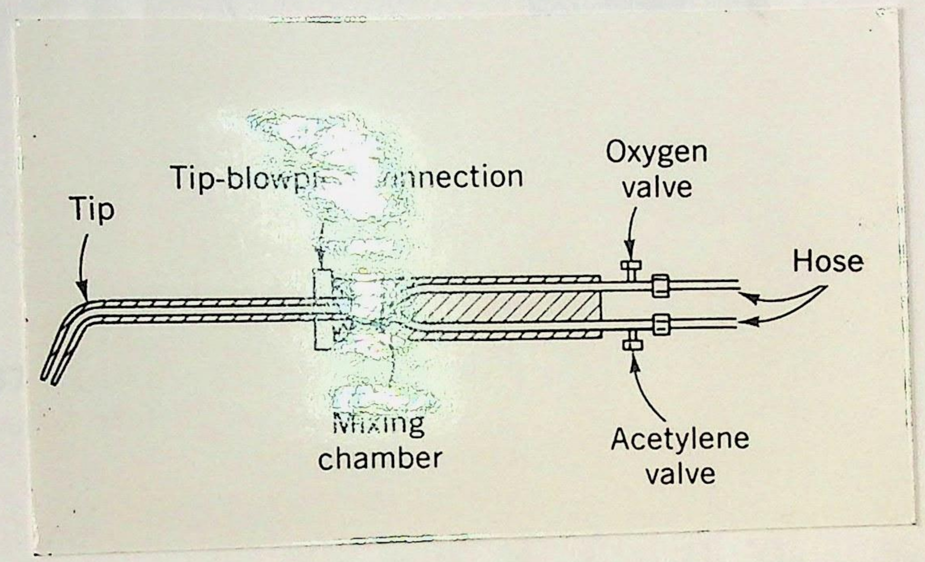


Fig. 35. Schematic drawing of oxyacetylene welding torch.

Fig. 36 Typical gas welding operation.

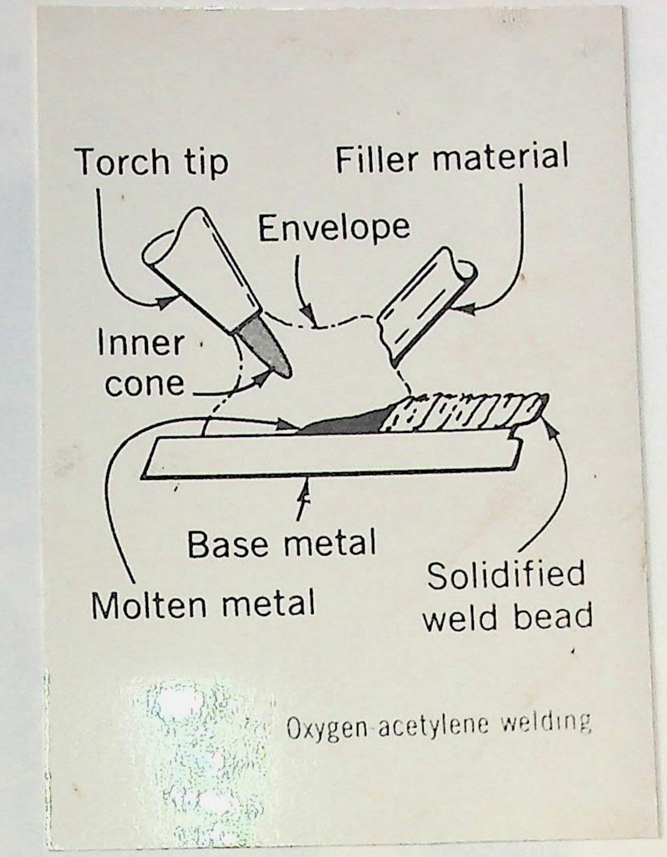


Fig. 37 Schematic drawing of oxyacetylene welding process.

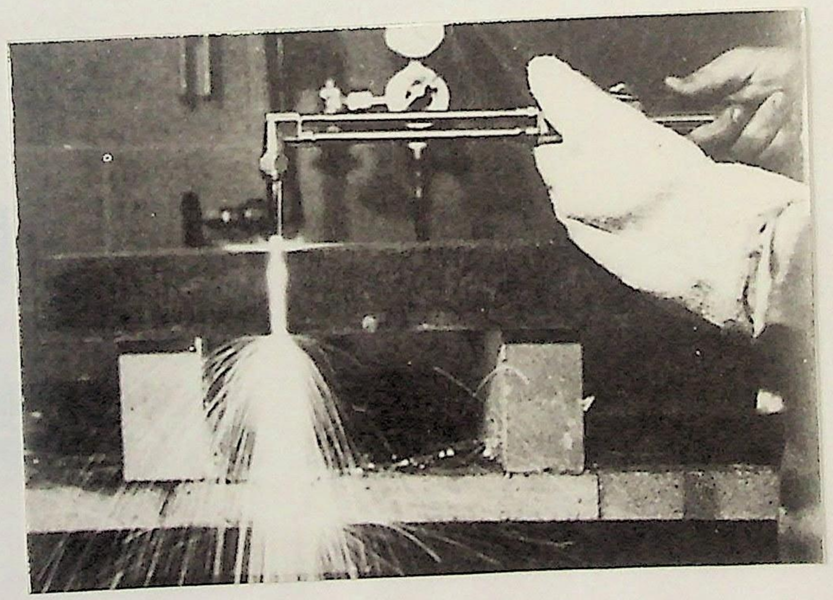


Fig. 38 Modern standard cutting torch in operation.

Various types of machine cutting systems using oxyacetylene.

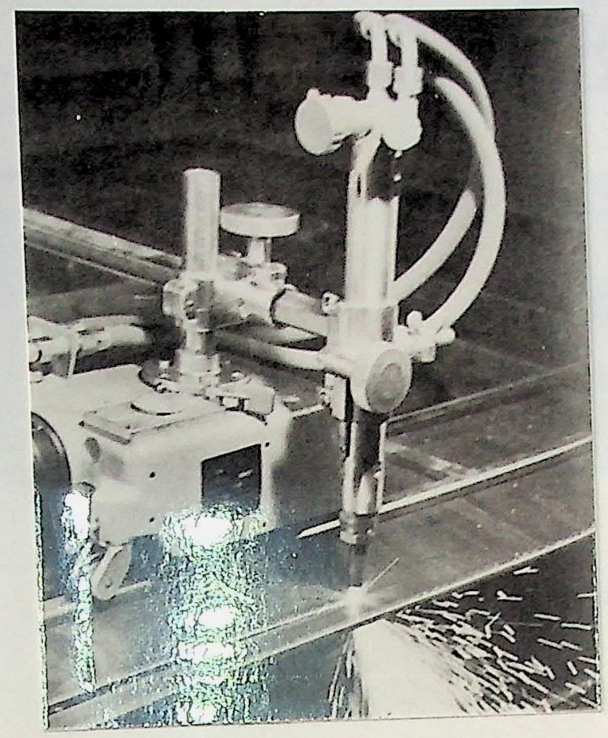


Fig. 39 Portable single-cutting torch.

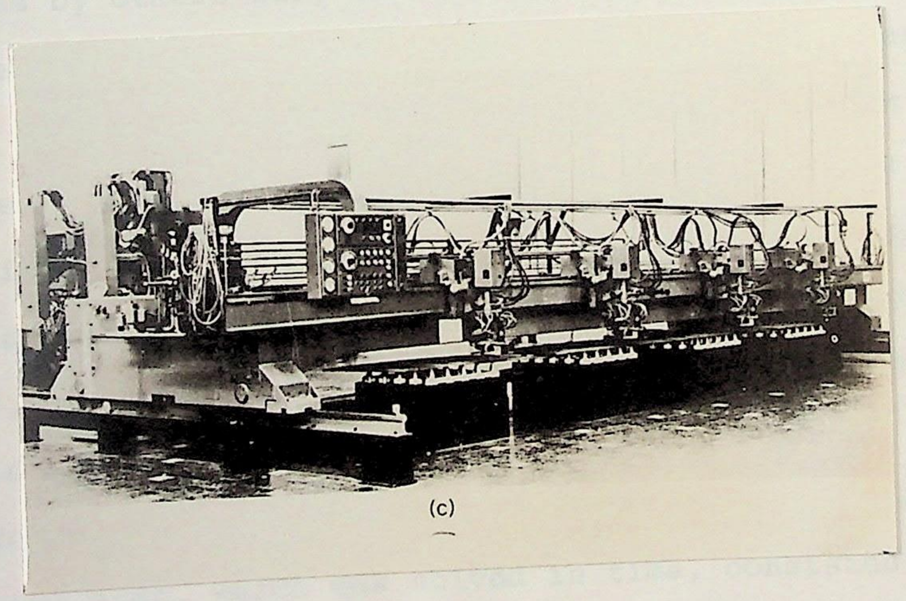


Fig. 40 Numerically controlled cutting machine.

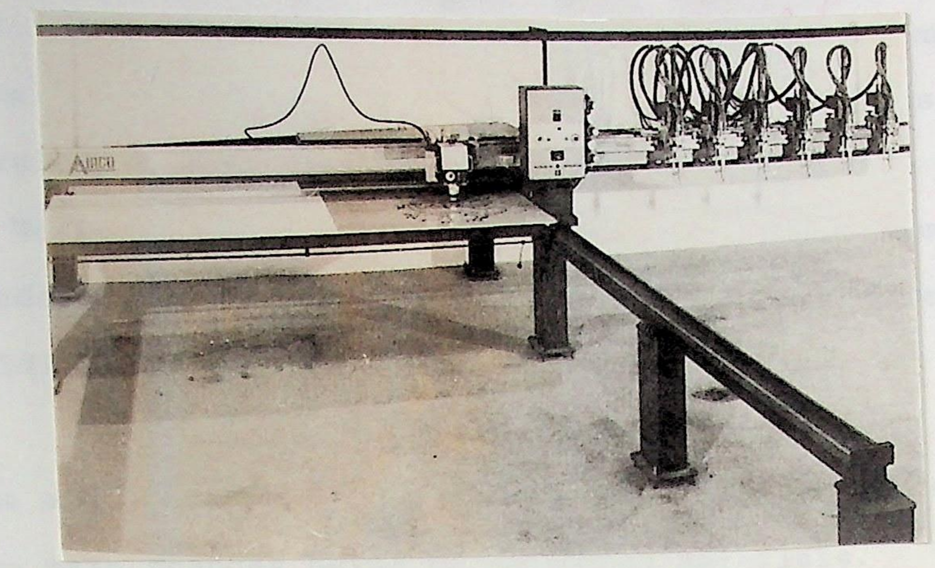


Fig. 41 Stationary pantographic multiple-cutting machine.

"The work by Le Chatlier coupled with the development of torches by others was, in itself, not sufficient to ensure the future success of the oxyacetylene process. Other requirements were a source of acetylene and a source of oxygen. Coincidentally with the work of Le Chatlier, a method for commercially producing calcium carbide from which acetylene is made was discovered at Spray, N.C., in 1892; also, in 1895 a machine for making liquid air was placed in operation and was soon to be the forerunner of processes for manufacturing oxygen. The next step, which was solved in time, consisted of devising methods to supply both gases in steel cylinders for transportaion to points of use.

Oxyacetylene welding - particularly for repair work - and cutting received almost immediate acceptance among steel fabricators. However, the greatest impetus to development of the process did not come until the years of World War 1. Then, under the stress of wartime needs during 1914-1918 the effectiveness of oxyacetylene welding and cutting became remarkably clear." [22]

The actual process has changed little since that time, the main changes being in equipment materials. It can be said that the two World Wars gave the necessary impetus required by the industry to develop. These were employed afterwards commercially, which in turn provided the necessary capital for research and development work. Some new processes developed since the Second World War are gas metal-arc, electron beam, electroslag and electrogas, plasma and most recently - the laser. All have had and will continue to have their use as have and will the older processes.

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[17] Editorial Staff of 'Welding Journal', <u>An Industry in Retrospect - Fifty Years of Progress</u>, April, 1964, pp165-169.

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G L O S S A R Y

Arc Cutting: A group of cutting processes wherein the severing of metals is effected by melting with the heat of an arc between an electrode and the base metal.

Arc Voltage: The voltage across the welding arc.

Arc Welding: A group of welding processes wherein coalescence is produced by heating with an electric arc of arcs, with or without the application of pressure and with or without the use of filler metal.

Axis of a Weld: A line through the length of a weld, perpendicular to the cross section at its centre of gravity.

Back Weld: A weld deposited at the back of a single-groove weld.

Bare Electrode: A filler-metal electrode, used in arc welding, consisting of a metal wire with no coating other than that incidental to the drawing of the wire.

Bare Metal-Arc Welding:	An arc welding process wherein coalescence is produced by heating with an electric arc between a bare or lightly coated metal electrode and the work. No shielding is used. Pressure is not used and filler metal is obtained from the electrode.
Base Metal:	(Parent metal). The metal to be welded or cut.
Brazing: (noun)	A group of welding processes wherein coalescence is produced by heating to suitable temperatures above 800F and by using a nonferrous filler metal having a melting point below that of the base metals. The filler metal is distributed between closely fitted surfaces of the joint by capillary attraction.
Carbon Arc Cutting:	An arc cutting process wherein the severing of metals is effected by melting with the heat of an arc between a carbon electrode and the base metal.
Carbon Arc Welding:	An arc welding process wherein coalescence is produced by heating with an electric arc between a carbon electrode and the work and no shielding is used. Pressure may or may not be used and filler metal may or may not be used.

Carbon Electrode: Carbon or graphite rod through which current is conducted between the electrode holder and the arc in arc welding. A non-filler-metal electrode.

Cire Perdue: See waste wax process.

Coalescence: (1) growth of particles of a dispersed phase by solution and reprecipitation, (2) the growth of grains by absorption of adjacent undistorted grains.

Complete Fusion: Fusion which has occurred over the entire base metal surfaces exposed for welding.

Covered Electrode: A filler-metal electrode, used in arc welding consisting of a metal core wire with relatively thick covering which provided protection for the molten metal from the atmosphere, improves the properties of the weld metal and stabilizes the arc.

Current Regulator: An automatic electrical control device for maintaining a constant current in the primary of the welding transformer.

Cutting Tip: (Nozzle) That part of an oxygen-cutting torch from which gasses issue.

Cutting Torch:	A device used in oxygen cutting for controlling and directing the gasses used for preheating and the oxygen used for cutting the metal.
Depth of Fusion:	The distance that fusion extends into the base metal from the surface melted during welding.
Die: In Resistance Welding.	A member usually shaped to the work contour to clamp the parts being welded and conduct the welding current.
In Forge Welding.	A device used in forge welding primarily to form the work while hot and apply the necessary pressure.
Deposited Metal:	Filler metal that has been added during a welding operation.
Effective Length of Weld:	The length of weld throughout which the correctly proportioned cross-section exists.
Electrode: In Arc Welding	See Bare Electode, Carbon Electrode, Covered Electrode, Lightly Coated Electrode, Metal Electrode and Tungsten Electrode.

Electrode :

In Resistance Welding — The parts or part of a resistance-welding machine through which the welding current and, in most cases, pressure are applied directly to the work. The electrode may be in the form of a rotating wheel, roll, bar, cylinder, plate, clamp, chuck, or modification thereof.

Electrode Holder: — A device used for mechanically holding the electrode and conducting current to it.

Enamel: — A vitreous (glassy) material applied in powdered form to a metal background and then fused. Various metallic oxides are used to produce different colours.

Filigree: — Ornament formed by soldering wires of various types to a metal background.

Filler Metal: — Metal to be added in making a weld.

Flux: — Fusable material or gas used in welding or oxygen cutting, either to dissolve or prevent the formation of oxides, nitrides, or other undesirable inclusions, or both.

Forge Welding: A group of pressure welding processes wherein the parts to be welded are brought to suitable temperatures by means of external heating and the weld is consummated by the pressure of blows.

Fusion: The melting together of filler metal and base metal, or of base metal only, which results in coalescence. (see Complete Fusion, Depth of Fusion).

Gas Welding: A group of welding processes wherein coalescence is produced by heating a gas flame or flames, with or without the application or pressure, and with or without the use of filler metal.

Gilding: The application, in whole or in part, of a thin layer of gold to an object, e.g. silver gilt.

Ground Connection: (Welding Ground) The connection of the work lead to the work.

Hammer Welding: A forge welding process wherein coalescence is produced by heating in a forge or other furnace and by applying pressure by means of hammer blows.

Induction Welding: A welding process wherein coalescence is produced by heat obtained from resistance of the work to the flow of induced electric current, with or without the application of pressure.

Inert-gas Metal-Arc-Welding: An arc-welding process wherein coalescence is produced by heating with an electric arc between a metal electrode and the work. Shielding is obtained from an inert gas such as helium or argon. Pressure may or may not be used, and filler metal may or may not be used.

Joint: (unwelded) The location where two or more members are to be joined by welding.

Lightly Coated Electrodes: A filler metal electrode, used in arc welding, consisting of a metal wire with a light coating applied subsequent to the drawing operation. Used primarily for stabilizing the arc.

Manual Oxygen Cutting: Oxygen cutting wherein the entire cutting operation is performed and controlled by hand.

Manual Welding: Welding wherein the entire welding operation is performed and controlled by hand.

Melting Rate: The weight or length of electrode melted in a unit of time.

Metal Arc Cutting: An arc cutting process wherein the severing of metals is effected by melting with the heat of an arc between a metal electrode and the base metal.

Metal Arc Welding: See: Shielded metal-arc welding, submerged arc welding, bare metal-arc welding, inert-gas metal-arc welding and stud welding.

Metal Electrode: A filler or non-filler metal electrode, used in arc-welding, consisting of a metal wire, with or without a covering or coating.

Millefiori: Originally flower motifs produced by casing a cane of glass with several layers of differently coloured glass, rolling on a corrugated surface and cutting into short lengths. Other designs are produced by laying together glass rods of different colours and fusing them. The whole then being drawn, cut and set, in the Irish examples in a background of red enamel.

Mixing Chamber: That part of a gas-welding or oxygen-cutting torch wherein the gases are mixed for combustion.

Multiple Carbon Arc Welding: See Twin-carbon arc welding.

Oxyacetylene Cutting: An oxygen-curring process wherein the severing of metals is effected by means of the chemical reaction of the necessary temperature being maintained by means of gas flame obtained from the combustion of acetylene with oxygen.

Oxyacetylene Welding: A gas welding process wherein coalescence is produced by heating with a gas flame or flames obtained from the combustion of acetylene with oxygen, with or without the application of pressure and with or without the use of filler metal.

Parent Metal: See Base Metal.

Polarity: Direction of flow of current.

Porosity: Presence of gas pockets or voids in metal.

Pressure Welding: Any welding process or method wherein pressure is used to complete weld.

<u>Regulator</u>: A device for controlling the delivery of gas at some substantially constant pressure regardless of variation in the higher pressure at the source.

<u>Repoussé</u>: Decorative motifs in relief produced by heating from the back. Usually the design is finished from the front by chasing with punches and hammers.

<u>Resistance Welding</u>: A group of welding processes wherein coalescence is produced by the heat obtained from resistance of the work to the flow of electric current in a circuit of which the work is a part and by the application of pressure.

<u>Root of Weld</u>: The points at which the bottom of the weld intersects the base metal surfaces.

<u>Seam Weld</u>: A weld consisting of a series of overlapping spot welds made by seam welding or spot welding.

<u>Shielded Metal-Arc Welding</u>: An arc-welding process wherein coalescence is produced by heating with an electric arc drawn between a metal-stud, or similar part, and the other work part until the surfaces to be joined are properly heated when they are brought

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Root of Weld: The points at which the bottom of the weld intersects the base metal surfaces.

Seam Weld: A weld consisting of a series of overlapping spot welds made by seam welding or spot welding.

Shielded Metal-Arc Welding: An arc-welding process wherein coalescence is produced by heating with an electric arc drawn between a metal-stud, or similar part, and the other work part until the surfaces to be joined are properly heated when they are brought together under pressure. Shielding is obtained from an inert gas such as helium or argon.

Slag Inclusion:	Non-metallic solid material entrapped in weld metal or between weld metal and base metal.
Spot Welding:	A resistance welding process wherein coalescence is produced by the heat obtained from resistance to the flow of electric current through the work parts held together under pressure by electrodes. The size and shape of the individually formed welds are limited primarily by the size and contour of the electrodes.
Stud Welding:	An arc-welding process wherein coalescence is produced by heating with an electric arc drawn between a metal stud, or similar part, and the other work part until the surfaces to be joined are properly heated. They are then brought together under pressure. No shielding is used.
Submerged Arc	An arc-welding process wherein coalescence is produced by heating with an electric arc or arcs between a bare metal electrode or electrodes and the work. The welding is shielded by a blanket or

granular, fusible material on the work. Pressure is not used, and filler metal is obtained from the electrode and sometimes from a supplementary welding rod.

<u>Tungsten Electrode</u> A non-filler-metal electrode, used in arc welding, consisting of tungsten wire.

<u>Twin-Carbon-Arc Welding</u>: (Multiple-Carbon-Arc Welding). An arc welding process wherein coalescencence is produced by heating with an electric arc and maintained between two carbon electrodes and no shielding is used. Pressure is not used, and filler metal may or may not be used.

<u>Voltage Regulator</u> An automatic electrical control device for maintaining a constant voltage supply to the primary of a welding transformer.

<u>Waste Wax Process</u>: (also called cire perdue). A form of metal casting by which a mould of clay is formed over a model of wax. By heating the mould, the wax is drained or 'lost' and the hollow remaining is filled with molten metal. When the metal has cooled, the mould is broken to reveal the object which can then be finished.

Weld:	A localized coalescence of metal wherein coalescence is produced by heating to suitable temperatures, with or without the application of pressure and with or without the use of filler metal. The filler metal has a melting point approx. the same as the base metals or has a melting point below that of the base metals but above 800F.
Weldability:	The capacity of a metal to be welded under the fabrication conditions imposed into a specific, suitably designed structure and to perform satisfactorily in the intended service.
Welded Joint:	A localized union of two or more members produced by the application of a welding process.
Welder:	One who is capable of performing a manual or semiautomatic welding operation.
Welding: (noun)	The metal joining process used in making welds.
Welding Current:	The current flowing through the welding circuit during the making of a weld. In resistance welding, the current used during preweld or post weld intervals is excluded.

Welding Generator:	A generator used for supplying current for welding.
Welding Machine:	Equipment used to perform the welding operation. For example, spot-welding machine, arc-welding machine, seam welding machine, etc.
Welding Pressure:	The pressure exerted during the welding operation on the parts being welded.
Welding Rod:	Filler metal, in wire or rod form, used in gas welding and brazing processes and those arc-welding processes where the electrode does not furnish the filler metal.
Welding Transformer:	A transformer used for supplying current for welding.
Weldment:	An assembly whose component parts are joined by welding.
Work Lead:	The electric conductor (cable) between the source of arc-welding current and the work.
Work:	A term used in this case to describe the operation of welding a produce.

Note: Technical glossary extracted from "<u>Welding Engineering</u> by Rossi, McGraw-Hill, New York. 1954 and '<u>Artists and Craftsmen</u>' National Museum of Ireland 1980.

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