# Welding Kaleidoscope in India

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### Introduction

Man had learnt the art of fashioning and joining of metals by forge welding and brazing from the period of bronze age. Welding of the present era can be traced to the discovery of carbon arc welding by the Russian scientist Barnardos in 1880. Contrary to the popular belief, arc welding and oxyfuelgas cutting were discovered and industrially used before gas welding. Some of the modern spectacular achievements of mankind would not have been possible but for the developments in welding and allied processes. Some of the historic milestones in the development of welding processes since the discovery of Barnardos, are given in Annexure I.

Between the two world wars, welding has shown phenomenal progress. The pioneers in welding technology had hoped that someday welding technology would be accepted as a "technological discipline" by its own rights. Today, their selfless dedication and efforts have borne fruit; their hopes and aspirations were not mere abstract imagination. In many countries, including India, welding technology is now in the curriculum of post-graduate studies. The International Organisation for Standardization (ISO) has a Technical Committee on Welding (ISO/TC-44) and the International Institute of Welding (IIW) was established in June 1948; the latter body maintains close liaison with the International Organisation for Standardization—in fact, much of the basic work of the Technical Committee on Welding of ISO is done in the various Commissions and Study Groups of the International Institute of Welding. India is a member of both these International Bodies—of ISO through the Indian Standards Institutions, and of IIW through The Indian Institute of Welding.

In the context of modern applications of welding, the processes cover broadly the technique and art of joining two or more pieces of material—metal and/or non-metal—by localised coalescence across an interface (or interfaces), with or without the application of heat, with or without the application of pressure and with or without the application of filler material so that a continuous homogenity may be obtained. A list of welding and allied processes is given in Annexure II. From a very humble beginning, welding and allied processes today come to play a dominant role in industry all over the world. Dr. R. Weck, Director General, Welding Institute (U.K.) in delivering the Cantor Lecture to the Royal Society of Arts in 1973, said of welding—"there is no other production process used by so many different industries or that affects the operation of so many. Equally, no other production process requires so much real understanding."

### Three Decades of Welding in India :

Until the middle of 1930s, welding was mainly used for repairs and reclamation. A few foot over bridges fabricated entirely by welding by the then BB & CI Railway were, perhaps, the first few completely welded constructions in India. Another important welded fabrication around that period was the structure of the Brabourne Stadium. However, the biggest impetus to the use of welding as a tool of fabrication commenced from the World War II—in real terms from 1940.

#### (i) The Decade of 1940s

During the war years, India became an arsenal for supply of a large variety of war stores and materials making extensive use of welding and cutting processes. Ships, barges and landing rafts were repaired by the use of these processes in the shiprepairing workshops in Indian ports. From the aspect of welding, important developments were large scale production of armoured vehicles by oxyfuelgas cutting and welding from armour plates produced in India by TISCO-initial tests having been carried out at Rawalpindi arsenal towards the end of 1939, production of Jerricans by welding at the Jerrican Factory, Madras, installation of welded oil storage tanks, welding of the oil pipelines between Bombay and Busawal and in Eastern India, oxyfuelgas scarfing for reconditioning of steel blooms, billets and slabs by TISCO—the first Indian steel works to adopt this process. Processes introduced and adopted by industry during this period were brazing with silver brazing alloys, metal spraying, surfacing by arc welding including resurfacing of railway points and crossings, surfacing with cobalt base hardfacing alloys. It was during this period, copper locomotive fireboxes were repaired by oxyacetylene welding at the Parel Workshop of GIP Railway. Also during this period, arc welding was initially used for fabrication of tanks of railway tank wagons; while most of the fabricators used manual metal arc welding (MMA), a few used mechanised carbon arc welding —filler wire and a tape flux being mechanically fed into the molten pool.

With the cessation of hostilities, a different pattern of industrial growth commenced. The first Indian manual metal arc welding electrode factory commenced production towards the end of 1947. A few river valley projects, construction of Chittaranjan Locomotive Works, Hindusthan Shipyard, Hindusthan Motors etc. had commenced. The factory building of the last named workshop was of fully welded construction.

It was during this period that certain fundamental differences in the approach between the various approving authorities became apparent—Lloyds and Mercantile Marine Department responsible for approval of work relating to ships and vessels for inland waterways permitted the use of machine oxyfuelgas cutting for preparation of plate edges for subsequent welding but the Department of Inspection of the Government of India responsible for approval and inspection of fabrications on behalf of the Railways and other Government Departments insisted that every oxyfuelgas cut edge must be machined back 6.3 mm (¼) from the cut edge—this was insisted even in case of preparation of plate edges for subsequent welding. This ruling was, however, changed some years later.

### (b) The Decade of 1950s

This was the golden decade of Indian industry. The First Five Year Plan was launched and was followed by the Second Five Year Plan the major portion of which was also in this decade. Many nation building activities were commenced. Steel production was increased by expansion of the existing steel works and by establishment of new ones, railways were expanded, production of locomotives, railway carriages, automobiles, fertilizers etc. were commenced. River valley projects gathered momentum and new ones were undertaken—the list is endless. These developments kept industry fully occupied, compelling expansion of the existing manufacturing facilities and establishement of new ones, requiring new capital investments. Welding and cutting processes were being increasingly used. Many new welding processes were introduced and industrially applied viz submerged arc welding (SAW), automatic arc welding with continuous coated electrodes (Fusarc), gas tungsten arc welding (GTAW or TIG), gas metal arc welding (GMAW or MIG), firecracker welding and foil welding (a combination of seam and mash welding with a foil filler).

Some of the interesting applications were: extensive use of various welding processes in the construction of integral railway coaches, welded-cum-rivetted BOX wagons (containing approximately 1350 m of welds all welds equated to 6.3 mm size fillet), welded pipe-lines for oil and water, oil refineries, rail-cum-road bridges (with fully welded floor and partially welded verticals), penstock, flood control sluices, gates (of various river valley projects) etc. In shipbuilding, commencing with 20 percent welded design, the extent of welding was raised to nearly 70 percent and was employed in the fabrication of double-bottom floors with girders, bulkheads with frames, 'tween and top decks, derricks, masts, pillars, sternframes, rudders, tunnels, partly welded keel and shell plate butts (seams rivetted).

All these developments, made increased demands for oxygen, acetylene, electrodes, equipment etc. A second electrode manufacturer established production and the first manufacturer also increased their production and later there were other entrants in the field of manufacture of welding products. In this period, new forms of distribution of oxygen through pipeline from evaporation of liquid oxygen and also directly from the production factory, were introduced. Also local production of arc welding equipment (mainly transformer welding sets), gas welding and cutting equipment' various types of welding rods, brazing alloys, argon etc, were commenced.

It was during this decade that resurfacing of railway points and crossing and of switch rails at situ and under traffic conditions by oxy-acetylene welding was introduced and proved highly successful. Despite this being a very hot job, it is still being extensively used in some of the Indian railways because of highly satisfactory results. Another interesting development was the introduction of (hard) surfacing with tubular manual arc welding electrodes depositing chromium carbide in an austenitic matrix (general hardness Rc-60 and carbide hardness Rc-72) and tungsten carbide composite in high carbon matrix (general hardness Rc 56 and carbide hardness Rc 90). Local manufacture of tubular electrode depositing chromium carbide in austenitic matrix type electrode, has now commenced and the other type may also be available in the near future. The possibility of substituting partly or wholly, tungsten carbide with titanium carbide, not only in the case of electrodes but also for sintered hard metal tool tips, should be investigated. This suggestion is based on the fact that deposits of titanium bearing materials in this country in comparison to wolframite etc. are far more extensive. Titanium carbide (sometimes in combination with tungsten carbide) sintered tool tips are extensively used in many industrially advanced countries and in performance, these are equal to sinstered tungsten carbide tool tips, if not better for some applications.

It was in this decade, standardization activity in the field of welding was commenced and the first welding standard was published in 1957.

### (c) The Decade of 1960s

The Second Five Year Plan spilled over into 1960 and the Third Five Year Plan commenced. The industrial climate of this decade was somewhat mixed. In the first half, the tempo of industrial activity of the preceding decade was maintained but in the second half there were definite trends of industrial recession. Nevertheless, many important projects were undertaken and some of the older ones were kept going.

Manufacture of power and energy generation plant and equipment, plant for petro-chemical complexes, of aircraft jet engines etc. were commenced. New welding and cutting processes continued to be introduced—to name a few, machine scarfing of steel bloom and slabs on the rolling mill line, electro-slag welding, plasma arc cutting, gas metal arc welding (GMAW or MIG) of ferritic steel with carbon dioxide gas shielding, oxyfuelgas cutting with profile cutting machines having photoelectric tracing heads and also with ratio cutting machine (the last one at Hindusthan Shipyard), resurfacing of some important steel mill components such as blast-furnace bell, rolling mill rolls etc., by submerged arc welding, gravity welding etc. Many new and varied welding equipment and consumables were being manufactured in the country for the first time—such as some types of the filler wires and fluxes for submerged arc welding, filler wires for GMAW or MIG welding, more varieties of transformer welding power sources, motor generator rectifier power sources, a few types of resistance welding machines, smaller oxyfuelgas cutting machines, gas tungsten arc welding (GTAW or TIG) equipment, Fusarc continuous coated electrodes, gravity welding electrodes etc.

### Discussion:

First half of the next decade is nearly over; notwithstanding the somewhat mixed industrial picture, only a pessimist would possibly predict a gloomy future. Crystal-gazing is always dangerous, but some conclusions can be drawn with high degree of probability. If one has to go by the trends over the past few years and also considering some of the future industrial possibilities, this country has every reason to hope for resurgence of increased industrial activity in the future years. Against such a possibility, some of the welding processes, equipment and applications are being discussed.

### (i) Thermal Cutting

In the shaping and forming of metal components, thermal cutting processes play significant role. The processes which are of importance, are: (a) air carbon arc cutting (mainly used in iron and steel foundry fettling operations and in welding for removal of weld defects and underside of weld seams); (b) laser beam cutting (though metals can be cut, this process till now is mainly used industrially for extremely high speed cutting of wood, plastics, fabrics, etc with high degree of accuracy); (c) plasma arc cutting (large scale industrial applications being high speed cutting and fashion of corrosion and heat resisting steels, aluminium and its alloys and a number of metals and alloys not normally "cutable" by the normal oxyfuelgas cutting processes) and (d) oxyfuelgas cutting.

Oxyfuelgas cutting—both manual and machine—is by far the most commonly used cutting process, for preparation of plate edges for subsequent welding and for shaping and forming of "cutable" steels, machine cutting is mainly used.

Straight line and circle cutting machines with their variations are the simplest of the cutting machines. Oxy-plane cutting machine was developed and used for simultaneous edge preparation of the four sides of a plate. Investment in such a machine can only be worthwhile if a workshop is solely engaged in manufacture of large diameter welded pipeline, penstocks or similar items, ensuring high work load on the machine. Unless this can be ensured, investment in such a machine can be only a luxury. Furthermore, development of co-ordinate drive cross-carriage profile cutting machine, of ratio cutting machines and of numerically-controlled (N-C) cutting machines has very substantially reduced the demands for oxy-plane cutting machines; as these comparatively new cutting machines can do all that an oxy-plane cutting machine can do, and also substantially more.

The simplest of the profile cutting machines are the pantograph and the articulated arm types; these machines carry a magnetic stylus which follow the path round a steel template. The operating ranges i.e. the area of cutting, of these cutting machines are rather small. The next in the range are the cross-carriage type cutting machines whose range can easily vary from approximate 0.5m to 4.0m in width and in length (at least in theory) as long as the lengths of the travel rails. These machines also trace the profiles to be cut with the help of magnetic stylus fitted to one end of the travelling cross arm. With the development of photo-electric tracing device, it was possible to cut shapes following line or silhouette drawings but the tractive force obtained from a serrated drive wheel controlled by the photocell tracing device and riding on the perspex sheet or on a rubberised roller across the width of the machine, was not entirely satisfactory. Improvements were achieved through the use of co-ordinate drive servo-motors and cutting of large shapes from scale drawings accurately became comparatively easy. Both these types of cutting machines can be fitted with multiple cutting burners permitting simultaneous cutting of a number of identical shapes at the same time. Also with these machines, it is possible to cut bevels parallel to the carriage.

The next phase of development was possible due to improvements achieved in photocells and electronics, these permitting the use of reduced scale drawing in the ratios of 1 : 1, 10 : 1 and 100 : 1. Besides, these machines can be mounted with a number of cutting blowpipes permitting cutting of a number of shapes within the range of the machine at the same time and also when mounted with three burner cutters (for top bevel, nose and bottom bevel) for bevel cutting along curved edges. The machines are usually fitted with many automated devices such as cutter height sensing device, cutter lighting device etc. Usually in such machines, the drawings are placed in a console or a table in the machine and the operator rides with the machine which are of robust portal gantry type, the main drive being through co-ordinate servo motors controlled by the tracing photocell. From the ratio machines finally emerged the computor controlled NC cutting machines as the backbone of integrated flowline fabrication. These machines similar to the ratio cutting machine are of portal construction and have all the features of ratio cutting machines and in addition can be fitted with automatic marking device etc. These machines are highly accurate machine tools, accuracy being of the order of ±0.63mm (0.025 in) or less within the machine range. In order to maintain this accuracy, generally plates prior to cutting are straightened by using plate stretcher, some of these machines even incorporate provisions for vacu-blasting of both sides of the plate and painting it with a quick drying priming paint. Additionally, nesting of the shapes to be cut on the drawing (in case of ratio machine) or on the tape (in case of N. C. machine) permit best utilization of plates with minimum of scrap loss. With the introduction of these machines, lofting, template making, plate marking are totally eliminated. A useful adjunct to a N. C. cutting machine is a N-C drafting machine with director with which it is possible to nest easily profiles of like thickness from a number of tapes containing programmes of profiles; this also provides a visual means of checking the drawings and nesting. These cutting machines are costly; depending on the size and various ancilliaries, these machines can be well over Rs. 10 lakhs or more. To maximise the utilization of these machines, workshops layout is extremely important in respect of loading and unloading of the work on the machine, their nearness to other machines etc.; With each machine, if not supplied with double work area, it will be desireable to order extra rails for doubling the work area, so that while one plate is being cut in one area, the already cut plate can be removed and a new plate placed in position for cutting. This permits higher utilization (almost 100%) of these costly machines.

In what direction does the future lie—template controlled machines will always find a place in smaller workshops for occasional repeat jobs, the medium size workshops will prefer photocell controlled machines of the cross carriage and co-ordinate drive types, but on integrated production line basis the choice lies between the ratio cutting machine and N-C cutting machine of the portal type because of their high quality performance. It may be, however, noted that most of the modern profile cutting machines are fitted with cutters for high speed cutting and most can be fitted with also plasma arc cutting torches. In cutting a large number of profiles from a plate, attention must be paid to the starts and stops of the cut to prevent distortion of the profiles.

### (ii) **Manual Metal Arc Welding (MMA)**

Manual metal arc welding is by far most commonly used for fabrication, not only in India, but all over the world. The reasons for this are not far to seek—low capital investment, the flexibility and versatility of the process are the main attractions. Nevertheless, in the industrially advanced countries, a feeling exists that the growth rate of this process will slow down and that this process may be even supplanted in many applications by gas metal arc welding (GMAW or MIG) and flux cored arc welding (FCAW). One may rightly ask—what are the possibilities in India? It is felt that in the next decade, if not in the next two decades, manual metal arc welding will maintain its growth rate firstly because of the possible substantial increase in steel production and also because of the change in the pattern of steel product mix—flat products requiring more application of welding. Higher capital investment required for gas metal arc welding (GMAW) and for flux cored arc welding (FCAW) together with high costs of consumables for these processes will, perhaps, deter extensive adoption of these processes, especially by small and medium sector industries. Notwithstanding such a possible situation, there is every prospect of very substantial increases in the growth rates of usage of GMAW and FCAW processes, which are not extensively used currently.

A very large variety of power sources are presently manufactured in the country, viz. single and multi-operator transformers; motor, belt and engine driven generators and rectifiers. Transformers are by far the most popular power sources for manual metal arc welding. It may be worth noting that in many countries including the USA and many European countries d.c. output power sources were more popular a few years ago but recently there has been a reversal of this trend. A very significant achievement of many manufacturers in India is the use of aluminium conductors for the windings of the welding transformers saving very substantial imports of copper. While aluminium windings in welding transformers of moving coil or moving core types are used in some other countries as well, tapped choke type transformers in this country are being manufactured, at least by one manufacturer with aluminium windings for nearly the past decade—possibly India is one of the first few countries in the world to do it. On the power consumption aspect, the reputable manufacturers of this country, the author is sure, will not be willing to accept the views expressed by NCST Special Group on Joining Machinery. The author regrets to point out that the NCST Committee took no cognizance of a situation that exists in this country regarding the use of single phase transformer and single phase transformer/rectifier welding power sources. These welding power sources under the Indian Electricity Act cannot be directly connected to a 400/440 volts 3-phase supply. In industrially advanced countries such restrictions no longer exist. As a consequence of this restriction in India, small and medium sector industry most of whom do not have a high tension sub-station in their workshops, are compelled to use three to single phase transformers or 3-phase d.c. rectifier or motor generators; all these types of power sources require substantially more raw material i.e. core laminations and copper conductors most of which are imported, for their manufacture, in comparison with a single-phase transformer welding power source, and the d.c. power sources are also more energy consuming.

Although the normal type of multi-operator transformers are being manufactured in the country, not much attention has been yet given to the other types of multi-operator power sources. These types of power sources which may be transformers, rectifiers or generators, offer substantial advantages in respect of cost of installation and operational expenses for workshops having a large number of welding stations in a small area and a consistant welding load in all the shifts. If one assumes a small area of workshop where there are 50 welding stations and each operator using an average of 200 amp per arc for about 25 per cent of the time, with standard type of welding power sources each having an output of 300 amp, the total installed welding capacity will be 15,000 ampers; but with this special type of multi-operator welding power source which takes into account the diversity factor of operation, the output capacity required will be only 2,500 amps to handle this load. Such power sources, of necessity and in general, have to be tailored to individual requirements.

In the field of manual metal arc welding (MMA) consumable, sufficient degree of expertise has been developed in India. Almost all types of welding electrodes can be manufactured by the local manufacturers—given sufficient notice, one feels confident that the manufacturers can and do meet demands of special nature. No doubt one often hears that high metal recovery electrodes with high deposition rates are not extensively used in this country; these electrodes are popular in the industrially advanced countries. High deposition rate is not always synonymous with low welding cost. These high metal recovery electrodes contain large quantities of iron powder in the flux coating—the iron powder content varrying according to metal recovery rate aimed at and the metal recovery rate varying from 110 to 170 per cent. There are also electrodes with recovery rates of nearly 200 per cent or more. Indian electrode manufacturers know the technique of making these electrodes but the high prices of these electrodes do not make these attractive to the consumers; such is not the situation in the industrially advanced countries. The primary reason for this situation is the high cost of iron powder produced in India, by the electrolytic process. The price of iron powder in this country is approximately 60—70 per cent higher than those in the advanced countries. This factor alone makes the cost of the deposit obtained from iron powder approximately two to two and a half times more than that obtained from the solid core wire, thus nullifying the advantages that can be accrued from the use of iron powder electrodes. Of the many essential properties required in iron powder for electrode making an important one is the bulk density. Iron powder of bulk density of less than 2.5 gms per cc is not suitable for electrode manufacture. This property also limits the possible metal recovery rates—with iron powder of 2.5 gm per cc bulk density the maximum recovery rate will be in the region of 130-140 per cent; with iron powder of 3.5 gm/cc bulk density, the maximum recovery rate will be in the region of 170 per cent and for greater metal recovery rate, iron powder of higher bulk density is required. Electrolytic Indian iron powder has a bulk density in the region of 3-3.2 gm/cc; this will limit the metal recovery rate possible. Many processes are used for manufacture of iron-powder; various factors determine the cost of a product such as scale of operation, process employed, cost of energy used, cost of raw materials etc. Of the various processes used for iron-powder manufacture, the electrolytic processes are the costliest.

Iron powder is also used in the manufacture of flux-cored consumables used for flux cored arc welding and for submerged arc welding; the iron powder content in these consumables may be as high as 60 per cent by weight.

### (c) Gas Metal Arc Welding (GMAW) & Flux Cored Arc Welding (FCAW)

There is a striking similarity between these two processes excepting that with flux cored arc welding using certain types of tubular filler wire it is not necessary to use any shielding gas which is generated in the arc from the fluxes contained in the filler wire. The general types of equipment for these processes are now made in India and equipment for mechanised welding will also be shortly available. There, however, exists the necessity for extension of the variety viz equipment for pulsed arc welding, single knob control machines, equipment for feeding hot or cold secondary filler wire in the arc for increased deposition rate in mechanised welding. The range (i.e. the distance from the wire feed unit to the torch or gun) of Indian made equipment is about 5 meters—this can be a drawback for many applications. Extension of the range should be considered—a manufacturer in the USA can now offer equipment feeding wires upto a distance of about 70 meters and through 180° bends. The range of solid filler wires available locally are fairly limited and flux cored filler wires for flux cored arc welding will be, possibly available from local manufacture in the forseeable future.

Various gases and gas mixtures are used as shielding gas, the choice of the shielding gas depends on the metal or alloy to be welded. Contrary to the popular belief, many of these shielding gases are not inert—details given in Annexure III—Table 1. In the welding of carbon and low alloy steels by these processes one faces the problem of the choice of shielding gas viz Argon-Oxygen mixture or Argon-Oxygen—Carbon Dioxide mixture or Argon-Carbon Dioxide mixture or Carbon-Dioxide. Carbon Dioxide is a reasonably cheap gas but it produces a rather harsh arc and the metal transfer is spattery. In comparison, argon with 2-5 per cent oxygen gives a stable arc, promotes favourable metal transfer and minimizes spatter, thereby giving higher metal recovery rate—details given in Annexure III—Table 2. Now a days argon—oxygen mixture for this purpose is obtained as a by-product from large size oxygen plants as crude Argon which has an oxygen content of less than 5 per cent (usually about 2.0 per cent)and nitrogen content of less than 0.5 per cent (preferably less than 0.2 per cent). Production capacity of crude argon now and at a later date in this country will be sufficiently large. For gas tungsten arc welding (GTAW or TIG) high purity argon is used, this is produced by further refining of crude argon: this gas can be used as a shielding gas and carbon dioxide can be added to this gas if desired. It is felt that crude argon should be competitive in price with carbon dioxide but the price of a product is fixed not necessarily on the grounds of pure technical costings. The current trend in many countries is not to use pre-mixed bottled gases but to use gas mixing devices which give flexibility to the user of the process and many other advantages.

However, these gas mixing devices are not yet made in India and equipment manufacturers should consider manufacturing these in this country. This mixing device should be preferred to the supply of pre-mixed bottled gas mixtures.

### (d) Submerged Arc Welding (SAW)

Constant potential d-c power sources came into use first for gas metal arc welding (GMAW or MIG) in 1953. Later this type of power source was used for submerged arc welding. Constant current (i.e. drooping characteristic) d.c. power sources and a-c transformers were in use earlier as power sources for this process. Submerged arc welding equipment with both constant potential and constant current d-c power sources are manufactured in India. Constant potential d-c power supply offers several advantages over constant current power supply such as easier starting, uniform bead contour and penetration, greater tolerance to joint variations, simplified control circuit etc. Alternating current assumes importance at high welding currents, multiple wire and multipower welding—one cannot deny that the opportunity for the use of a-c submerged arc welding where real advantages can be derived is still somewhat limited in this country. Semi automatic submerged arc welding suffers in comparison with semi-automatic gas metal arc welding (GMAW) or flux cored arc welding (FCAW)—if however, one accepts the semi-automatic submerged arc welding equipment as a flexible nozzle attachment, there exists a somewhat limited field of application. The possibility of using narrow groove welding with ceramic flexible and adhesive type backing, permitting full penetration welding from one side should be investigated. Some of the equipment manufactured in the country can also be used for consumable nozzle arc welding which like the electroslag is carried out in vertical position—one of the applications can be high quality butt welds with little distortion in flange and web plates of plate girders—an open type nozzle cage can be made from straightened filler wires of appropriate lengths clipped together in the form of a triangle, square or hexagon and the current carrying filler wire is fed through the centre of the fabricated nozzle. As in electroslag welding, the molten weld deposit has to be supported with dams.

Although a few types of filler wires and fluxes for this process are manufactured in the country, the range is limited and quality often varies from batch to batch. Considerable development work in this field for more varieties of flux powders and wires and for ensuring consistant quality requiring high degree of quality control during all stages of manufacture, are needed; this will no doubt call for substantial capital and recurring revenue investments. There also exists a striking similarity in the consumables for this process and those for gas metal arc welding and flux cored arc welding in respect of capital equipment and manufacturing procedures.

The use of submerged arc welding for fabrication and surfacing is well established. An interesting application developed jointly by the British Steel Corporation and ESAB (an European welding product manufacturer) is the manufacture of duplex steel mill rolls by depositing a hard wear-resisting deposit on a tough carbon or alloy steel arbour by this process, using tubular type filler wire. Depending on the service conditions, chrome-steels (5 Cr/Mo and 12 Cr) and austenitic steel (16 Cr 8 Ni 6 Mn) with buffer layers of alloy steels (Mn/Mo) and austentic steel (24 Cr 13 Ni) respectively are used. The plant at BSC's works can handle rolls upto 25 ft. long, 60 in diameter and 50 tonnes in weight. A deposition rate of 25 kg per hour with tubular filler wires can be achieved with this plant. The amount of weld metal to be deposited on such a duplex steel mill roll can vary from 100 kg to 5000 kg.

### (e) Indian Structural Steels:

Welding of steel structures preponderates over other applications of welding and the steels mainly used in this country for this purpose conform to IS:2062 and IS:226. IS:2062 places no restrictions on the use of welding; but IS: 226 stipulates that when material conforming to this standard is over 20 mm thick, special precautions may be required in case the material is to be welded. This stipulation even led to conclusions in many quarters that steel conforming to IS: 226 and over 20 mm thick is not weldable. Also one often hears the suggestion "let us go back to the earlier 'tested' and 'untested' steels as 'tested' steel was fully weldable." It is, perhaps, not realised that IS: 226 specification was developed from the specification of the so called "tested" steel. At the same time, one cannot help feeling that the term "weldability" is not often clearly understood and one is apt to put his own interpretations to this term. The International Organisation for Standardization (ISO) suggested the following definition of weldability: "A metallic substance is considered to be weldable to a stated degree, by a given process and for a given purpose, when metallic continuity can be obtained by welding using suitable procedure, so that the joints comply with the requirements specified in regard to both their local properties and their influence on the construction of which they form part."

This definition emphasises that weldability is a processing property for providing the joint with desirable qualities. On the basis of extensive investigations carried out in various parts of the world and over the past many years, it has become apparent that the judgement of the weldability of a steel under given conditions of design and welding, must take into account both the overall and local aspects. The first becomes a combination of certain local properties which are intended to prevent the initiation and propagation of unstable cracks. This is usually assessed on large scale specimens but may be ultimately determined on the construction itself —the British Standard Institution in its latest specification on general requirements for electric arc fusion welding of structural steels has recommended joint simulation tests which should be used as guides in subsequent fabrication for which these will be appropriate. The second one is usually more related to the behaviour of the separate components of the welded joint such as parent metal, heat affected zone (HAZ) and weld metal and their various properties i.e. mechanical properties, influence of hydrogen inclusion, hot and cold cracking etc. This aspect of studies involves consideration of metallurgical, physio-chemical and physical factors—these studies are often called "Weldability Tests". Of the various weldability tests, perhaps, two tests viz: "Controlled Thermal Severity Test" and "Implant Test" with their modifications are more important than most of the other weldability tests developed. Other aspects of the weldability tests are: (i) whether these tests should be carried out for every batch or heat of the steel supplied and (ii) who should carry out the tests—the steel makers or the fabricators? On the first, if the steel maker provides test certificate with every heat or batch giving details of physical properties and chemical composition (of all major alloying elements and impurities affecting the properties of steel), it is not necessary to carry out any basic weldability test of the steel by either the steel maker or by the user. Regarding the second, since the process and procedure of welding play significant roles, will it be fair to suggest that the tests should be carried out by the steel mills who are not aware of all the factors involved. A review of the modern structural steel specifications of many countries would indicate that "weldability tests" as generally understood has disappeared from these specifications.

One of the most important factors for ensuring satisfactory welding of structural steel is to ensure reduced hardening of the heat affected zone (HAZ) and take due account of hydrogen from the weld metal on HAZ. Of all the alloying elements, carbon plays the most important role, but the influence of other elements such as manganese, chromium etc, cannot be disregarded—the total effect of all the alloying elements can be best determined by the carbon equivalent worked on the basis of "Ladle" analysis as given by the formula given below:

$$Ceq = C+\frac{Mn}{6}+\frac{Cr+Mo+V}{5}+\frac{Ni+Cr}{15}$$

(Formula as approved by International Institute of Welding)

In IS: 2062 and IS: 226 no mention has been made regarding the manganese contents. No doubt on the basis of physical properties, one can compute the manganese contents but this aspect leaves much to be desired from the view point of the fabricators. Every steel manufacturer tests the manganese contents of every heat and stipulation of this important element in the specification will not rob the steel makers of the flexibility they need for steel making. In these two specifications a few other important physical property aspects need to be incorporated—these particulars are provided in the specifications of structural steels of other countries. It has been observed in other countries that in practise carbon equivalent calculated on the basis of maximum specification limits of the elements is not reached—such a possibility is extremely remote; generally it is in the region of 80—85 per cent of the maximum carbon equivalent. Studies conducted (by the author) of well over hundred heats of steel conforming to IS: 226 also confirm this view.

The Indian Standards Institution has appointed a Special Committee to investigate this aspect. The preliminary studies indicate that there exists scope for revision of the present standards, but also there exists scope for better understanding of the needs and problems involved of the steel manufacturer on one hand and of steel users on the other.

It has also been observed (by the author) that maximum carbon equivalent noted in the hundred heats of IS: 226 steel (referred to earlier) was "43"—only in 3 per cent cases—and all the heats were for production of thicknesses over 20 mm; rest of the readings were "41" or lower. In the U. K, USA, Australia and many other countries such a steel will be considered satisfactorily weldable in all thicknesses but appropriate welding procedure and technique must be employed. Without going into exhaustive details, it is felt that the problem that exists today will be, perhaps, resolved by the Special Committee of Indian Standards Institution without radical changes in the specifications concerned, thereby easing the supply position of structural steels.

### (f) Miscellaneous

Attention must also be drawn to a few other welding processes such as adhesive bonding, friction welding electron beam welding and vacuum brazing. The last process assumes special importance under Indian context; this process permits flux-free brazing of aluminium and and can be used for the manufacture of automobile radiators, condensers of window air conditioners and refrigerators. For manufacture of these, copper and its alloys are used; large quantities of copper which is also a strategic material, has to be imported to augment local copper production. By changing over to manufacture of these components from aluminium employing vacuum brazing, substantial savings in foreign exchange can be achieved.

It is now almost certain that a National Welding Research Institute will be shortly established—this recommendation was first made by the National Productivity Council Study Team on Welding Industry in its report in 1963. One must not, however, assume that no research or development activity in the field cf welding was and is being carried out in the country—in fact, major welding product manufacturers, many large scale users of welding processes and even a few technical and research institutions were and are carrying out developmertal activities but mainly confined to their individual production or other needs. Of late, a few R & D investigation reports carried out in India have appeared in foreign welding journals. Let it not be also assumed that the establishment of the National Research Institute will be the panacea of all welding problems—establishment of facilities, staffing, training of personnel etc., will take considerable time. Individual problems of a specific industry or of an industrial unit will often need to be solved by the "R & D" unit of the establishment. Another important aspect is to avoid indulgence in "Re-discoveries". Also it should be investigated whether and how best, the total research and development facilities of the country can be used to the maximum advantage. It should be borne in mind that technology is international and should not be restrictive in approach and execution; also technology accepts no national frontiers and technologists generally accept a world without borders.

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The author also thanks a host of his acquaintances from many walks of life and from many parts of the world, who over the years have contributed directly and indirectly to the thoughts he has expressed.

## MILESTONES IN WELDING INNOVATION AND ACHIEVEMENT

**1880-1885**

1. Carbon-arc welding developed by Barnardos (Russia) and Coffin (USA).

**1886**

2. Resistance butt welding invented by Elihu Thomson (USA).

**1887**

3. Oxygen cutting by Fletcher (Britain).

**1890-1892**

4. Bare wire metal-arc welding developed by Slavianoff (Russia) and Coffin (USA). (This process was applied in the Baltic Shipyards of Imperial Russia but the welds were rather brittle).

**1902**

5. Dr. Carl von Linde produced cheap oxygen in Germany.

**1903**

6. Oxy-acetylene welding invented by Le Chatelier (France) and in use in Europe.

**1905**

7. Spot welding and flash welding invented—load applied manually.

8. Oxy-acetylene cutting machine developed in France and used industrially.

**1907**

9. Coated electrode developed by Kjellberg of Sweden.

**1909**

10. Asbestos yarn wrapped electrode developed by Strohmenger (Britain)—this was the "Quasi-Arc" electrode.

**1918**

11. A O Smith (USA) employed the cellulosic electrode by wrapping paper soaked in sodium silicate round steel wire to replace the British Quasi-Arc electrode, then unobtainable because of the World War I.

12. British Admiralty tested metal-arc welds and the launching of barge AC 1320 led to Lloyds Register permitting metal arc welding in main structures of ships on an experimental basis.

13. Arc-stud welding used by the British Navy.

**1919**

14. American Welding Society formed.

**1920**

15. "Fullager", first vessel with all-welded hull, launched by Cammell Laird shipyard at Birkenhead (Britain).

**1922**

16. Electric resistance seam welding of tubes in USA.

**1923**

17. Institution of Welding Engineers in Britain formed (later to be the Institute of Welding and now the Welding Institute).

**1924**

18. Mechanical flash welder for joining rails developed in USA.

**1925**

19. A O Smith (USA) fabricated the first single-piece heavy-wall pressure vessel entirely by welding.

20. Dr Ancel St John (USA) completed nine years' work on X-ray inspection and devised machine for shop inspection of pressure vessels.

**1926**

21. A O Smith (USA) introduced solid extruded coating for metal-arc electrodes.

**1929**

22. Lincoln (USA) also produced extruded coatings for electrodes, was sued by A O Smith and won the case.

**1932**

23. British Corporation Register and Lloyds' together introduced revised rules and approvals for the use of welding on ships.

**1934**

24. Lloyds Rules for pressure vessels with X-ray inspection.

25. Westinghouse (USA) developed the "ignitron", the basis of all timing circuits of resistance welding.

**1935**

26. Submerged-arc welding developed in the USA by Linde; about the same time in Germany and Russia.

27. Solid extruded electrodes introduced in Britain and the first British Standard for covered electrodes.

28. Arc welding electrode having rutile type coating for easier welding introduced.

29. Continuous coated electrode metal-arc welding developed by Fusarc in Britain.

**1936**

30. Submerged arc welding applied to the all-welded US vessel, the 18, 500 ton J. W. van Dyke.

**1938**

31. Germany apply extensively welding to save weight on their so called "pocket" battleships.

32. Quality pipe welding made possible by the developments by ICI and Babcock and Wilcox (Britain)

33. Arc-air gouging developed in USA.

**1940**

34. Construction of "Liberty" ships begins.

35. J. Dearden and H. O'Neil of Britain discuss weldability in terms of carbon equivalent.

36. Basic coated arc welding electrodes developed for high quality weld deposits.

**1941**

37. Gas-Tungsten Arc Welding (GTAW) i.e. Inert gas shielded tungsten arc welding (TIG) commercially developed and introduced in USA—the process was patented in the USA in 1929.

**1942**

38. Failures of "Liberty" ships drew attention to fracture problem in welded structures.

39. G. L. Hopkin of Woolwich Arsenal (Britain)

defined problem of cracking in alloy steels and hydrogen in electrodes.

40. All-welded submarine produced in Sweden—probably the world's first.

**1944**

41. Three-phase resistance welder by Sciaky in USA.

42. Multi-wire submerged arc welding developed and used in USA.

43. Iron-powder electrodes with high metal recovery developed by Phillips in Holland.

**1946**

44. High-frequency stabilised a.c. tungsten-arc (GTAW or TIG) welding of aluminium.

45. Cold pressure welding invented by General Electric Co. Ltd (Britain).

**1948**

46. International Institute of Welding (IIW) founded at a meeting convened in Brussels on 9 June 1948, with thirteen member countries.
(India became a member in 1970).

47. Gas metal arc welding (GMAW) i.e. Inert-gas-metal-arc (MIG) welding process developed by Air Reduction Company (AIRCO) in USA.

**1949**

48. American Westinghouse developed selenium rectifier arc welding sets.

49. US Navy used "Gas metal arc welding (GMAW or MIG) to weld aluminium hulls of vessels.

**1950**

50. Kurpflaz Bridge in Germany opened—first bridge with welded orthotropic deck.

**1951**

51. Electroslag welding developed and first used in production in Russia.

**1952**

52. World's first plastic design structure (commissioned by Welding Institute) and erected in Britain.

**1953**

53. Carbon dioxide ($CO_2$) used for shielding in automatic spray-transfer type GMAW or MIG welding in USA and similarly for semi-automatic welding in Russia.

54. Si-Mn-steel filler wire for carbon dioxide welding patented in Holland

**1954**

55. Bernard Welding Equipment Co. USA introduces automatic welding in carbon dioxide ($CO_2$) with cored wire.

56. Lincoln Electric Co (USA) develop cored wire or tubular wire with flux inside the steel sheathing for welding without gas shielding—"Inner-shield Process".

57. Stohr develops electron-beam welding in France for welding nuclear fuel elements.

**1955**

58. Constricted arc developed in the USA for cutting by Linde.

59. A A Wells at Welding Institute (Britain) developed wide-plate test which makes possible great advances in the investigation of brittle facture in welded ships and structures.

**1956**

60. Friction welding invented in Russia.

61. High-frequency resistance welding first applied to aluminium tubing in USA.

**1957**

62. Russia announced development of electro-gas welding.

63. Short-circuit transfer for low-current low-voltage welding in carbon-dioxide discovered in Russia, USA and Britain simultaneously.

**1958**

64. Iron Powder electrodes of rutile type introduced in Britain by Phillips of Holland.

65. Deep welding by electron-beam reported.

66. Vacuum diffision welding developed in Russia.

**1960**

67. Laser welding developed.

68. Explosive welding developed in USA.

69. Conference on Fatigue of Welded Structures Organised by Welding Institute.

70. Mixtures of argon and carbon dioxide used in Europe and USA for practical GMAW or MIG welding of steel.

**1966**

71. F.M. Burdekin and D.E.W. Stone published a paper on the "Crack Opening Displacement" (COD) approach to fracture mechanics in yielding materials.

**1967**

72. Gravity welding introduced in Britain following its earlier use in Japan.

(This process was initially developed in Britain by Murex in 1941 but electrodes of the right property i.e. touch type was not sufficiently developed at that time and therefore, the process was not extensively used).

(Based on "Steps in Welding Innovation and Achievements" by Peter Houldcroft—Metal Construction and British Welding Journal—Volume 5, Number 12 and "Welding—Black Art or Red Hot Technology" by Dr. R. L. Apps—Metal Construction (incorporating the British Welding Journal—Volume 5, Number 8).

## MASTER LIST OF WELDING AND ALLIED PROCESSES

| *Welding processes* | *Letter designation* | |
|---|---|---|
| **Brazing** | B | |
| Infrared Brazing | IRB | |
| Torch Brazing | TB | |
| Furnace Brazing | FB | |
| Induction Brazing | IB | |
| Resistance Brazing | RB | |
| Dip Brazing | DB | |
| Diffusion Brazing | DFB | |
| Twin Carbon Arc Brazing | TCAB | |
| Block Brazing | BB | |
| Flow Brazing | FLB | |
| **Oxyfuelgas Welding** | OFW | |
| Oxyacetylene Welding | OAW | |
| Oxyhydrogen Welding | OHW | |
| Pressure Gas Welding | PGW | |
| Welding with other fuel gases | | |
| **Gas Welding** | | |
| Air Acetylene Welding | AAW | |
| **Resistance Welding** | RW | |
| Resistance Spot Welding | RSW | |
| Resistance Seam Welding | RSEW | |
| Projection Welding | RPW | |
| Upset Welding | UW | |
| Percussion Welding | PEW | |
| Flash Welding | FW | |
| High Frequency Resistance Welding | HFRW | |
| **Arc Welding** | AW | |
| Carbon Arc Welding | CAW | |
| Twin Carbon Arc Welding | TCAW | |
| Shielded Carbon Arc Welding | SCAW | |
| Gas Carbon Arc Welding | GCAW | |
| Atomic Hydrogen Welding | AHW | |
| Bare Metal Arc Welding | BMAW | |
| Shielded Metal Arc Welding (Arc Welding with Covered Electrodes) | SMAW | (2) |
| Stud Welding | SW | |
| Gas Shielded Stud Welding | GSSW | |
| Submerged Arc Welding | SAW | |
| Gas Tungsten Arc Welding | GTAW | (2) |
| GTA Pulsed Arc Welding | GTAW-P | |
| Gas Metal Arc Welding | GMAW | (2) |
| GMA Pulsed Arc Welding | GMAW-P | |
| GMA Short Circuit Arc Welding | GMAW-S | |
| GMA Electrogas Welding | GMAW-EG | |
| Flux Cored Arc Welding | FCAW | (2) |
| FCAW Electrogas Welding | FCAW-EG | |
| Plasma Arc Welding | PAW | |
| **Solid State Welding** | SSW | |
| Ultrasonic Welding | USW | |
| Friction Welding | FRW | |
| Forge Welding | FOW | |
| Explosion Welding | EXW | |
| Diffusion Welding | DFW | |
| Cold Welding | CW | |
| Roll Welding | ROW | |
| Hot Pressure Welding | HPW | |
| Die Welding | DW | |
| Hammer Welding | HW | |
| **Other Welding and Miscellaneous processes** | | |
| Thermit Welding | TW | |
| Pressure Thermit Welding | PTW | |
| Non-pressure Thermit Welding | NTW | |
| Laser Beam Welding | LBW | |

| *Welding processes* | *Letter designation* |
|---|---|
| Induction Welding | IW |
| Electroslag Welding | ESW |
| Electron Beam Welding | EBW |
| Flow Welding | FLOW |
| High Frequency Induction Welding | HFIW |
| Welding of Plastics | — |
| Thermal Spraying—Flame, Electric-Arc and Plasma | — |
| Flame Heating | — |
| Flame Hardening | — |
| Krypton Light Welding | — |
| **Soldering** | — |
| Soldering with iron | — |
| Torch Soldering | TS |
| Resistance Soldering | RS |
| Oven Soldering | OS |
| Induction Soldering | IS |
| Wave/Flow Soldering | FS |
| Dip Soldering | DS |
| **Oxygen Cutting** | OC |
| Chemical Flux Cutting | FOC |
| Metal Powder Cutting | POC |
| Oxygen Arc Cutting | AOC |
| Oxyfuel gas Cutting | OFC |
| Oxyacetylene Cutting | OFC-A |
| Oxyhydrogen Cutting | OFC-H |
| Oxynatural Gas Cutting | OFC-N |
| Oxypropane Cutting | OFC-P |
| Oxygen Lance Cutting | LOC |
| **Arc Cutting** | AC |
| Air Carbon Arc Cutting | AAC |
| Carbon Arc Cutting | CAC |
| Gas Tungsten Arc Cutting | GTAC |
| Metal Arc Cutting | MAC |

| *Welding processes* | *Letter designation* |
|---|---|
| **Plasma Arc Cutting** | PAC |
| **Laser Beam Cutting** | LBC |
| **Electron Beam Cutting** | EBC |
| **Adhesive Bonding**<br>Metal to metal, metal to non-metal and non-metal to non-metal | |

**Note**

1. (a) The following suffixes are generally used to indicate the methods of applying the processes

| | | |
|---|---|---|
| (i) | Automatic | (—AU) |
| (ii) | Machine | (—ME) |
| (iii) | Manual | (—MA) |
| (iv) | Semi Automatic | (—SA) |

(b) The designations indicated above are mainly based on the recommendations of American Welding Society—AWS Welding Journal, Volume, 54, Number 4, but the list also includes some of the earlier designations which have been eliminated in the latest list.

2. The processes against which (2) are indicated are known by other names and/or letter designations also i.e.

| | | |
|---|---|---|
| (i) | Shielded Metal arc Welding, or Manual Metal Arc Welding | SMAW, or MMA |
| (ii) | Gas Tungsten Arc Welding or Inert-gas Tungsten Arc Welding | GTAW, or TIG |
| (iii) | Gas Metal Arc Welding | GMAW, or MIG. |