Welding in the Eighties*

By A. A. WELLS**

There are now at least a dozen distinctly different fusion welding processes, each well developed and having its own appropriate applications, and this number is substantially supplemented by those processes involving solid phase bonding. No attempt at looking forward would be complete without an appraisal of these and their possible future roles. They are the means with which to face challenges ; changing sources of energy will provide the toughest of these, such as the large-scale production of hydrocarbons from coal, but welding is also bound up with the electronic revolution, microprocessors and robotics.

Introduction and Scope

Welding technology does not of itself create products ; it is a means to an end and a service to a wide range of industries. It might therefore be expected that welding processes suited to particular needs would emerge in response to demands, but that has not been the universal pattern. The initial necessity for the inventive step, and for the self-evident property of conformity in equipments with natural laws of physical and chemical behaviour has meant during the past century that each such development has passed through an early stage of existence as "a solution looking for a problem". This may account for the seemingly long gestation periods for some joining processes, of which diffusion bonding might be a prime example. These considerations will influence this presentation ; thus, process developments which are conceptual or totally new at this time will not be considered likely to contribute significantly during the 1980 decade, although they may not deserve to be so summarily dismissed. The subject will also mainly be considered in terms of the appropriate broader developments in engineering and metallurgy which are envisaged on national and international scales, rather than in terms of the welding process developments themselves. Nevertheless, it is worth considering the contemporary range of developed welding processes, additional to those of brazing and soldering, as follows,

Resistance	Spot Seam Projection Flash Magnetically impelled arc butt*
Arc	Manual coated electrode Submerged arc and cored wire Tungsten inert gas, carbon and atomic hydrogen Metal arc gas (including CO_2) Plasma
Combustion	Oxy-acetylene
Melt	Thermit Electroslag Electrogas
Electronic	Ultrasonic Electron Beam Laser*
Solid Phase	Forge, cold pressure and explosive Friction and radial friction* Diffusion bonding*

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The list of 20 is not exclusive, and the arc classification in particular could be expanded, but it represents at least those processes on which work has at some time been conducted at The Welding Institute.

The more obvious forthcoming industrial developments which invite consideration relate to energy conversion, oil, chemicals and cryogenics, automotive and earthmoving vehicles, and microelectronics ; the associated production engineering development clearly embrace control, automation and robotics. The pervasive theme is the search for quality assurance and consistency, alleviation of the perpetual scarcity of rare skills, and elimination of boredom from repetition in the workplace. Welding technology increases the range of what is possible in technology, and increases the human estate ; it cannot rightfully be accused of contributing to the social difficulties of unemployment, obsolescence and pollution. Lord Ashby of Brandon, one-time Professor of Botany in the University of Sydney, and Chairman of the Royal Commission on Pollution in the UK, recently made reference to Grimes Graves, the ancient flint mines at his birthplace. He noted that the thriving community of long ago had decayed to an archaeological site, but could not conclude thereby that the Stone Age should not have given place to the Bronze Age.

Energy Conversion

Abundant energy remains as the material foundation of civilisations, and the prophets of doom will be confounded when it is demonstrated that the promise of a sufficient supply extends far into the future, as is likely when alternative sources are fully considered. Relative price movements over the past few years give an indication of the task ahead; those for basic industrial fuels in the UK doubled between 1974 and 1978, and increased again by 70% in the two years to 1980. Relative levels for 1980 as recently reported by the Financial Times of London are as follows,

	Coal	*Natural gas*	*Heavy fuel oil*	*Gas oil*	*Electricity*
Pence/therm	15	19*	23	36	78

*Inclusive of interruptible supplies and long-term contracts.

The special position of electricity as a premium source deserves comment ; the use in the UK during the past decade has not increased as much as was anticipated. This may be attributed on the one hand to the advent of more readily accessible gas and oil ; on the other hand the development of the undoubtedly cheaper nuclear equivalent has been restrained for its own reasons by public opinion. Hence the sustained interest in the UK and other countries in hydroelectric power, of which there is a limited supply, and more recently in tidal schemes and wind and wavepower. With respect to the latter, attention should be drawn to the development of efficient pneumatic turbines which rotate at almost constant speed when fed with a slowly alternating airflow displaced by wave-induced movements at a watersurface within a cavity ; no valves are employed. The development of wavepower could be significant within the decade, but it is unlikely to create welding problems beyond those now being solved in relation to the generality of offshore structures.

The greatest challenge exhibited by the relative cost data is undoubtedly to restore the use of coal to its former pride of place, on account of the relatively large scale of reserves. Discarding other important factors, this requires that it should be made compact and viable for transport, in relation to supply and demand. No better example of the latter is to be found than that of Australia and Japan, the one with ample supplies of coal and the other with a strong demand for imported fuels. The use made by Japan of imported liquefied methane (LNG) provides an admirable example of engineering to facilitate the transport of fuel, at a scale represented by the current generation of 18 gigawatt in natural gas fired power stations in Japan and in circumstances where natural gas was produced at the relevant time as a byproduct without a local market in many parts of the world, and was therefore economically priced. It is proposed to increase this usage to 50 gigawatt in the next ten years.

The hydrogenation of coal can produce a variety of hydrocarbon products, from synthetic natural gas to residual oils, but the liquids are the most readily transportable by tanker, even if refrigerated as indicated above. The well-known water gas reaction between hot carbon and steam, leading to carbon monoxide and hydrogen, is basic to the process. The addition of oxygen necessarily restores a heat balance. A larger charge of steam, accompanied by evolution of some carbon dioxide which must subsequently be removed, permits the generation of more hydrogen, but it is possible to produce a wide range of ratios of hydrogen/carbon monoxide in the synthesis gas in this way, while maintaining a refined heat balance so that efficiency is maintained.

The Slagging Gasifier already developed to an industrial scale by British Gas follows this route, and resembles a blast furnace in operation at high top pressure, since steam and oxygen are introduced through tuyeres near the base, and the ash is fused within a hearth which can be tapped from below. A wide range of coals is accepted.

Catalytic hydrogenation is characteristically conducted at lower temperatures but much higher pressures. The counterpart to the Slagging Gasifier makes use of a fluidised bed of catalyst and is relatively compact. In other cases a liquid is circulated in the hydrogenator, having first been extracted from the coal as a slurry, or by use of an organic solvent. The residue with remanent calorific value may then be burned to provide ancillary heat and power. Other processes are well established, such as developed in Germany before World War II, and more recently in South Africa.

It is of value to the welding technologist to learn something of all these processes, which seem to be poised for expansion, since insight into the new welding tasks can be gained in this way. The first lesson to be learned relates to the expected scale of operations in producing synthetic fuels. It can be borne in mind, for instance, that the average daily consumption of all fuels even in a relatively small country like the UK approaches 1 million tonnes of coal equivalent. That may then be compared with the scale of standard plant for a comparable chemical conversion, such as synthetic ammonia, which is of the order of 1000 tonnes a day. Hence, there will be an incentive to expand the unit plant size, as was the case with blast furnaces for the world steel industry during the past decade. This in turn demonstrates the need for economic fabrication and field assembly of vertical cylindrical vessels of large heights and diameters, having thick walls. Some of these of the greatest wall thicknesses will require to be operated at high internal pressures. Others will require to withstand severe conditions of internal corrosion and erosion. Yet other parts of plants will be subjected to aqueous corrosion, with sour constituents such as hydrogen sulphide. It can be envisaged that the growth of world markets in fuel, in response to the needs both to use lower grades of coal and to concentrate and render consistent for transport and trade, will increasingly encourage that conversion be conducted near the source rather than the destination. To consider the extremities, brown coal and liquid methane are alike in bulk density, but the latter has three times the calorific value of the former.

Fabrication of large reaction vessels

Without attempting to be precise, the eventual concern is with vertical cylindrical vessels of the order 100m high, 10m diameter and 0.25m thick, having hemispherical ends, for service at elevated pressures and temperatures appropriate to steels of A508/A533 types, or $2\frac{1}{2}$ CrMn at higher operating temperatures. Both are well suited to fusion welding at these thicknesses. Such vessels would require to be field erected in most cases, at weights of about 7000 tonnes, and post-weld heat treatments would be costly, although possible. Nevertheless, the experience that has been gained over many years, on the one hand with light-water nuclear vessels of large thicknesses, and gas-cooled reactor vessels of large sizes, helps to demonstrate the inherent practicablility of the concept.

In times past, electroslag welding might possibly have been considered for making vertical joints in the component rings, or submerged arc welding for the same joints and for joints between rings. However, the first process would have required th rings subsequently to be normalised, and the latter welds would have had to be made with the axes of the rings horizontal. The envisaged large scale of the operation, including the need artificially introduced to lift the completed shell from horizontal to vertical, tends to disfavour both processes. The need for a reasonable production rate in terms of 50 or more courses of plating in each vessel would also discourage the use of narrow gap metal inert gas welding, for which many runs would be required in each joint, but exposes better than hitherto the imminent promise of electron beam welding.

Both processes introduce the distinct advantage of narrow fused and heat-affected zones, which also substantially l.mit the width of the residual stress zone and diminish the likelihood of unstable fracture from extension of weld defects in the aswelded condition. The toughness properties of electron beam welds and weld metals with these materials can reach high values in the post-weld heat-treated condition, and show some promise without it. Of course, weld defects can be experienced with electron beam welds in heavy plate, but the sterility of the associated conditions coupled with the high degree of compositional control now associated with heavy plates assist in their avoidance ; rapidly accumulating experience has given rise to such as beam oscillation and control of flashover whereby further improvements are effected.

A 100 m^3 vacuum chamber has recently been commissioned at The Welding Institute to facilitate the use of the 75kW electron beam welding equipment which it has developed, and which is capable of welding 0.3m thick steel in one pass with a fused zone width of 7mm. Fig. 1 shows the ion trap which has been developed to prevent metal vapour reaching back to the cathode, so to minimise the incidence of flashovers. The trap functions by bending the electron beam to negotiate a compact chicane. The suite of equipment installed at Cambridge, England, is designed for a wide range of applications, as indicated by its use of an XY numerically controlled worktable, with Z motion being provided by the slide mounting of the electron gun itslef. The latter projects through the wall of the chamber and is therefore accessible at all times, especially with respect to viewing the work.

Electron beam welding equipment more appropriately optimised for long horizontal and vertical seams in locally applied vacua has been developed by the Sciaky and Kawasaki Heavy Industries Companies, in France and Japan, respectively. Fig. 2 shows the scheme now employed by Sciaky for the welding in situ of thick cylindrical courses in vertical vessels. In this case the gun is rotable inside the vacuum space, which is confined by means of an upper mounting drumhead and a lower diaphragm, which could have a friction grip in the case of a tall vessel, in order to limit the volume of the vacuum space by lift after completion of each ring joint. A movable outer ring with seals is provided to hold vacuum at the joint itself, prior to welding.

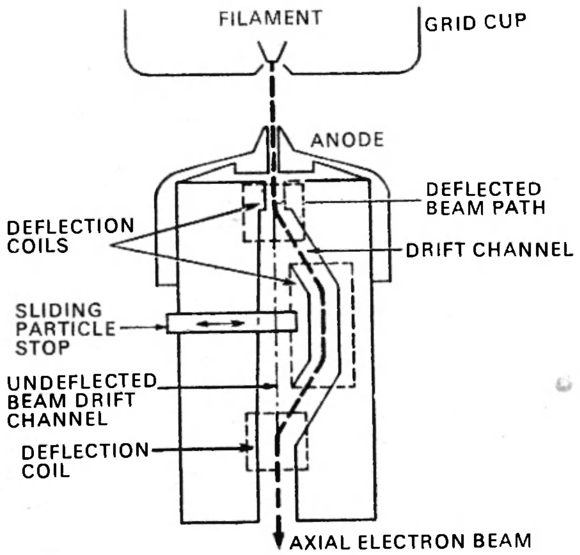

Fig. 1. Three bend magnetic trap device developed by The Welding Institute.

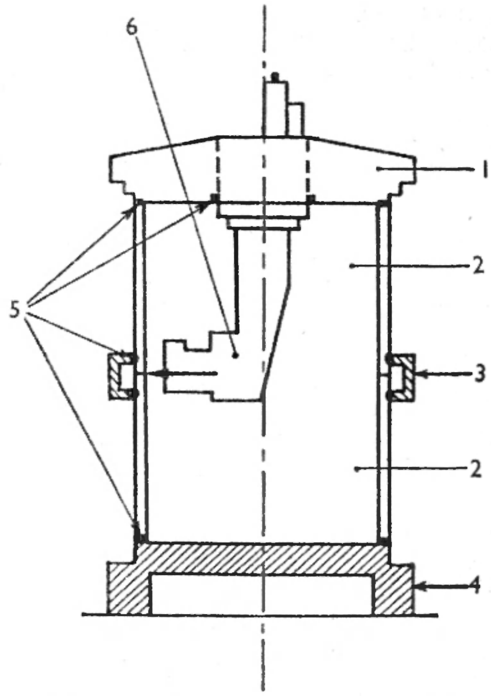

Fig. 2. Principle and view of equipment for EB welding 3m diameter shells. 1—top plate; 2—shell to be welded; 3—counter chamber; 4—base plate; 5—seals; 6—EB gun. (Courtesy of Sciaky)

Although the preferred position for making electron beam welds in thick plate is horizontal-vertical, it is also possible to weld vertically up. The welding speed is comparatively high in both cases so that it might additionally be appropriate to use the same equipment for making first the vertical joints in situ, with provision ot more local seals and each ring wedged to a clearance at the horizontal joint.

Here is a case where it might be concluded that much of the preparatory work has now been conducted, although the question of post-weld heat treatment has still to be resolved. The complete development of such heavy vessels should be possible during the decade, if it is needed ; inclusive of welding techniques for internal cladding where this is necessary.

The oil and Chemical Industries

Welding is so intimately connected with progress in the development of plant used in these industries that it would be difficult in some cases to pick out specific topics suited to this presentation. For instance, the improvement of resistance to aqueous corrosion and associated pitting and cracking is a case where advances are sought and won in an unspectacular manner over a broad front. The link with welding technology concerns the enhanced vulnerability of welded joints, which represent gradients of composition, microstructure, stress and geometric discontinuity. It is perhaps easier to discern that improved reliability will ensue from the accumulation of many data in the previous decade, but particularly from their incorporation in data banks, organised with the help of orderly scientific models of corrosion processes which also make use of basic measured data. Similar advances have been made in relation to weld defects, and assessment of their significance through application of non-destructive examination and fracture mechanics methods.

Pipelines represent a field of rapid development where welding technology is making substantial practical gains, on land and undersea. Automatic fusion welding now competes strongly with manual electrode field welding of girth seams, and this trend must surely grow stronger in the near future because of the high potential costs of repair and delay. Present levels of defect tolerance are dictated unambiguously by the levels of safety which must be achieved, in consideration of the consequences of failure, since most pipelines conduct energy in concentrated form. It is increasingly being realised in this as in other spheres of welded fabrication that the best rewards are obtained when the work is conducted correctly at the first attempt, and that investment to this end is more effective than that which is addressed to inspection and repair on the assumption of a significant repair rate. Automatic welding methods considerably favour measurement and control during welding, as compared with manual mathods. They remain attractive even after allowing for higher initial cost of equipment with no reduction in manpower, although there is an advantage in that the skills become less specialised.

The most recently developed automatic fusion welding equipment for pipeline girth welding introduced by GKN Arcos makes use of a spread of up to eight independent welding heads, each with an operator, and each dedicated to one run of the sequence from root pass to completion. The welding heads and individual power sources are themselves identical, except with regard to setting. Responsibility for setting, and maintenance on an exchange basis, rests with a compact stores and maintenance unit moving with the spread.

With this emphasis on organisation it would be a natural development for the near future to introduce recording equipment for current, voltage and travel speed at a console in the maintenance unit, in order to provide records for each joint that the work has been conducted within the agreed "tolerance boxes", and such might eventually match the importance of the methods of non-destrctuive examination which are now used. It would not supplant them until such time, if ever, that these simpler methods of recording provide the means to identify lack of fusion, and such as trapped slag and porosity.

Such methods are more obviously applicable to thicker pipelines of larger diameters, and to submarine pipelines where the high operational costs of lay-barges dictate the maximum possible speed of laying. The problems of non-destructive examination are here at their extreme, since it is often necessary to film, develop and examine X-ray exposures within time-windows of a few minutes, so that agonising decisions are sometimes required.

It would be advantageous for pipelines at the smaller ranges of size to make use of a solid phase welding process. The Russians have persevered for many years with flash welding in the field, but the equipment is necessarily heavy, and was intended for large diameters. The Welding Institute radial friction welding method was designed for application to the smaller pipelines. The long and successful experience of friction welding to join the enlarged screwed ends to barrels in drill-pipe readily demonstrates the high consistency of the process. The method produces a very clean pipe bore at the joint, and axial bending fatigue tests have shown that the joints are not inferior in strength to the pipe, whether or not the reinforcement is removed. The method applied to submarine pipelaying would have the advantage of permitting the lay-barge to use a much increased travel speed. This is a development which can confidently be expected to be demonstrated in the field during this decade.

The development of welded steel structures for use offshore receives much attention from the oil and chemical industries, particularly for service in the temperate latitudes where ocean wave loading is capable of producing fatigue damage. Much scope for further development of such structures exists for the near future. A large programme of corrosion fatigue tests on welded joints was mounted in the UK and Europe several years ago, with specific reference to tubular joints and similar sources of stress concentration, and the corresponding assembly of results is now approaching completion. This work has greatly expanded the detailed knowledge of behaviour of welded joints which endure loading spectra, but the differences from behaviour with constant amplitude loading are not spectacular, nor are the effects attributable to sea-water remarkable, provided that effective cathodic protection is applied. Here again it is the knowledge of detailed behaviour which is now of almost inestimable value, in that it will enable offshore operations to be extended to deeper waters under more exposed weather conditions. In particular, the 1980s will certainly be associated with the commissioning of tethered tension leg welded steel platforms which can be moved from site to site, and knowledge such as described will have helped to make it possible.

The testing programme has particularly confirmed the value of improving the cross-section profiles of fillet welded members and attachments, and of selected surface coating techniques, both in raising fatigue strengths to economically viable levels. Many of these features have been clearly exhibited in testing laboratoroes for years past; the time has now arrived when the methods will have to be used inorder to secure the performance that are required.

Moored ocean structures are not ideally suited to non-destructive examination at site, with the objective of finding fatigue and other cracks at an early stage, although this has already been counteracted to some extent by deliberate introduction of structural redundancy, and by exposing the inside skins of constructions for examination to the maximum possible extent. A notable result of the UK Department of Energy programme described above was obtained by corrosion fatigue tests of unwelded fatigue precracked specimens, of sizes compatible with valid fracture mechanics' assessments. These tests, conducted by UKAEA, showed that fatigue crack propagation rates are increased almost by an order of magnitude under free corrosion conditions (not effectively cathodically protected) at given loading amplitudes, if a substantial tensile mean stress is superimposed. The result at first seemed incompatible with many tests on welded components, where large tensile residual stresses are often present, since little improvement could be effected by stress relief treatments. This part of the anomaly has still to be resolved, but it now seems to be evident that the mean stress effect is mainly exhibited when cracks have grown into parent material beyond the zones of influence of residual stresses, so that the final growth of length to failure occurs in a shorter time than with structures* loaded in air. If proved to be true this effect would emphasize the importance of frequent scanning for cracks in members with high static tension components in order to win time for action and, of course, of effective maintenance of cathodic protection. The residual life of a steel structure containing sizeable fatigue cracks is in any case a small proportion of the total life to unstable fracture.

* Of CMn steels as-rolled or normalised; the property has long been recognised with welded quenched and tempered steels in contact with aqueous media.

The Automotive Industries

Welding technology often relates to more than one group of industries. The automotive group may be said to embrace the design and manufacture of earth-moving, agricultural, heavy road and all equipments, including cranes and those for mechanical handling ; all of these both use welded joints and require them to be proof to the maximum possible extent against fatigue failure. Similar considerations apply as to offshore structures, and there should be an interest in methods for improvement of fatigue strengths of welds.

The industries collectively use almost allthe welding methods listed above, but special consideration should be given in this section to those methods which are suited to the repetitive manufacture of high performance components associated with vehicle suspensions and transmissions, and to vehicle bodies of lighter weight. The requirements are intrinsic of high quality compatible with low rejection rates at inspection, and of conformity with use in a production engineering environment.

Welding processes which have been introduced comparatively recently under high production rate conditions include magnetically impelled arc butt welding (MIAB), electron beam and laser welding. The first of these was extensively developed in the GDR. and welding development with the aid of a machine acquired from there has been conducted for some years at The Welding Institute. The process is applicable to thin circular and non-circular closed sections which might otherwise be flash welded, and makes use of stationary magnetic fields to drive a welding arc at high speed around the periphery of the section before the ends are butted together at high pressure. Ford Motor Company uses the process for joining bearing housings to the ends of differential casings, and in this case the precise angular registration at the completion of welding makes the application superior to that of friction welding. The process many also be so refined as to be suitable for very thin tubular components associated with shock absorbers and fuel systems. The equipment uses power sources akin to those for arc welding, rather than heavy current transformers. The process will find many more uses, including those in situations where tubes of square and other non-circular sections are to be joined. Developments are likely to be limited for the time being to material thicknesses less than 5 mm, in order to maintain uniform heat flow from the arc across the thickness of the section.

Electron beam welding at low powers of compact vehicle transmission components has been facilitated by the introduction of vacuum boxes povided with entry and exit airlocks, so that pumping times are reduced. The very narrow fused zones achieved with the concentrated heat source in electron beam welding limit the total heat input to the work, so that temperature equalisation after welding occurs at low elevations. This feature has permitted the widespread conduct of welding operations on fully machined, hardened, ground and honed products, such as for the attachment of synchromesh cones to transmission gears. Recent developments in the USA have led to the adoption of pressed housings for automatic transmissions and these, like the housings for refrigerator motors over many years past, are closed by welding ; in this case it is electron beam welding performed at very high welding speeds. An interesting consequence is that the lubricating greases applied to the standards of reliability would ensue from the clean conditions of assembly. In other circumstances the sealing of all manner of packages under ultra-clean conditions has become a fruitful field for the use of electron beam welding at lower powers.

The carbon dioxide laser has become a counterpart to the electron beam welder at metal thicknesses up to 10 mm, although The Welding Institute's laser developed to an output of 7kW has a capability approaching 13 mm. The two methods lead to comparable weld widths and welding speeds at smaller thicknesses, so that it might be expected that the laser would compete with electron beam welding for automotive assembly tasks such as that described, or would be used preferably on larger parts of similar thicknesses, since it does not require the vacuum environment. The aero gas turbine manufacturers have installed laser equipment for the precision end-to-end joining of rotor ring forgings at their peripheries. One task which the laser performs exclusively is precision surface hardening. The fast thermal cycle produces high surface hardness on low carbon steels without the need for water quenching. The precision with which the energy is applied to the surface is of considerable value, not only in terms of conferring uniformity of hardness and wear resistance but also in terms of reduction of distortion to negligible values. The process is therefore well suited to application to cams and camshafts, as in diesel injection pumps.

Resistance spot, seam and projection welding have for many years been the mainstay of motor car body assembly from pressings, but the ubiquitous low-carbon deep drawing steel is likely to be displaced in the 1980s by other materials. Two contending types are high-strength low alloy steels and high-strength aluminium alloys ; both are likely to confer a reduction in weight. The former materials have acquired an excellent reputation in past years for strength and ruggedness in pressed steel mechanical toys, and the latter materials offer enhanced resistance to corrosion. Collision resistance is a property which has become increasingly necessary, as recognised by any who have experienced a low-speed multiple pile-up when approaching a motorway construction. (Why is it that some cars in the middle are driven away with no more than scratches when those in front and immediately behind are irreparably damaged ?). Both the steel and aluminium alloys have required the investment of much effort in developing acceptable resistance spot welding properties, such as contribute to impact and fatigue resistance. The problem with the former is notch-sensitivity in the weld HAZ, arising from enhanced hardenability ; the more serious problem with the latter is concerned with limited electrode life, arising from erosion associated with the high welding currents which have to be employed to counteract high electrical conductivity. By analogy with experience of many years ago connected with the application of spot welding to the materials of those times, which were then required for aerospace applications, the current problems are likely to be solved during the decade. Much depends upon specifying the precise properties that are required and The Welding Institute has recently installed a drop weight equipment for the purpose, having greater drop height and impact velocity than was formerly available.

Electronics

Welding technology has benefited from developments which have taken place in digital electronics, and has contributed in some measure to them. Solid state devices such as those having many circuits on silicon wafers also require multiple connections to be made in very confined spaces. The connecting wires are of exceedingly small diameters, and a preference has emerged for welded joints which satisfy exacting require ments for reliability. The Welding Institute with Government encouragement and support has engaged in this development by acquiring and extending the necessary skills in a special clean-conditions laboratory ; the aluminium ball bonding process has resulted from this work and is now increasingly used by manufacturers of solid state components. The minute ball end is formed by electrical discharge fusion on to the end of the wire, after which the attachment may be made to the metal foil tag on the device with the help of ultrasonic welding.

The benefit which has been conferred by solid state and digital electronics on welding technology is substantial by comparison with the modest contribution just described. It extends to improved welding power sources, measurement and control devices, microprocessors and robotics.

Welding arc power sources have traditionally been electromagnetic machines and transformer rectifiers. The control and consistency of deposit of weld metal are always at the mercy of the associated electrical systems, and the greater precision and flexibility of switching associated with the use of banks of power transistors as energy sources have introduced substantial benefits. Typical uses relate to the pulsing of arcs at an exact rate to achieve control of metal droplet transfer, and to control the extent of melting, and applications have been made for instance to the automatic tungsten arc welding of condenser tube ends into banks with close proximity (such that the whole process is under precise control from start to finish of each weld, and then from each to the next of a large number), and the deposit from outside of unbacked internal root runs for the joining in any position of thickwalled pipes. This experience has been transmitted to the remote conduct of repairs to nuclear reactor components after many years of service, such that erosion and corrosion have intervened. It can be confidently predicted that this decade will embody a revolution in welding power sources, and that the practically obtainable level of weld quality will greatly benefit thereby. Just as has happened with respect to machine tools during the past thirty years, there will be a leap forward with respect to precision and sophistication of achievement. Such equipments will cost more, much more in some cases, and the proportion of costs attributable to equipment will rise in comparison with those attributable to consumables and labour. Reference to published company reports of sales by manufacturers of welding consumables shows that this is already happening.

The advent of the microprocessor has led to practicable systems for the sequential control of welding operations, and the compact storage of data (current, voltage, travel speed, starting and finishing conditions respectively) obtained while they are in progress. The stored information can be processed afterwards in summary forms, as for instance mean values and standard deviations during sequential periods of one second or more. Alternatively, the results can be produced as a permanent record on an automatic graph plotter. Exhaustive study may reveal that some weld defects have characteristic signatures when conditions of deposit are monitored in this way. Whether this ensues, or not, the method will provide an economic method of proving that welding conditions have been maintained within a desired "tolerance box".

The microprocessor also has the capacity to dictate long sequences of automatic welding operations in a manageable way. Most technologists are by now familiar with the admirable reliability of inexpensive electronic pocket calculators. This kind of relative infallibility can be employed to great advantage in controlling the many elementary but essential operations which comprise the start and stop of an automatic welder, the misplacement of any one of which can now-a-days ruin work in which large monetary sums have already been invested.

The search for suitable automatic sensors to provide feedback control of electric arc welding operations was first mounted many years ago. Those which have a physical presence or "feel" in following the weld preparation are usually too delicate and unreliable, and few have survived on the market for long. Much progress has been made in the interim with improving the performance of closed circuit television monitors, which are now capable of overcoming the problems of contrasting light intensity at the welding arc, and operate well with colour. They already offer the welding operator a considerable advantage in avoidance of fatigue compared with direct viewing. Using microprocessors, the step is now being taken of extracting information on movements of "markers" of various types forming the total image, and this can be expected to lead to more satisfactory forms of feedback control, especially since the viewing camera, unlike the human eye, can move in closely maintained spatial relationship with the welding electrode. These two are developments which should make much progress before the end of the decade.

The ultimate application of microprocessors as seen by the public must surely be linked with robots of the types now used for spray painting, mechanised assembly and some welding operations. Spot welding presented a first opportunity, followed quickly by fusion welding applications on compact and repetitive components. These applications are well justified, as was observed earlier, by the considerable increase of consistency which can be obtained. The robot can seldom out-perform good craftsmanship, but does not incorporate the faults to which the work is vulnerable when operators are subject to lapses of concentration, fatigue or boredom. The present generation of robots is innocent of sensors and feedback control, and this is more of a disadvantage with welding than with assembly, since the work distorts during heating with the former so that tolerances cannot so readily be defined as they are with assembly operations. Nevertheless, this generation of robots has much to offer for certain work, which need not be in large batches to justify programming, since the programs are easily changed and stored, The use of robots in welding can be expected to become commonplace, but their supervisors will still be needed, mainly to perform other tasks than depositing weld metal.

Education and Training

It will not have escaped the reader that reference to much earlier events has been frequently made in this discourse. The associated truism is that "plus ca change, plus c'est la meme chose"+. The present concern is increasingly concentrated upon transfer of information, data banks and all that is involved with retrieval of experience. This is natural with a technology that has now expanded at a steady rate over considerably more than half a century, and it gives cause to emphasize the importance of education and training in preparing for further demands in the future.

Efforts of The Welding Institute towards the development of education and training in welding technology and non-destructive testing were facilitated by the fusion of the Institute of Welding and British Welding Research Association in 1968, and subsequent establishment of a school, conference centre and residential accommodation at Abington, Cambridge. Present facilities embrace the School of Welding Technology (SWT), School of Applied Non-Destructive Testing (SANDT) and Certification Scheme for Weld Inspection Personnel (CSWIP). Short courses are offered consecutively, with residential capacity in excess of 70 students throughout the year, now almost fully taken up. Courses are also offered in the regions and at centres abroad. The vitality of the activity is indicated by the recent decision to increase the capacity by 50% and the first of three new buildings for this purpose has just been commissioned. The Institute now employs 20% of its total resources in this field and the effort will be proportionally increased in the decade. It is worthy of note that the Institut de Soudure in France devotes 80% of total resources of a similar overall magnitude to education and training.

The view which prevails in the UK is that welding technology is considered as a postgraduate activity in universities, although an increasing number of departments are introducing limited study at undergraduate level. There remains the important task of introducing the subject as part of trade and professional training, and intensive courses of short duration offered over a whole range have been found to be the most suitable under the existing conditions. The courses are widely recognised for their useful and practical content by the responsible government departments and educational institutions alike.

Facts of life demand that research, development, information transfer and practice be considered as an entity in any discipline, and the overriding task in welding technology for the next decade will be to strengthen the components, but especially the interactions.

Concalsion

This discourse has ranged over a broad field of welding technology, and it would be difficult to extract generalisations by way of conclusion. If the spirit of the 1980s related to this topic had to be contained within a phrase, it should become the decade when we resolve to "do it right the first time."

+ Alphonse Karr, La guepes, 1849.