New Developments in Welding Technology

With Special Reference to Ultrasonic and Electron Beam Welding General Remarks and Metallurgical Principles

By H ZUERN*

Welding involves many sciences, and metallurgy and physics are among the most important. The engineer who has to take charge of welding in its various methods and innumerable applications, needs a combined knowledge of general mechanical engineering, electrical engineering, metallurgy, chemistry, physics and, of course, also of production engineering.

Metallurgy broadly speaking is the art and science of extracting metals from their ores and preparing them for use.

Process metallurgy involves the extraction, refining, alloying, casting, shaping, heat treating, and joining of metals to produce semi-finished designs and finished articles.

Physical metallurgy includes crystallography, mechanical testing, physical characteristics determination, metallography, and many other sciences employed in the examination and testing of metals and the articles into which they are fashioned.

Welding metallurgy embraces both, process and physical metallurgy. Much process metallurgy is involved in the basic methods of welding.

Fusion welds are similar in many respects to metal-producing operations. The composition limits which must be by weld metal, are similar to those applied to regular cast and wrought products.

Welds in the solid state are governed by diffusion and recrystallization phenomena which appear in many processing operations. Welding processes are unique, however, because of the unusual conditions of time and temperature prevailing. Temperatures range from far above the melting and boiling points of metals down to the sub-zero levels, which sometimes are applied to weldments undergoing special hardening treatment.

Extremely rapid thermal changes often occur. These unusual conditions result in localised expansion and contraction, chemical reactions between the metal and the ambient atmosphere, abrupt micro-structural changes and alterations in mechanical and physical properties.

A knowledge of welding metallurgy is useful from the very start of welding where the basic problems of oxidation and nitrogen fixation arise, to the final operation, where the microstructure and resulting mechanical properties may depend upon the rate of cooling down from a high temperature. Where certain requirements for mechanical properties or for corrosion resistance must be met by the weldment, a knowledge of metallurgy will help in planning the welding procedure and any necessary postweld treatment.

Much of the progress made in welding has come from the practical application of metallurgical principles.

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The use of these principles has resulted in greater control over microstructural changes in the weld metal and base metal heat-affected zones. A greater understanding of metallurgy reveals why detrimental microstructures are formed in some metals through rapid cooling, as compared to others through slow cooling.

The application of sound metallurgical rules has been largely responsible for the elimination of many defects which previously were common to welding. Answers to many of our current welding problems can be discovered through a study of the fundamentals of welding metallurgy. The results of increased knowledge in welding metallurgy will be reflected not only in the efficiency of the weld joints, but progressively in every phase of weldment fabrication. The increasing speed in technological development has to be reflected in the emphasis on metallurgy. A knowledge of the metallurgical changes which take place in a metal during the heating and cooling cycles is becoming of even greater importance as we enter new fields.

Metals and their weldability have proved to be an important field in technology. The ability to evaluate the weldability of a metal is invaluable to fabricators and enables them to select a metal with the desired properties which can be welded with the equipment at their disposal.

It speaks very highly of technological processes, that the material values given in the tables today are considerably higher than comparable tables, for example, five years ago.

The increased use of light metals has continued and this has been reflected in the coverage given to these metals.

Many new aluminium alloys have been developed and, because of the increased strength and other properties made possible by advanced alloying techniques, are being used for applications ranging from sea-going vessels and space equipment, to structural members and armour plating.

New developments in magnesium and magnesium alloys and many other new materials have to be recorded.

In many technological fields an increasing speed of development has taken place.

In space technology strength-to-weight ratios are vitally important. In under-water operations, while strength-to-weight ratios are important emphasis is on strength. Deep-diving submarines in future may be constructed of nickel-chromium-molybdenum alloy plate up to 100 mm thickness and in the 90 to 105 kg/mm^2 range (130,000 to 150,000 p.s.i.).

New alloys developed for the space programme, nuclear devices and underwater operations, are coming into use, and a knowledge of their metallurgical structure, properties and behaviour is essential, if they are to be used commercially.

In many, or I would prefer to say, in nearly all technological areas, there exist complex welding problems. Many of the new welding processes are for specialised use to solve some of these problems.

Some of the newer processes have considerable growth potential. No reduction in the use of the more popular, older processes is anticipated, but their growth curve will probably level off.

Developments of materials, developments of new construction machines and other engineering units in all technical fields are processes parallel to the development of technology in which welding technology is one of the most important sections.

Engineering structures and components can be manufactured by casting or forging, or they can be fabricated from a number of smaller components, by riveting, bolting or welding parts together.

When comparing welding to other methods of construction, both technical and economic aspects must be borne in mind.

The choice of one or the other manufacturing method, or the choice of one or the other particular welding process is dictated by the material used, and by the type of work and design to which it is to be applied.

Industrial Applications of New Methods in Welding Technology

The welding processes generally used, are classified into two main groups.

1. Forge welding processes, and
2. Fusion welding processes.

In the following, two of the more recent welding processes will be presented, one from the group of *forge welding* i.e. *ultrasonic welding* and one from the group of *fusion welding* i.e. *electron beam welding*.

ULTRASONIC WELDING

Ultrasonic welding is a process for joining similar and dissimilar metals by the introduction of high frequency vibratory energy into the overlapping metals in the area to be joined. No fluxes or filler metals are used, no electrical current passes through the weld metal, and usually no heat is applied.

The Principle of Ultrasonic Welding is illustrated in Fig. 1.

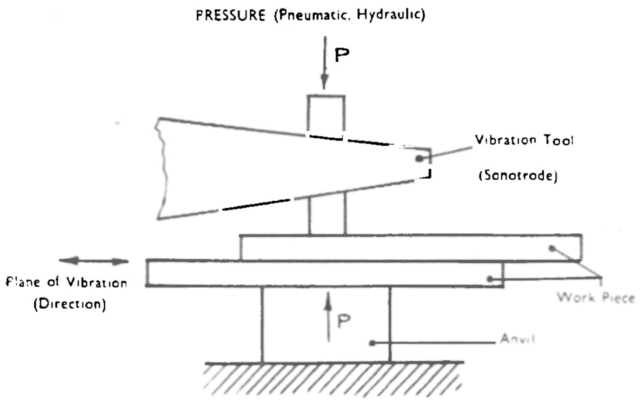

Fig. 1. Process of Ultrasonic Welding (Schematic).

The workpieces are clamped together under a moderately low static force, and ultrasonic energy is transmitted into the intended weld area.

A sound metallurgical bond is produced without arc or melting of the weld metal and without the cast structure associated with melting. There is minor thickness deformation.

Ultrasonic welding is a combination of friction welding and (cold) pressure welding processes. The joining process has demonstrated its versatility in application involving bimetallic junctions, and in producing a variety of joint configurations ; it is in production use in the semi-conductor and microcircuit industries, in the manufacture of aluminium foil, in the fabrication of aluminium products, in the packaging field and in other applications. Many other applications are in the pilot-production stage as equipment is being engineered to manufacturing demands. The ultrasonic welding process is utilised by means of spot type welding, ring welding, line welding and continuous seam welding.

The mechanism by which ultrasonic welds are produced, has not been completely established, although continuing research has probably spot-lighted most of the fundamentals.

In all types of ultrasonic welding, a static clamping force is applied approximately normal to the interface between the workpieces. The contacting sonotrode oscillates approximately parallel to the plane of this interface. The combined static and oscillating forces cause an oscillating stress at the weld interface, which results in a very localized slip between the workpieces in portions of the weld locally expelling foreign matter and permitting metal-to-metal contact.

The relation of the factors 'material properties' and 'material thickness', the required energy etc. to metallurgical bonding are complex.

Energy delivered to weld zone, power requirements and weldability, temperature developed in weld zone etc. are problems which have not been completely investigated.

Almost every metal and alloy can be ultrasonically welded, although other welding processes may be more economical for certain of the more readily weldable materials.

Ultrasonic welding is particularly useful for materials and certain geometries that are difficult or impossible to join by other techniques.

Aluminium, copper and copper alloys, iron and steel, precious metals, refractory metals etc. have a good weldability. From Fig. 2 the weldability by this process of various types of similar and dissimilar metals can be ascertained.

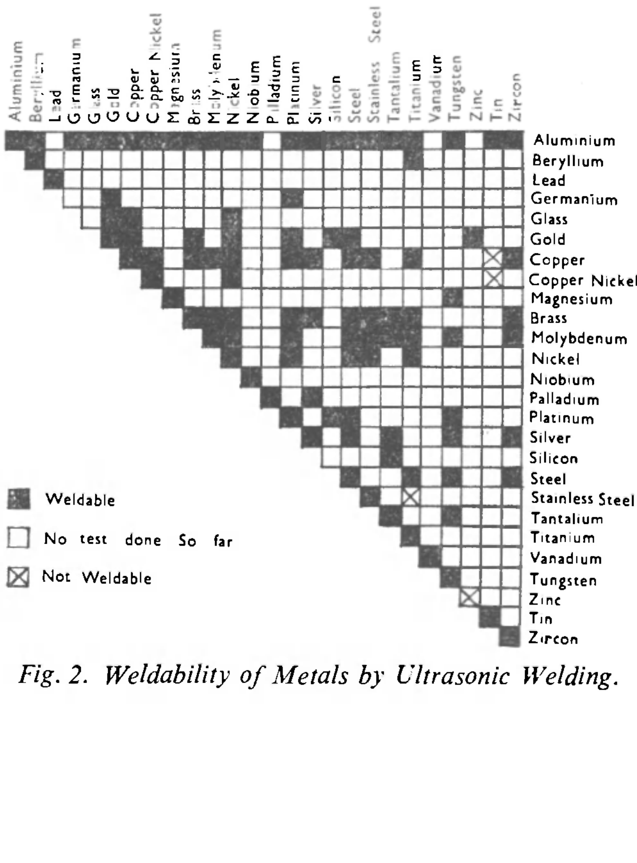

Fig. 2. Weldability of Metals by Ultrasonic Welding.

There is an upper limit to the thickness of any given material that can be effectively welded. E.g. Aluminium : Spot type welding 1 mm ; continuous seam weld 0.5 mm.

A lot of details could be mentioned about the weld characteristics, the physical and metallurgical properties, surface appearance, weld area, thickness information, microstructural properties, mechanical properties and weld quality shear strength, fatigue strength, effect of base material properties, corrosion resistance etc.

ELECTRON BEAM WELDING

Electron Beam Welding is a fusion-joining process in which the workpiece is bombarded with a dense stream of high-velocity electrons, and virtually all of the kinetic energy (energy of motion) of the electrons is transformed into heat upon impact.

The process derives its name from these basic particles of matter (electrons) which are characterised by a negative charge and very small mass.

Electron beam welding usually takes place in an evacuated chamber with the beam generating and focussing devices as well as the workpiece all being in this vacuum environment. Fig. 3 is a schematic diagram of the equipment used. Welding in a chamber imposes several limitations, but at the same time, provides one big advantage of the process, namely, a pure and inert environment in which the metal can be welded without fear of chemical contamination.

The outstanding feature of electron-beam-welding is its capability of making exceedingly narrow, deeply-penetrating welds resulting for example, in 1.5 mm width when butt-welding a steel plate of 12 mm thickness. This is remarkable in contrast to the fusion pattern in arc and gas welds and is attributable to the unique penetration mechanism of the electron-beam weld.

Conventional arc and gas heating sources melt little more than the surface, so that further depth of penetrations comes solely by conduction of heat in all directions from this molten surface spot, hence the fusion zone widens as it deepens.

By contrast, the electron beam is capable of such intense local heating, that it almost instantly vapourizes a hole through the entire joint thickness. The walls of this hole are molten and, as the hole is moved along

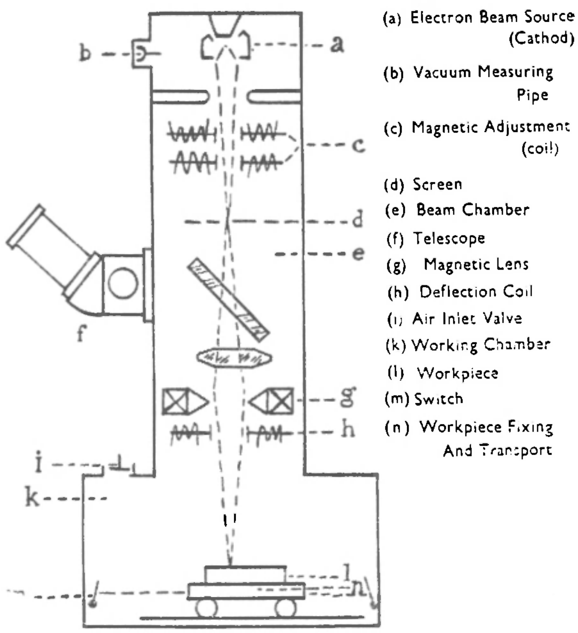

Fig. 3. Schematic diagram of Electron Beam Welding Equipment.

the joint, more metal is melted on the advancing side of the hole. This flows around the bore of the hole and solidifies along the rear side of the hole to make the weld. The intensity of the beam can be diminished if desired, to give a partially penetrated weld of the same narrow configuration.

The core of the process is the electron gun. In the gun, electrons are emitted from a cathode, focussed into a beam, and accelerated towards the workpiece.

A fundamental law of electricity is applied to accomplish these functions when the electrons are generated from a heated filament. An accurately focussed negatively charged electrode cup, surrounding the cathode electrostatically, focusses the electrons into a beam. Speed and direction are imparted to the electrons by their attraction to a positive electrode (accelerating anode).

The finally focussed beam of electrons, accelerated to speeds estimated as between 30,000 and 120,000 m per sec. passes through a small hole in the centre of the main piston speed anode and continues towards the workpiece. The mutual repulsion of the electrons causes the beam to diverge as it travels, and requires electromagnetic systems to align and to establish the exact focus of the beam before it reaches the workpiece.

This beam convergence and divergence, as a result of opposing focussing and electron-repulsing effects, is gradual so that the usable length of the beam (depth of focus) for most welding applications may be several centimetres.

An electron gun is a device which generates, accelerates, and, to some extent, focusses a beam of electrons. The constituents of an electron gun logically divide themselves into two categories :

(a) the elements necessary for the generation of free electrons, or, cathode elements ; and

(b) the field shaping elements necessary for the production of effective beam.

Although the major design effort is directed towards generation of the electrode configuration, and hence beam focussing, careful attention must be paid to the cathode elements from the beginning, to be sure, effectiveness of the final design is not hampered.

The mechanism by which a metal is able to release electrons, has to be taken into consideration. This is most accurately explained by quantum dynamics.

There are different types of guns and general equipment. Regarding high voltage and low voltage supply, considerations about the electron optical column, the power supply, the vacuum equipment and the work handling are essential.

An important item is the weldability of different materials.

The electron beam welding was first used in joining metals whose mechanical or chemical properties were seriously impaired by even a minute amount of atmospheric contaminants (oxygen and nitrogen). These are refractory or highly active materials, such as molybdenum, tantalum, tungsten, beryllium, columbium, zirconium etc.

Today, the electron beam welding process is applied not only to refractory metals, but also to a wide range of other metals. Significantly, the major emphasis has now passed from the refractory metals to those which might be best described as the structural metals, particularly in view of their extensive use in aero space structures, but also in electronics, atom power plants etc.

These applications take advantage of the higher weld joint efficiences and reduced distortion and shrinkage, compared to other types of fusion welds, that result from the narrow weld and heat affected zone in electron beam welding.