ADVANCES IN JOINING PROCESSES AND MATERIALS

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ABSTRACT

This paper presents the advances in the welding processes. It presents the trends in the application of special welding processes such as micro welding, microwave welding, friction stir welding, etc. Wherever pertinent, the joining of advanced materials such as intermetallics, biomaterials, ceramics, plastics, composites, etc is discussed.

INTRODUCTION

In the recent years, considerable interest is shown in the application of newer welding processes for joining of materials. This is mainly because of the reduction in the gap between invention and application of a particular welding process. This is also due to the rapid advances in the development of newer materials. Processes such as micro-welding processes are increasingly being considered for electronic components. Microwave welding is being considered as an energy source for joining of ceramics and plastics. Friction stir welding is another process, which attracted lot of attention in the recent years and is being considered for commercial applications.

Apart from these new processes, application of modified techniques with the existing welding equipment is also considered seriously to improve the material properties. Application of alternating current tungsten arc pulsed current and magnetic arc oscillation to improve the properties of several advanced alloys is an example in this direction. Workers have also used the electron beam welding techniques to improve mechanical properties, especially fracture toughness of advanced materials.

The development of new materials forcing joining engineers to come up with newer welding techniques. Nano materials are one such group of materials, which may change the face of industry in the years to come. Welding engineer has to keep pace with these new developments. There is a serious effort to promote composites, ceramics, and intermetallics as future materials of industrial applications. With the current rise in the interest in the biotechnology area, biomaterials are gaining importance. All these developments in the newer materials demand welding engineers to meet the joining requirements of these materials. The aim of the paper is to present the current developments in these areas.

ADVANCED JOINING METHODS

Micro joining

Welding a fabrication method often associated with large, thick, heavy, tall, big and wide structures. Thousands products that are thin, narrow, flat, small and miniature, are being produced which have applications in many components such as Cellular phones, medical devices, electronic chip for circuitry of the computers. They are so small that microscope is often needed to assist in their joining. Current range used is typically 0.5 to 50A for fusion processes. The component thickness or diameter is typically 0.1in and much less, down to 0.001in. With laser processes, 10to 100 J is considered in the micro joining area. Weld force with resistance welding might be in the range of 100g to 70 kg. One important thing with this process is; often we have to use a microscope to see the joint and typically we are joining dissimilar materials. Electronics design has steadily progressed to getting more onto less space, and micro joining developments.

Specific Micro joining Technologies and Equipment include Micro-resistance welding; Micro-plasma arc welding; Ultrasonic welding; Low-power lasers, 50 to 500 watts; Wire bonding; Percussion welding; Micro-brazing and soldering; Micro-induction heating. Typical Applications include Lighting (welding of refractory metals); Medical apparatus manufacturing and packaging; Electronics connections and packaging; Miniature motors, mechanical components; Surface treatment; Appliances; Automotive components and interconnections; Specializer sensors; Welding of shape memory alloys; Joining of superconductors; Joining of fiber optics.

Micro-Resistance Welding

Micro-resistance welding processes use the heat generated by the passage of electrical current through the two parts to be welded to form the joint. The heat may cause the materials to fuse locally and form a nugget at the interface or may be just high enough to produce a solid-state bond. In some cases, the heat generated is designed to melt only the plating (usually tin or an alloy of tin), which flows and bonds with the two materials to be joined; the process is then referred to as resistance soldering or brazing, depending on the temperature reached. The materials to be welded have to be held together with a clamping force, a job that is usually done by the resistance welding electrodes themselves.

Examples of micro-resistance welding works include the joining of: Stranded copper wire to an automotive airbag igniter; Fuel injector stems to ball tips; Be-copper foil to spring steel for gold leaf lettering printer; Seam welding of nickel screen for a battery application; Platinum coil to stainless steel wire for a medical device; Tungsten wire to brass plate for electrical contacts

Micro-Plasma Arc Welding

Micro-plasma welding applications often overlap with laser welding applications, especially for thin tubes and sheet. Thicknesses of as little as 0.1 mm can be welded with this process, and the current can be as low as 0.05 amps. The process can be used to seam weld a variety of materials. The focused spot heat source of this process lessens the overall heat input to the assembly so that temperature-sensitive electronics and metals may be successfully joined.

Ultrasonic Welding

Because the welding materials do not melt, the formation of harmful intermetallics is avoided. Dissimilar metals can also be joined with this method. The welding process, with proper selection of the horn, is able to convert up to 90 percent of the input energy into welding energy.

Because the process requires localized plastic deformation of the materials, soft metals such as aluminum, copper and their alloys are well suited for ultrasonic welding. High thermal and electrical conductivity is not a deterrent in ultrasonic welding. Materials that are difficult to deform plastically, such as the refractory metals, are more challenging to weld ultrasonically. For such materials, a thin layer of slightly more 'giving' material, for example a platinum foil between molybdenum components, produces a satisfactory weld.

Low Power Lasers

Low power lasers have a variety of uses in micro joining applications. The controlled energy density and non-contact aspects of the process are ideal for joining wires, cutting plastics, and sealing electronic packages. The laser can be used to reflow existing platings (solder coatings) or to form in-situ eutectics such as gold tin. Laser processing is applicable to high-volume applications where fast cycle time and high machine up-time are required. The non-contact nature of the process is ideally suited to thin sheet materials, small diameter wire, and electronic packaging. The infrared wavelengths are also quite useful in plastics processing, especially hole-drilling of thin sheet materials. Numerous applications include automotive electrical components, pressure sensitive bellows, and joining small diameter wires for medical devices.

Wire Bonding

Wire bonding can be done by ultrasonic and thermo-sonic wire bonding using gold and aluminum wires. In this process, small diameter (0.0007- 0.002 inch) wire is clamped between a tool and a bonding site under a specific force. Ultrasonic energy is applied parallel to the joint interface and a solid-state weld is formed. This is the common interconnect technique for silicon and gallium arsenide integrated circuit devices. The wire bonding process is very mature with strong support from industry OEMs. The process allows a designer to compress an electrical circuit design and often can result in improved performance due to elimination of extra circuit elements.

Micro joining for Electronic Packaging

The relentless trend in the electronics industry towards denser chips, processing more circuits per unit area of semiconductor, and with progressively smaller feature sizes has significantly increased the complexity of semi-conducting devices. Simultaneously, the associated problems of thermal, power and signal management have magnified to the point where the ability to package a device often limits the usefulness of the component. Hence, the importance of electronic packaging has rapidly increased in the past few years.

Electronic packaging is done by wire bonding, die attach, opt electronics packaging, ceramic and metal package sealing as well as glass to metal sealing. The materials involved include traditional materials such as Au, Si, and Kovar as well as more advanced materials such as SiC, AlN, GaAs, Cu, and Al for various applications.

Brazing and soldering of AlN for electronic packaging applications. AlN is a relatively new ceramic for electronic packaging applications.

Reactive brazing of Alumina for electronic packaging at low temperatures (400 C) to allow hermetic sealing of packages. A reactive brazing process will eliminate the need for gold plating. Reactive bonding relies on reactive wetting wherein an interfacial chemical reaction promotes flow of the solder of braze alloy. Hence a reactive bonding approach may significantly reduce the probability of void formation at the die-substrate interface. This will be particularly important for large area devices such as those envisaged for Multiple Chip Modules and Water Scale Integration.

Opto-electronics packaging Work is going on direct brazing of bare and aluminized quartz fiber to metals such as Kovar for hermetic sealing of fiber optic cable to metal packages containing laser diodes and sensors for communlcation equipment. Future efforts in opto-electronics packaging will involve redesign of the packaging process used for opto-electronic laser diodes including use of alternate joining processes and substrate materials.

In microwave packaging, Al-[40-55%] SiC composite has emerged as a leading candidate for substrate materials. The material possesses high thermal diffusivity and is tailored to match the expansion coefficient of GaAs. Work is done in soldering of this material to itself for package sealing and for feed-through applications. Examples of electronics adhesives-oriented activities include: Evaluation and selection of conformal coatings ;Conductive die attach adhesive for silicon wafers; Structural sealants for container closures; Rapid curing structural adhesives for assembly; Hotmelt adhesive for re-openable containers; Repairable chip attach adhesives

Micro joining of M.E.M.S

Micro electro-mechanical systems (M.E.M.S.) are used in many different technical areas, e.g. automotive control, information technology, biomedical or environmental application. Due to an increasing miniaturization of components and devices and a great variety of materials, the M.E.M.S. has become very interesting. To mount different materials like ceramics, plastics or metals to hybrid M.E.M.S., sophisticated joining technologies have to be developed. The assembly and mounting of micro-components can be performed by a low temperature joining process, e.g. transient liquid phase bonding (TLP) or low temperature active compound joining. For these joining techniques, a solder system has to be deposited on the M.E.M.S. components locally. The TLP solder system is a composition of a thin film layer with a high melting point (e.g. Cu, Ni and Ag) and a second thin film with a low melting point (e.g. Sn, In and In.Bi). The deposition of a low temperature active compound solder system recommends an ingenious field of process parameters because of the multiplicity of solder elements, their stoichiometry and distribution within the deposited film. The deposition process can be carried out by the magnetron sputter ion plating (MSIP) PVD technique by adapting process parameters like discharge power, total gas pressure, substrate bias, or substrate heating, to obtain a defined film constitution.

Microwave welding

Microwave welding is still a technology in a fairly early stage of development. Microwaves have higher frequencies than either induction or RF (dielectric) welding. As with RF welding, heating is caused by interaction with dipoles, such as those found in water or similar compounds, or with ionic species, such as carbon black. Materials that can be welded by microwave method include ceramics and Materials that absorb microwaves include some iron oxides, ferrites, and electrically conducting polymers, such as polyaniline salts (emeraldine). The heating mechanism, which governs the bonding process, depends on the type of material, which interacts with the electromagnetic wave. Commercially available ovens operate at a frequency of 2.45 GHz.

Microwave welding occurs as a result of the interaction between an electromagnetic absorbent material and electromagnetic waves in the range of 70MHz-180 GHz. An electromagnetic susceptor material, the gasket, is placed at the interface of the samples. The gasket is actually a composite of the bulk material and an electromagnetic absorptive material. As shown in the figure below the susceptor is a composite of a conductive polymer, polyaniline (PANI), and high-density polyethylene (HDPE). The electromagnetic waves are absorbed by the gasket, which heats up. The generated heat is conducted into the samples, thus forming a molten layer. A static force is applied in order to promote fluid flow and intermolecular diffusion, which generates the final joint. When pressure is applied, due to the shear stresses within the molten layer, the gasket breaks and flows into the flash. However, a certain amount of the gasket remains at the interface.

Microwave joining of ceramics

Microwave heating of ceramics is both quick and efficient, and industry is becoming increasingly aware of its potential. For example, microwave energy is already being applied to the drying/firing of refractories and whitewares. Now it is being considered as an energy source for joining (diffusion bonding in particular) ceramics such as alumina, zirconia, mullite, silicon nitride and silicon carbide. Conventional diffusion bonding techniques use radiant heating methods and so the time to reach temperature and the time at bonding temperature can be as long as 8 hours (480 mins). This is particularly so for materials such as alumina, which are diffusion bonded at temperatures approaching 1600°C. Using a microwave heat source, bonding times can be reduced by an order of magnitude (<30 mins).

The nature of the interaction between microwaves and ceramics is complex and is dependent on the dielectric properties of the ceramic and any secondary phases such as glass. The direct coupling of the microwave with the ceramic results in volumetric heating (exactly analogous to heating food), and so there is great potential for heating large sections uniformly. Alternatively, control of the location of the maximum electric and magnetic fields also enables precise, selective heating - for example, at a joint interface. A range of ceramic-ceramic bonds has been produced and a common factor established thus far is the presence of a secondary phase (most often a glass) in the ceramic. The most likely bonding mechanism is softening of the residual glassy phase to allow grain migration and movement across the interface. Deliberate additions of a glass at the interface have been shown to enhance bonding.

Very high purity aluminas (96%) are difficult to heat, owing to adverse dielectric properties along with the low glass content - this makes joining difficult. On the other hand, relatively impure 85% alumina is joined easily. Joints between 85% alumina show bond strengths equivalent to that of the parent material. Joint formation has been studied and a number of possible mechanisms have been identified, depending on the material. For impure alumina, the glassy grain boundary phase softens and assists in the bonding process. The figure shows two 85% alumina rods joined using microwave radiation with a scanning electron micrograph of the interface. The original interface is virtually impossible to distinguish - supporting the ideas already discussed.

The use of interlayers, including both sealing glasses and alumina gels, has been investigated for producing joints with high purity alumina. Alumina gels offer the advantage that, at the joining temperature, the gel transforms into colloidal α alumina, which subsequently sinters to provide a homogeneous interface. Problems associated with the technique relate to the design and manufacture of microwave heating systems capable of bonding ceramics using applied pressure and, if necessary, an inert atmosphere. It is also difficult to measure the temperature in a microwave (most thermocouples distort the field giving inaccurate measurements). Microwaves are a form of radiation and therefore appropriate health and safety measures must be followed.

Microwave welding of plastics

The possibility of using microwaves to weld thermoplastics has existed since the development of the magnetron in the 1940s. A typical microwave-welding oven operates at a frequency of 2.45 GHz and has the capability to apply pressure to a joint. Most thermoplastics do not experience a temperature rise when irradiated by microwaves. However, the insertion of a microwave susceptible implant at the joint line allows local heating to take place. If the joint is subjected simultaneously to microwaves and an applied pressure, melting of the surrounding plastic results and a weld is formed. Suitable implants include metals, carbon or one of a range of conducting polymers, but whichever is selected becomes a consumable in the welding process. The particular advantage of microwave welding over other forms of welding is its capability to irradiate the entire component and consequently produce complex three-dimensional joints. Welds are typically created in less than one minute. The technique is still in the development stages and as such there are currently no reported industrial applications. However, it is anticipated that microwave welding may prove to be suitable for joining automotive under-body components and domestic appliance parts.

Hermetic Wafer Bonding by Use of Microwave Heating

Microwave heating is the basis of a simple technique for quickly and gently bonding two metallized dielectric or semiconductor wafers to each other. The technique can be used, for example, to bond a flat, gold-coated silicon wafer to another gold-coated silicon wafer that is flat except for a cavity, in order to hermetically seal the cavity (see figure). The technique has the potential to become a standard one for bonding in the fabrication of micro-electro-mechanical systems (MEMS).

The predecessor of this technique is thermo-compression bonding, in which two substrates to be bonded are clamped together with considerable pressure and the entire resulting assembly is heated to melt eutectic metal alloy coats on the faying substrate surfaces. (Even though elemental metals could be more desirable under some circumstances, eutectics are used because they have lower melting temperatures.) The bonding process can take as long as 24 hours. The heat and pressure can degrade the product; the degradation can include deleterious effects of clamping stresses, diffusion of the metal into the substrate material, and diffusion of substrate material into the metal bond. Bonding could be effected in a few seconds, with minimal or no clamping, and without heating the entire assembly. Two pieces to be bonded are simply placed (e.g., one atop the other), in a microwave cavity. The position and orientation of the pieces in the microwave cavity is chosen to optimize coupling of the metal in the bond with the electromagnetic mode that is to be excited in the microwave cavity. The microwave cavity is evacuated to prevent the formation of a plasma. A pulse of microwave power (typically a few hundred watts for a few seconds) is applied.

Because the substrates are nearly transparent to microwaves in the presence of metal layers, heating by the microwave field is concentrated in the metal layers in the bond region. More precisely, by virtue of the electromagnetic skin effect, most of the deposition of electromagnetic energy occurs within a skin depth ($\approx$ 1 μm at microwave frequencies) at the surface of the metal. Thus, heating is concentrated exactly where it is needed — at the interface between the two metal layers that one seeks to melt together. By the time the pulse is turned off, the metal layers have been melted together, yet the substrates remain cool. Of course, heat is conducted from the interface to adjacent depths, but the resulting heating of the substrate is transient and minimal — not enough to cause appreciable diffusion of metal or substrate material.

In an example, each piece started as 5-mm square silicon wafer. A strip 2 mm wide around the edge of one face of each piece was coated with Cr to a thickness of 150 Å, then Au to a thickness of 1,200 Å. The gold coat was to serve later as the bonding metal. Each piece was etched to form 3-by-3-mm, 100-μm-deep recess in the middle of one face; the recess was to become half of a hermetically sealed cavity. Then pairs of these pieces were bonded to form the hermetically sealed cavities. In a test of their hermeticity, the bonded pairs were found to leak at low rates comparable to the background level of a leak-measuring mass spectrometer.

Advances in friction welding processes

Conventional friction welding processes have been well accepted by the automotive industry, and are now widely used to produce safety relevant parts such as suspension parts, steering columns and driveshafts. Several newer processes are currently under investigation by automotive companies

Rotary friction welding

Rotary friction welding can be performed in three ways – continuous drive, inertia friction welding or a combination of the two energy variants. In all these variants, friction welds are made by holding a rotating component in contact with a non-rotating component while under an axial load. Having achieved a suitable plasticized condition at the weld interface, the rotating part is stopped or allowed to come to rest, while the pressure is either maintained or increased to consolidate the joint.

The process is suitable for many dissimilar metal combinations. Metals with different microstructures as well as with differing thermal and mechanical properties can often be joined. This process is widely used by automotive manufacturers because of the short cycle times, its excellent reproducibility and simple on-line monitoring of the welding parameters.

Welding studs to plates

In friction stud welding a round stud is rotated and pressed against a sheet or plate. The process can be used for joining dissimilar materials, e.g. joining a steel earthing pin to an aluminium car body. For welding small diameter studs to thin sheets, small portable friction stud welding machines are available, which can be operated either attached to a robot or hand held. Extensive studies are necessary to evaluate whether applying high rotation speeds can reduce the forging forces. For welding small diameter studs to thin sheets, small portable friction stud welding machines are available, which can be operated either attached to a robot or hand held.

Linear and orbital friction welding

The machine uses a fully balanced reciprocating mechanism to move one component across the face of the second rigidly clamped component and small amplitude of ±1-3mm, at a frequency of 25-75Hz and a maximum axial welding force of 150kN. Linear friction welding is suitable for joining metals with non-round cross-sections, and complex parts with a number of weld sites. Concepts Linear friction welding can be used for a large variety of alloys and no shielding gas is required even for those reacting with atmospheric gases, such as titanium.

Non round parts can also be joined by applying an orbital relative motion. This motion can be generated by moving one part with an orbital motion. The requested relative motion can also be generated by rotating both work pieces with the same rotation speed in the same direction with the axes off set. At the end of the friction phase, the relative motion will be stopped by moving the work pieces to the same rotation axis.

Friction taper stitch welding

A new friction welding method has been developed for the repair of cracks is known as friction taper stitch welding. A tapered hole is drilled to remove part of the crack. A tapered plug is then welded into this hole and the process is repeated with a series of overlapping holes until the whole crack is repaired. Same technique can also be used to repair the defect at the end of welds, for example the end hole of friction stir welds or the frozen weld pool of keyhole processes (laser and EB).

Friction hydro pillar processing

Friction hydro pillar processing (FHPP) can be used to fill holes by rotating a consumable bar in a hole, which has a slightly larger diameter than the bar. The rotating rod is pressed downwards with an axial load applied. One end of the rotating rod contacts the bottom of the hole and friction heats the rotating rod and the walls of the hole. Due to heat generated by friction the end of the rod becomes soft and gets welded to the bottom of the hole. As this process continues the hole get filled by consuming the rod.

Friction surfacing

By traversing a substrate underneath a rotating consumable, deposits can be laid onto the substrate, as the consumable tries to friction weld itself to the substrate. This process is being commercially applied in the manufacture cutting edges of blades. In the automotive industry friction surfacing could be used to apply wear resistant layers onto brake disks or drums.

Friction stir welding

Friction stir welding is the most remarkable and potentially useful new welding technique that has been invented and developed in last decade. The process was invented by W.M.Thomas in December 1991 [Principal research engineer, Friction & forge process dept., TWI, UK] and developed by TWI at Cambridge UK. This process enables the advantages of solid phase welding to be applied to the fabrication of long butt and lap joints, with very little post weld distortion. Moreover, it is simple to operate, very cost-effective machine tool technology offering many advantages. The first commercial application took place at marine aluminum (Norway) in the year 1997, welded panels designed for use in the construction of fast ferries.

Principle: Friction stir welding, the new technique, based on friction heating at the faying surfaces of two pieces to be joined, by means of a non-consumable rotating tool, results in a joint created by interface deformation, heat, and solid state diffusion. The rotating tool is a specially designed cylindrical tool with a profiled pin, made from a hard and wear resistant material relative to the material being welded. The tool rotates with a speed of several hundred rpm and slowly plunged into the joint line of work piece to be joined. The pin may have a diameter one-third of the cylindrical tool and typically has a length slightly less than the thickness of the work piece. The pin is forced into the work piece at the joint until the shoulder contacts the surface of the work pieces. The tool rotates at a certain peripheral speed and transitioned along the joint line. The rotating tool develops frictional heating of the material, causing it to plasticize and flow from the front of the tool to the back where it cools and consolidates to produce high integrity weld, in the solid phase. The weld is left in a fine-grained, hot worked condition with no entrapped oxides or gas porosity. The maximum temperature created by this process is usually less than 0.8 melting temperature.

Joint configurations: The process research to date has concentrated on conventional butt and lap joints. The friction stir welding technique however is suited to several other joint configurations. The joint configurations mentioned below offer further design opportunities for numerous industrial applications and consequently will be investigated.

a. Square butt
b. Combined butt and lap
c. Single lap
d. Multiple lap
e. 3 piece T butt
f. 2 piece T butt
g. Edge butt
h Possible corner fillet weld

Orbital friction stir welding: The NASA Marshall Space Flight Center has developed an apparatus for joining two cylindrical (i.e., pipe-shaped) sections together with friction stir welding process. The Orbital Friction Stir Weld System is comprised of a base frame, a cylindrical lamping mechanism for securing a cylindrical work piece, a weld head, a reaction support, a means for transmitting load from the weld head to the reaction support, and a means for rotating the weld head in conjunction with the reaction support around the longitudinal axes of the clamping mechanisms. Since the cylindrical work piece will probably be in two sections, the cylindrical lamping mechanism must be capable of securing both sections of the work piece. The weld head and the reaction support separate the two pieces of the cylindrical clamping mechanism. The weld head and the reaction support are rotationally mounted to the base frame such that the weld head can rotate completely around the longitudinal axis of the cylindrical clamping mechanism and the reaction support can be maintained in a position diametrically opposed to the weld head.

Advantages of friction stir welding process: The process is solid phase, thus avoiding problems, which can occur in fusion welding, such as porosity, alloy segregation, hot cracking. No special edge preparation is required, only nominal square edged abutting plates are needed for a butt joint, thus saving material, time and money. The weldment have comparatively low distortion levels even in long welds.Equipment is simple, with relatively low running costs. The surface appearance approaches that of a roughly machined surface, which in most cases reduces production costs in further processing and finishing- The weldments have excellent mechanical properties as proven by fatigue, tensile and bend test. The process is well suitable for automation and adaptable for robot use. The process is essentially an autogenous, non-consumable technique, eliminating problems associated with selection and storage of consumables.

Limitations: Welding speeds are moderately slower than those of some fusion welding process. It is necessary to clamp the work piece materials firmly to prevent the abutting plates moving apart. It requires backing bar to prevent material breaking out through the under side of the joint. Key hole [run hole] is left at the end of each weld. Although this problem can be overcome by using run-on or run-off plates.

Applications:

a. Shipbuilding and marine industries

Panels for decks, sides, bulkheads and floors, Hulls and superstructures, Helicopter landing platforms, Offshore accommodation,

b. Aerospace industry

Wings, fuselages, empennages, Cryogenic fuel tanks for space vehicles, Aviation fuel tanks, External throwaway tanks for military aircraft, Military and scientific rockets, Repair of faulty MIG welds *c. Railway industry*

High-speed trains, Rolling stock of railways, underground carriages, trams, Railway tankers and goods wagons, Container bodies

d. Land transportation

Engine and chassis cradles, Wheel rims, Tailored blanks, Truck bodies, Fuel tankers, Armour plate vehicles.

e. Construction industry

Aluminium bridges, Facade panels made from aluminium, copper or titanium Window frames, Aluminium pipelines, Aluminium reactors for power plants and the chemical industry ,Heat exchangers and air conditioners, Pipe fabrication

f. Electrical industry

Electric motor housings, Bus bars, Electrical connectors,Encapsulation of electronics

g Other industry sectors

Refrigeration panels, Cooking equipment and kitchens, White goods, Gas tanks and gas cylinders, Connecting of aluminium or copper coils in rolling mills, Furniture

Super plastic forming (SPF) and diffusion bonding (DB) of ceramics and intermetallics

In SPF process, two or more materials are bonded together by stressing each material to the point where it changes its dimensions (deforms) and intersperses with the other materials. The technique has tremendous potential for overcoming the difficulties of using high-tech materials for the manufacture of complex engine parts. SPF/DB using ceramic and metallic materials is highly promising. Attempts are made on zirconia-toughened alumina ceramics of the family Y-TZP/Al2O3 with different volume fractions to study the bonding of similar and dissimilar materials.

Considerable attention is being directed towards the diffusion bonding of superplastic aluminum alloys, as SPF-DB has demonstrated substantial cost and weight savings in fabricating aircraft structures. The SPF-DB process has recently become an emerging technology in aerospace industries for production of complex net shape parts made of high strength aluminum. Although aluminum SPF technology has already been developed for implementation in production, limited success in solid-state bonding of aluminum, especially high strength aluminum alloy has been reported to date.

Research is going on other materials known to undergo superplastic deformation at high temperatures, such as intermetallics, cermets, electronic ceramics, fiber-reinforced composites, and metal matrix composites.

Lead-free soldering

Sn–Pb solders for metal interconnections have a long history, dating back 2000 years. This solder and the alloys developed with it have long provided and continue to provide many benefits, such as ease of handling, low melting temperatures, good workability, ductility, and excellent wetting on Cu and its alloys. At present, soldering technology has become indispensable for the interconnection and packaging of virtually all electronic devices and circuits. Lead-bearing solders, and especially the eutectic or near-eutectic Sn–Pb alloys, have been used extensively in the assembly of modern electronic circuits. However, increasing environmental and health concerns about the toxicity of lead, as well as the possibility of legislation limiting the usage of lead-bearing solders, have stimulated substantial research and development efforts to discover substitute, lead-free solder alloys for electronic applications.

Although several commercial and experimental Sn-based lead-free solder alloys exist, none meets all standards, which includes the required material properties (e.g. low melting temperature, wettability, mechanical integrity), good manufacturability, and affordable cost. Current processing equipment and conditions (involving fluxes) have been optimized for Sn–Pb solder alloys over the last 30 years. The development of proper alloy compositions for the new solder systems -- with suitable fluxes and assembly processes for lead-free solders — is also needed. Already, several big projects on developing lead-free solders have been carried out. The reports on these projects have been made available to the scientific community, providing us with much useful information on processing electronic products with lead-free solders. In addition to the practical usage of lead-free solders, however, we need scientific information that enables us to understand the various phenomena occurring in electronic packaging employing lead-free solders. The development of a lead-free solder alloy that has all the aforementioned desirable properties and that allows easy assembly will be a formidable task unless we have established the scientific basis.

In 1995, the world Pb consumption was about five million tons, of which more than half was used in recycled batteries. In contrast, electronic consumption was about

2% of the total waste discarded into landfills after usage. The first step in finding suitable alloy candidates is, therefore, to search for some nontoxic, low-melting-temperature alloys that can replace this amount of Pb. The candidate alloy components involve Sn as the base element, Ag, Bi, Cu, and Zn as the major alloying elements, and some other minor additions such as In and Sb. Among these elements, indium is known to be a precious element, with a quite limited world production. Given its scarcity, indium cannot become a major alloying element; the NCMS report estimated that its maximum amount in the solder must be less than 0.5 wt%. There have been released commercial electronics products with solders containing about 3 wt% In. Such products can be described as in a transitional state between Sn–Pb soldering and lead-free soldering. According to the NCMS report, Bi is also recognized as a rare metal: its use must be less than 15 wt% in solders. However, information on the earth's total resource amount and its annual production amount is still ambiguous. Some reports estimate that the Bi supply is enough for solders even with Sn–58Bi eutectic solder systems. Further clarification of world resources and supplies of Bi will be required in the near future for Bi to become feasible for electronics assembling.

Cost is another important factor in the adoption of solders for practical electronic applications. In general, taking cost of raw metals into consideration, most lead-free solders cost about two to three times more than Sn–Pb solders. In contrast, the cost of Sn–0.7Cu eutectic solder is only about 1.3 times higher than that, which explains why Sn–Cu has been successfully transferred to practical production of consumer products. Although the cost increase of new alloy selections slows the development of lead-free soldering, strong driving forces for the lead-free technology exist (in the form of possible legislation by the WEEE and the commercial pressure exerted by the commitment of major Japanese companies to have lead-free production by 2001–2002 . In addition, the number of solders on a circuit board of a typical electronic product (such as a notebook computer or TV) is small, about 10 g, and does not affect the apparent price of each product. In any case, cost reduction will be continued in the future, such that reducing the content of precious elements such as Ag and In must always be a concern as we develop new processes and new solder alloys.

The current processing equipment and conditions for electronics assembly are optimized for Sn–Pb solders. Any new conditions for lead-free alloys must ensure both productivity and reliability at least equivalent to the present level of Sn–Pb solders. One of the most sensitive parameters for the quality of soldered joints is soldering temperature. The melting temperature of Sn–Pb eutectic alloy is 183°C, and the typical soldering temperatures are 230 and 250°C for reflow and wave soldering, respectively. The temperature margin beyond the melting temperature of solder is about 50°C for reflow soldering. In contrast, melting temperatures for typical lead-free solders such as Sn–Ag–Cu alloy and Sn–Cu are higher than Sn–Pb eutectic solders by about 30°C, which makes the process window narrower. Because some of the electronic components (such as capacitors and connectors) cannot at present withstand an increase in reflow temperature, we need to modify or develop processing conditions to incorporate heat-resistant components (another key factor in the promotion of lead-free soldering). In wave soldering, the soldering temperature does not need increasing, while wetting of most lead-free solders on electrodes needs to be improved by modifying fluxes and designing new approaches.

Reliability in electronic soldering involves various factors: strength, ductility, thermal and mechanical fatigue, creep, and shock resistance. Pure Sn has a melting temperature at 232°C. This low melting temperature makes it difficult for us to understand the various behaviors around room temperature because it is used almost beyond half of its melting temperature. This sort of usage implies that diffusion of elements is quite active, and creep can occur even at room temperature.

Temperature ranges in which electronic products are used can generally be divided into the following three categories:

-40 to 100°C: most consumer electronics (TV, PC, freezer, washing machine, etc.)

-40 to 125°C: reliable consumer electronics (mobile phone, notebook PC, etc.)

-40 to 150°C: vehicles (especially in an engine room) and factory equipment

Even for Sn–Pb solder alloys, a database of reliability factors for these categories has not yet been established. But the current research activity on lead-free soldering is accelerating the construction of a Sn–alloy system database, with the establishment of electronic-assembly reliability concepts as an ultimate goal.

Intensive research and development on lead-free alloys has been carried out since 1990 because of the environmental hazard potential from Pb in solders carried in electronic waste streams. Three strong lead-free solder candidates have arisen from those investigations: Sn–Ag–Cu near eutectic, Sn–Zn eutectic, and Sn–Bi eutectic alloys. Among them, Sn–(3–4) wt% Ag–(0.5–0.9) wt% Cu has emerged as the first choice.

Replacing Sn–Pb solders requires understanding both solder metallurgy and mechanical behavior to ensure the structural and electrical integrity of electronic products. We also need a refined database for phase diagrams, solder and interface microstructures, and mechanical behavior, something not yet established even for Sn–Pb solders. In addition to various experimental verification methods, solidification simulation becomes a useful tool for understanding soldering sequences and controlling microstructure.

The final goal of lead-free soldering research is, of course, finding out one drop in replacement. However, we already realize that it will be quite difficult to replace all Sn–Pb solders with just the Sn–Ag–Cu alloy (because of this alloy's high melting temperature) and that a more realistic solution is to combine two or three candidates for suitable applications. For instance, Sn–Zn solders are already used in soldering PC circuit boards, which requires low-temperature soldering. Up to now, the application of the Sn–Zn alloy had to be limited because of the care required for using such a new alloy in unknown environments. Further work is needed on the Sn–Zn alloys to realize its properties in various environments.

The other goal is to establish reliable lifetime prediction methods for soldered electronic circuits. By using lifetime predictions, we can improve microstructures by controlling alloying and processing conditions as well as the estimation of lifetime.

We have already stepped onto the stage of lead-free soldering and, in fact, we can now buy excellent lead-free products commercially. To continue the growth of this environmentally conscious new technology, we hope that much intensive work will be started, specifically in developing and using new databases with advanced analytical and simulation methods.

Flash Soldering

The electronics industry effectively uses mass reflow soldering techniques to bond the majority of through-hole and surface mount components to their printed circuit board (PCB) assemblies. However, some temperature sensitive electronic components can not tolerate the high temperature peak of 230°C for one minute that is typically encountered in the mass reflow soldering process without suffering damage. Hand soldering is slow and highly dependent on operator skill level to achieve a good solder joint. Hot bar reflow soldering utilizes a temperature controlled metal heating element that can be pulsed to the desired reflow soldering temperature or maintained at a constant temperature. Hot bar reflow soldering suffers from several major drawbacks which include mechanical deformation of the electronic component surface and reduced thermal transfer due to warping and flux build up on the heating element surface.

Micro-flame heating employs a miniature gas feed flame to create the necessary soldering heat. This process works well with more continuous applications like brazing, which utilizes brazing alloys that typically melt above 450°C, compared to soldering in the range of 180°. The micro-flame is generally turned on by using an electric discharge. This arc-discharge mechanism can potentially damage sensitive electronic components. Moving the micro-flame in and out of the joint area provides a rough way to "turn on" and "turn off" the heat source without having to extinguish and re-light the micro-flame.

As electronic components become smaller and the space between the components decreases to less than 0.5 mm, the opportunity for creating solder "bridges" or short circuits between adjacent contacts increases. What is needed in the realm of miniature and microminiature selective soldering is a more precise method of applying and controlling both the heat and the solder volume. Diode laser heating technology, coupled with solder bearing lead technology offers the electronic assembler a new tool for success.

"Flash Soldering", using diode laser technology, is a new, non-contact, selective soldering process that offers the electronic component assembler a highly controlled method for soldering a variety of temperature sensitive miniature and micro-miniature components. Flash Soldering applications include: making miniature magnetic components such as single and multiple toroidal transformer packages; LAN filters; low power DC-DC converters; single or multiple form coils and inductors; and joining fine magnet wires to high-speed data connectors. PCB applications include joining flexible printed circuits and other miniature electronic components to flexible or rigid mounting surfaces.

Four components comprise the Flash Soldering system. In the case of the magnet wire application, the first component is an "electronic contact" that locates and retains very fine insulated copper magnet wires during the soldering process. For flex circuit and other electronic component applications, the "electronic contact" is the mating surface, which could be another flex circuit or a rigid PCB.

The second component is the insulated magnet wire for the magnet wire application, the flex circuit pads for the flex-to-PCB application, and the component leads or feet for the electronic component application.

The third element is a precise amount of solder. The solder is plated on one or both contacts or mechanically attached to one contact in the form of a solder bearing "nugget" which may also contain flux. Solder can also be applied in the form of dispensed solder paste, but requires more volume compared to a solid soldering bearing "nugget".

The fourth and final component is a diode laser heat source. The growth of commercially available, low cost, highly controllable diode lasers with wavelengths in the 810 to 980 nm infrared range and self contained programmable power supplies makes non-contact, selective soldering economically feasible.

Developments in Activated Flux, A-TIG welding

The A-TIG arc shows a visible constriction of the arc compared with the more diffuse conventional TIG arc at the same current level. Focused arc will increase the penetration depth to 2.5 times that produced with the conventional TIG process. Activated fluxes that increased weld pool penetration of TIG welding (A-TIG fluxes) were first utilized in the late 1950s. A-TIG process reduces both the need for edge preparations and increases productivity due to the reduction in the number of weld passes. The concentrated arc energy increases weld penetration through an arc or weld pool mechanism.

Mechanism for increased penetration

Increase in penetration could be due to a change in the thermal coefficient of surface tension (TCST) producing a Marangoni effect in the weld pool. It was not clear from these welds whether the effect was due to arc constriction or weld pool flow. It can clearly be seen that the A-TIG fluxes do also have an effect on the penetration of the weld in the conduction limited mode. It was concluded from this work that the most plausible theory at present is that the arc or plasma is constricted by the action of the fluxes. The arc constriction increases the current density at the anode root and with the increase in the arc force; a substantial increase in the penetrating depth of the molten pool can be achieved compared with conventional TIG at the same welding current.

Hybrid welding processes

Laser-arc hybrid welding was developed to solve the problems like ;Limited gap bridging ability, Close edge preparation, Limited process efficiency, Use of filler reduces welding speed; in laser welding process. Laser welding has limited application in shipyards due to the requirements for joint fit-up have. Also, high cooling rates in autogenous laser welding result low toughness in structures. Thus, the hybrid laser welding approach is an attractive process. This method combines laser welding and arc welding i.e.; two welding processes acting at the same time in one zone.

Three major types are

- Plasma + Laser
- TIG + Laser
- MIG + Laser

The hybrid approach provides the deep penetration of a laser with the robustness inherent in the arc welding processes. Additional advantage of the hybrid approach is lower laser power requirements permit the use of lower-cost commercial equipment.

Generally in arc welding, the bead shape becomes more uneven as the welding speed increases. Hybrid welding can provide uniform beads even when the welding speed is high because droplet transfer from the wire takes place in a very short cycle. The welding speed limit for hybrid welding is at least seven times higher than that for arc welding. The arc remains steady in hybrid welding, even at high speeds, as explained below. In arc welding, the arc is maintained by thermionic emission from the sheet. When the welding speed is high, the heating becomes insufficient, and the arc becomes unstable. In contrast, during hybrid welding, the electron density in a keyhole formed by laser radiation reaches 10^{17} to 10^{20}/cm3. Moreover, the surrounding area is in a molten state, so that thermionic emission takes place very easily. When arc welding is combined with laser welding in this region, a stable arc is maintained even when the welding speed is high.'

RECENT TRENDS IN THE JOINING OF ADVANCED MATERIALS

Advanced materials generally require novel joining techniques. Developments in new materials should be conducted hand in hand with work on weldability and joining capacity aspects unlike the old practice first developing the material and then start looking for the fabricating technique. Sound joint quality fir any new material had always been considered a milestone in a research and development scheme for a new material. Weldability aspects of some advanced materials still require further research and development. They include 3.1 Intermetallics, 3.2 Ceramics, 3.3 Metal Matrix Composites, 3.4 Biomaterials. and 3.6 Nano materials

Intermetallics

Titanium Aluminide intermetallics

During the past decade, and extensive effort has been devoted to developing Titanium Aluminide (Ti_3Al – $á_2$ and TiAl – ã) based alloys. These alloys posses' very good high temperature properties, such as oxidation, high temperature fatigue, and creep resistances as they carry High specific modulus,High recrystallization temperatures, Low self-diffusion. There is, therefore, increasing interest in fabrication of these alloys using joining; e.g. fusion welding and solid state bonding techniques. However, their fabrication is limited as a direct result of their low room temperature ductility.

These materials are typical in their metallurgical aspects. Better microstructural features result in welds by either very rapid cooling or by very slow cooling. Rapid cooling from high temperatures while joining, results retention of meta-stable b phase, which is very ductile at room temperature, however poor notch toughness and thermodynamic instability at elevated temperatures makes it undesirable. Less rapid cooling from b phase field will yield a very hard a_2 martensite structure. Although this martensitic structure exhibits very high strength, it is very brittle, and therefore very undesirable. In order to obtain the most desirable structure in a_2 alloys, which consists a fine $a_{2/}$ b mixture, it is necessary to obtain very slow cooling rates in welding. Techniques like application of very high preheat temperatures and development of post weld heat treatment schedules (PWHT) to achieve slow cooling rates will result a wider HAZ, which will cause additional problems.

Workers from IIT madras and DMRL used techniques like pulsed current, arc oscillation and bead over bead techniques to achieve desired microstructures and found these techniques are giving considerable increase in ductility of welded joints. Lower net heat input in these techniques results in lower HAZ area in joint. Investigations using transmission electron microscope showed that the formation of fine acicular a_2 martensite is suppressed in weld joints where bead over bead technique was used. The fine mixture of $a_{2/}$ b, which was formed in the weld joint, resulted **2** % elongation in tensile testing, where it is giving 0% elongation when it is joined using conventional fusion welding.

Diffusion bonding presents few problems Up to 3mm thickness, sound welds could be made.Trials of isostatic diffusion bonding were carried out at various temperatures below the â transus temperature (reported to be 1080-1085°C) and satisfactory bonds were obtained at temperatures of 1030 and 1050' C. Other solid state welding methods tried include SPF/DB, capacitor discharge welding technique, friction welding flash butt welding.

Nickel Aluminides

NiAl alloys are of interest because of lower density, high elastic modulus, higher thermal conductivity, and high oxidation resistance than ã- Ni_3Al. NiAl has been regarded as a potential substitution for super alloys for high temperature apparatus.

Joining of Ni-Aluminides: Problems include, Cracking: Levels of alloying is very critical in FZ/ HAZ cracking, Boron plays imp role i.e; 0.02wt% is optimum, Micro segregation of Hf, Al, Ni led to cracking only in welding of castings, but not in wrought alloys, Increase of Zr decreased fusion zone cracking. Grain refinement by optimizing heat input in LB welding is achieved.

Iron Aluminides

There number of intermetallic phases are possible, but only the following are commercial importance Fe_3Al, FeAl. Iron base intermetallics have attractive electrical, magnetic and corrosion resistance properties. And it is cheaper too. Low density and adequate strength makes iron based intermetallics suitable for structural applications. Environmental cracking in the presence of moisture. Grain refinement achieved by adding Zr and Ti.

Joining of Fe- Aiuminides: Weldability—very sencitive to composition and welding parameters. Problems in TIG welding are : HAZ, FZ grain growth and cracking. How to improve weld properties: Remove water vapor effectively, Alloy to decrease YS, Grain refinement—EBW proved better than GTAW.

Ceramics

Due to processing difficulties and property scatter, ceramic parts should be fabricated as small as possible, setting a strong rationale for the development of reliable techniques for joining new ceramic parts to existing metallic components. Effectively, the reliability of a joined metal/ ceramic assembly is higher than that of a pure ceramic or of a pure metal (if stress, wear and/or corrosion is involved).

Typical types of ceramic joints

A. Bolting and threading

Bolting of ceramics to rigid substrates should be avoided as local fracture can be easily initiated at few bolt/ceramic contact points. If necessary, soft gaskets of non-spreading materials should be used (soft metal, nylon, plastic). Avoid bending stresses in bolted ceramics. Tight ceramic threads suffer large local loads due to the lack of load redistribution on plastic deformation. Coarse threads can be introduced in the green stage. Clamping needs all the safeguards required for bolting.

B. Adhesive joints

These are for *low-temperature, non-vacuum* applications only, they offer an alternative low- stress joint. The lack-of-flatness of the as-sintered ceramic can be compensated for by using excess adhesive. Portland cement can be used with roughened (sand-glazed) surfaces, such as for attachment of high voltage insulators.

C. Glass joints and seals

These types of joints are frequently used to assemble *complex multicomponent pieces* (e.g. high-voltage insulators). The components are coated with glass glaze and are fired to fuse the interface. Relatively high strength of this joint is achieved as most oxides form good, reaction bonds with glasses. A special formulation allows the crystallization of the originally glassy interface to allow use at *higher temperatures* than the joining operation. The thermal expansion oefficient of the glaze should be lower than that of joined materials to allow biaxial *compression of the glaze* (but not so low as to cause interfacial failure in shear).

D. Shrink fit

Shrink fit is feasible due to the *high compressive strength and low thermal expansion* of ceramics relative to metals. It is suitable for *strong, tough ceramics or cermets* (e.g. WC/Co). *Thermal shock* of ceramics during fitting should be avoided.

E. Brazed and diffusion joints

These are vacuum-tight joints. In order to form the bond, liquid metal must wet the ceramic, which is not always the case. Special reactive alloy formulations are used to trigger reaction of the braze components with the ceramic, e.g. Ti with oxide surface, and thus improve wetting

Applications

Compared to metals and plastics, ceramics are hard, non-combustible and inert. Thus they can be used in high temperature, corrosive and tribological applications. These applications rely on combinations of properties that are unique to industrial ceramics and which include: Retention of properties at high temperature, Low coefficient of friction (particularly at high loads and low levels of lubrication), Low coefficient of expansion, Corrosion resistance, Thermal insulation, Electrical insulation, Low density

Engineering ceramics are used to fabricate components for applications in many industrial sectors, including ceramic substrates for electronic devices, turbocharger rotors and tappet heads for use in automotive engines. Other examples of where advanced ceramics are used include oil-free bearings in food processing equipment, aerospace turbine blades, nuclear fuel rods, lightweight armour, cutting tools, abrasives, thermal barriers and furnace/kiln furniture.

Silicon-Direct-Bonding

Fields of Application

The Silicon-Direct-Bonding technique is used in a wide range of applications in microelectronics and microsystems technology. It is a suitable method for manufacturing devices based on pn-junctions. Different types of sensors and actuators contain movable structures or sensitive materials which have to be protected during dicing and assembly. Even fully processed devices have to be shielded from harsh environmental conditions like dust, humidity or aggressive gases. Two universal silicon-direct-bonded packaging modules (chip sizes 6 x 6 mm^2 and 4 x 4 mm^2) including a silicon cover and a basic substrate are reported. The basic wafer contains implanted wires for connection of the inner device area with the outer bondpads. The cover wafer contains an etched cavity for the sensor device and openings for the contact area.

Technology

The first step of low temperature SDB of two structured wafers is the cleaning and hydrophilization in an acid mixture (H_2SO_4 and H_2O_2). After rinsing and spin-drying one wafer is wetted with silicate solutions like sodium silicate (NaSi) or tetraethyl-orthosilicate (TEOS). Next the wafers are rinsed and dried. The so activated wafers are contacted in a bond-aligner with an accuracy of less than 10 pm at room temperature. The joined wafer pair is annealed in a furnace at atmospheric pressure in air within a temperature range of 200°C to 400°C. After an annealing time of two hours the wafers are bonded.

Voids at the bond interface are detected by infrared light transmitted through the sample and visualized in an interference image taken by an IR-camera. The bond strength can be described either by the surface energy [J/m²] or the tensile strength [MPa]. At IMSAS the surface energy is measured by the Mazara-method. A razor blade is inserted between the wafers and the energy is calculated from the crack length.

Description of the Technology

This joining technique shows great potential both for microelectronics and microsystems technology. It is already being utilized in the industrial production of sensors, light emitting diodes and semiconductor-on-insulator substrates. Currently, the effect which different chemical and physical surface preparations have on the subsequent bonding is being investigated through experiment as well as through molecular dynamics and quantum chemical calculations.

A capacitor discharge technique for joining ceramics

In the point of commercial use, it is necessary to produce more complex shapes than can presently be achieved in monolithic ceramics. In this respect, reliable, cheap and rapid joining new techniques are required. The various methods that are currently available to produce sound ceramic metal joints can be classified into two groups: (i) mechanical joining, such as bolting and clamping with load-supporting interlayers, and (ii) chemical joining, such as active-metal brazing, diffusion bonding, and ceramic adhesives . The latter group is particularly interesting in order to provide hermetic sealing. These joining processes require high-temperature stability of ceramics because the diffusion bonding and brazing necessitate heating the ceramics for a relatively long period. Long-time heating not only dissipates power but also limits available materials as interlayers owing to their lower melting points.

Metal matrix composites

Metal matrix composites (MMCs) are becoming more popular as structural materials, and joining them is, therefore, of paramount importance. As these new materials become available, it is necessary to define and optimize joining techniques, and a thorough understanding of each process is required. A number of joining processes have been addressed, namely; fusion welding (tungsten and metal inert gas welding, electron and laser beam welding, resistance, capacitor discharge, and plasma welding), solid-state bonding (diffusion bonding, friction and magnetically impelled arc butt welding), brazing, and adhesive bonding.

When compared with the un-reinforced matrix alloys, MMCs have superior properties, especially increased stiffness, high strength, good wear resistance and excellent elevated temperature properties (enhanced creep resistance), and these properties can be tailored to satisfy a number of requirements. Current MMC alloys are based on a number of light alloy matrixes, particularly Ti, Al, and Mg. These can be reinforced by ceramics in particulate, continuous fiber, chopped fiber, or whisker form. The greatest increase in mechanical properties (strength and stiffness) is found with composites containing a unidirectional array of fibers and occurs in the direction of the fibers. Particulate reinforced materials show less improvement in properties, but the materials are generally reasonably isotropic, easier to manufacture, and significantly cheaper. Secondary processing operations are much easier than with continuous fiber reinforced materials. A more isotropic fiber or whisker-reinforced material can be made using crossplies. When compared with particulate and continuous fiber MMCs; chopped fiber and whisker-reinforced materials are intermediate in terms of performance, isotropy, and ease of secondary processing.

It general all processes that can be used to join aluminum can be used to join Al-based MMCs, though account has to be taken of the unusual properties of MMCs. Most attention, in the fusion-welding context, has been paid to particulate reinforced systems. Various workers have observed defects commonly found in Al alloy fusion welds, such as solidification cracking. The incidence of such problems depends largely on the composition of the matrix, though they may well be exacerbated by the reinforcement. However, a number of difficulties have been identified specifically associated with fusion welding of MMCs, in particular:

1. High viscosity of MMC melts above the melting point when compared with un-reinforced melts.
2. Segregation effects on re-solidification
3. Reinforcement-matrix interactions
4. Evolution of occluded gases.

During fusion welding, the matrix will be heated to a temperature above its melting point, but the particulate will remain solid. In consequence, particle reinforced Al alloys have melts with high viscosities, making the mixing of the molten parent metal and filler difficult to achieve.5 This can, however, be alleviated by employing Si-rich Al filler wires such as ER4043 or ER4047, and may be less marked when welding MMCs based on Si-rich matrixes. The use of Si-rich Al fillers increases the wettability of the SiC in an Al matrix, enhancing mixing of the plate and filler materials.

Welding temperature cannot be raised to increase fluidity of the weld pool, as it may lead to further problems because of detrimental reactions between reinforcement and matrix materials. One more problem when fusion weld of MMC materials had been encountered if the composite material had been manufactured using powder metallurgy route.

Biomaterials

Biomaterial is a non-viable substance used in the fabrication of medical device that temporarily or permanently interfaces with viable tissues. Biomaterials science helps in the development, evaluation and application of special materials to meet their design goals. Range of biomaterials include Polymers,Metals and Alloys, Ceramics. Ceramics include large number of inorganic non metallic solids that feature high compressive strength and relative chemical inertness. Low temperature isotropic (LTI) carbon has excellent thromboresistance and has found use in heart valves and percutanious connectors,Aluminum oxide (Al_2O_3) forms the basis of dental implants and in the polycrystalline form is suitable for load bearing hip prosthesis.Bio glasses are surface–active ceramics that can induce a direct chemical bond between the implant and the surrounding tissue. One example is 45S5 bio-glass, which consists of 45% SiO_2 , 6%P_2O_5 24.5% CaO and 24.5% Na_2O.

Medical device manufacturing carries with it the need for absolute product reliability and performance under many conditions. End-users expect a manufactured device to withstand the rigors of sterilization, exposure to fluids, and occasional abuse. Adhesive bonding of components conjures up fears of catastrophic failure, further amplified by the necessary use of difficult-to-bond materials. Such materials may feature high temperature resistance, high corrosion resistance, or poor wettability, making them useful in medical environments but also making them difficult to bond. Proper procedures exist for adhesive bonding of most materials, however, and the medical products manufacturer is generally more motivated than most to pay attention to the requirements of good bonding practice.

JOINING CRITERIA

An adhesive should be considered for joining welding-incompatible materials, such as thermosets and some thermoplastics. Conditions that call for adhesive bonding include: Bonding of dissimilar materials or materials with poor mechanical property matches.Joining to promote maximum stress distribution or to promote impact resistance. Joining of materials that are too thin to be welded.Joining of pre-manufactured subassemblies. Bonding to augment the performance of a mechanical joint (bolts, screws, rivets, spot welds).

Choosing an adhesive for a medical application follows the same general protocol as choosing an adhesive for any other purpose. Criteria include the particular substrates to be joined, strength requirements, type of loading, impact resistance, temperature resistance, humidity resistance, chemical resistance, electrical resistance, and processing requirements. The choice of substrates often disqualifies many generic adhesive classes and establishes the basic adhesive chemistry. Strength and loading requirements will also disqualify certain types of adhesives. Because impact and temperature resistance are correlated, the softening of an adhesive to improve its toughness will most likely reduce its temperature resistance. Characteristics such as humidity, chemical, and electrical resistance are intrinsic properties of the adhesive material. The manner of processing is dictated by the choice of adhesive and its performance requirements in the application.

Adhesives bond only to surfaces. Because adhesive failure must be avoided, proper surface preparation is essential. Most materials rated as "difficult to bond" have poor adhesion chemistry or low surface energy. For an adhesive to function, it must wet the surface. Wetting is a function of the surface energy of both the adhesive and the substrates, the viscosity of the adhesive, and the surface tension of the adhesive. Surface Preparation of Metals. Metals are acid-etched or anodized using sulfuric, phosphoric, or chromic acids. Stainless steels, nickel, platinum, and titanium all require some type of surface etch or anodization for proper bonding. This may be followed by application of a primer. Etching acts almost as a deep cleaning, but does not give a high surface profile. Anodization produces a deeper profile, but is most effective with low-viscosity primers and adhesives. Otherwise, the deep profile remains unfilled and the mechanical advantage is lost.

ADHESIVE TYPES

The most common adhesives used in medical bonding are the acrylics, cyanoacrylates, epoxies, urethanes, and silicones. Acrylics are among the fastest curing adhesives, with excellent substrate versatility, good strength and humidity resistance, and a wide formulating range. Gap filling is modest, with joint thickness of 0.010 in. (0.25 mm) or less being favored. Maximum use temperature is approximately 300°F.

A derivative of acrylic chemistry, cyanoacrylates are sometimes referred to as the "superglues." These materials fixture rapidly to polar surfaces, especially those that have hydroxyl groups or residual moisture. Full cure requires about 1 day. Maximum temperature limit is approximately 220°F, which means that these adhesives are not autoclavable. Some are highly flexible and quite impact resistant, whereas others can be brittle.

Epoxies are among the most common structural adhesives for use with processing temperatures over 300°F, and they bond well to many materials. Their major positive attributes are high strength in many loading modes and excellent chemical and electrical resistance. The principal drawbacks of epoxies are relatively slow cure times and susceptibility to long-term moisture pickup in very humid atmospheres.

Urethanes are extremely versatile in bonding to many substrates, and are the first general adhesive of choice to use when joining plastics or difficult surfaces. They can cure rapidly and have good impact resistance. Their temperature limit maximizes at about 250°F, which makes them borderline candidates for autoclaving. They also display relatively poor bonding with metals under humid conditions. Some urethane versions will also moisture cure, which has been used as the basis for curing hot-melt urethanes. Newer urethane-adhesive formulations based on carbonate polyols show promise for implantable device bonding.

Silicones display a wide range of temperature applicability, being useful at temperatures as high as 500°F and as low as -60°F. They mechanically adhere to many different surfaces, but their tensile strengths and surface peel strengths are low, suggesting they are more useful as a structural sealant than as a structural adhesive. Silicones have excellent chemical and electrical resistance. Fluorinated silicones have shown benefits in bonding to fluoropolymers by virtue both of their low surface energy and the fluorination.

Ultraviolet (UV)-curable adhesives are increasingly popular because of their rapid cure properties and one-part chemistry. Most are acrylic based and cure in less than 1 minute. They often contain leachable materials but are widely used for plastics and metal assemblies outside the body. Many successful device applications take advantage of the inherent rapid assembly time and substrate versatility of UV-curable formulations.

Nanomaterials

There have been remarkable efforts in the scientific community to find new applications for nano-scaled particles. Nanoscaled particles with diameters of a few nanometer found wide application in the fabrication of nanocrystalline materials, which show modified physical properties associated with high fraction of inter-crystalline volume.

In a work , it has been shown that ,nano-scaled Al203-powders can be employed for diffusion bonding of Alumina ceramics. In order to accomplish bonding of the ceramics, Al203-nanopowder with a median particle size of 14 nm in diameter is sandwiched between two commercial microcrystalline corund discs, followed by uni-axially hot compressing of the assembly in vacuum at 80 MPa and 1100CC for 2 h. The results show for the first time that A1203- nano powders are suitable for diffusion bonding of alumina ceramics. The powders employed in the diffusion bonding experiment are generated in our laboratories via evaporation of commercial available corund rods (purity: 99,7% A12Q3) with the pulsed radiation of a high powder I(XX)W Nd:YAG- Laser and subsequent condensation of the vapor in a controlled atmosphere.

In a work on diffusion Bonding of Alumina, the two cylindrical corund discs to be joined are 12 mm in diameter and 10 mm in height. The surfaces to be joined are polished to a 1-ìm diamond finish and cleaned with ethanol. About 10 mg of AlzO3- nanopowder is sandwiched between the sample discs. The powder layer is pre-compressed between the polished disks by hand to a- 0.5 mm thick layer, and the sandwich is placed between the graphite pistons of a hydraulic uniaxial hot press {KCE, HPW 150/400) in which a maximal load of 100 k N and a maximum process temperature of 1600°C can be applied in a vacuum of 10-1 Pa. For subsequent heat treatment, the sample is sintered in air without load in a conventional sintering furnace. The superior mechanical properties of nanocrystalline materials improve the structural stability of the joint, because nanocrystalline materials require lower temperatures for bonding and less deformation of the ceramics being joined.

COMPUTERS APPLICATIONS IN WELDING ENGINEERING

Like any other industry, welding engineering also is being computerized, starting from areas such as production planning to testing and qualification. Computers are playing a major role in the welding industry and research. The role of computers is predominant in 4 major areas: Decision support systems; Prediction using simulation and modeling; Real time process controlling; robots

Decision Support Systems

Assist making decisions regarding the task of welding; simple database and retrieval systems or very complex knowledge based systems which can recommend processes and parameters for a given welding situation;The following are some examples:Filler2: welding software which selects filler metals and welding parameters.;Ezpipe: creates custom pipe welding and fitting patterns and templates, Modular Computer Systems; specializing in welding software for the construction industries;SOAR: Sandia Optimization and Analysis Routines - software for developing optimal laser and arc weld procedures, with an isothermal contours application. Licenses for use are free.;WELDplan- welding planning software; WeldPrint- by analysing the welding arc 8 times a second, this software can alert you to a welding problem instantly. Confirm the quality of every weld in real time.

Knowledge Base Systems or Expert Systems: help the shop floor engineer to analyze weld tasks in the pre-weld, weld and post- weld phases;Pre weld systems produce procedures that result in acceptable weld geometries and avoid any kind of cracking; During the weld phase, on-line sensors to detect process parameters are used, and based on the on-line information combined with pre-weld information, conditions varying from the stipulated welding procedure are identified, analyzed and modified accordingly by the expert system, resulting in consistent quality in welds; Post-weld expert systems conduct fault diagnosis and interpretation of weld inspection data. For weld defect diagnosis, the user is asked for information about welding process variables and the welding method used, and then the system lists its conclusions about the possible causes for the defect.

Some of the expert systems developed and used in welding are listed below: An Expert System for Welding Design : WELDEX;Expert System in Electron Beam Welding; Welding Cracking Prediction and Diagnosis Expert System; Expert System for Generating Welding Procedures for Boilers and Pressure Vessels;Ferrite Predictor Expert System; Expert System for Arc Monitoring and Casual Diagnosis in Robotic Arc Welding; Expert System for On-line Process Optimization in GMA Welding; An Expert Robot Welding System; Submerged Arc Welding Expert System.

Simulation and modeling

To predict the behaviour of weld pools under diverse welding parameters. Numerical methods such as Finite Element Method and Boundary Element Method have been used to predict heat transfer; fluid flow: depth of penetration and bead and HAZ geometry; solidification structure; fracture mechanics of welds; residual stress analysis of welds These simulation packages were able to help in estimating weld pool parameters, such as temperatures at the middle of the weld pool and fluid flow during laser and electron beam welding etc, measurement of which is almost impossible.

Neural Networks :

ANN are capable of capturing the hidden relation between the input and output data. The network is a mathematical function fitted to the experimental data and hence is capable of producing a suitable output for a new input. The following are some of the neural network models developed to predict various weld parameters: Estimation of optimal welding parameters; Nugget size sensing in spot welds; Prediction of weld bead geometry; Correlation between weld metal composition and properties; Impact toughness of C-Mn steel welds; Prediction of submerged arc weld chemistry; Modeling of solidification cracking; Prediction of ferrite content; Prediction of solidification mode in stainless steel welds.

There are other ways of using neural networks apart from predictions and one of those is real time control the welding machines and processes. Some of the ANN models developed related to this are: Ultrasonic welding control; Resistance spot welding control; Controlling of robotic arc welding; Controlling of weld pool width and cooling time in TIG welding. Neural networks are very good at Real time response; High learning capacity. Therefore they are being used in training and controlling welding robots.

Digital control of power sources

Digitization of process controller and other micro controllers; Use of Digital Signal Processors; Arc characteristics are represented by highly flexible software and not by hard ware which is hard to alter Very high welding performance

Integrated Systems

Present research is to create integrated software systems, which can provide the features, discussed above. The following are part of these integrated systems: Databases and retrieval systems: Knowledge based systems; Prediction using numerical methods (FEA &BEM); Prediction using ANN and GA; Machine an robot controlling software. Eventually the complete process of welding will be controlled by computers resulting in consistent quality and reliability.

CONCLUSIONS

As can be seen from the above information, the current trends in the welding research and applications point out towards newer processes and newer materials. With the process of miniaturization, welding processes have taken new turns in meeting the requirements. As the interest in newer materials such as nano materials, composites, intermetallics, bio materials, etc. is on the rise, welding engineer has a formidable task ahead finding means to join them for their successful operation in actual practice.

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CORRECTION

In the paper entitled
"Infuence of baking conditions of MMAW electrodes on weld metal mechanical properties"
by S. R. Gupta & M.V.V. Reddy
in the October 2002 Issue of Indian Welding Journal

Figures from 6 to 12 black rectangles correspond to 3 hrs. baking duration while white rectangles are for