Welding Technology

Electron Beam Welding

Electron beam welding is a welding method that essentially uses heat obtained by generating an electron beam in a vacuum.

Controlling the output of the electron beam enables adjustment of the penetration depth and the spot diameter, making this method applicable to a wide variety of base materials—from thick to thin plates—and even for ultra-detailed welding.

Currently developed electron beam welding techniques do not require a vacuum, opening the door to a growing range of applications.

Electron Beam Welding

Electron beam (light beam) welding is a welding method based on a principle of electrons emitted in a vacuum tube or Braun tube. Welding is essentially performed in a vacuum (high-vacuum welding), and is characterized by minimal distortion for applications from thick to thin plates and even detailed welding. In recent years, however, electron beam welding machines capable of welding even without a perfect vacuum (low-vacuum welding machine) or by moving an electron gun (moving electron gun welding machine) have been developed, further expanding the range of applications.

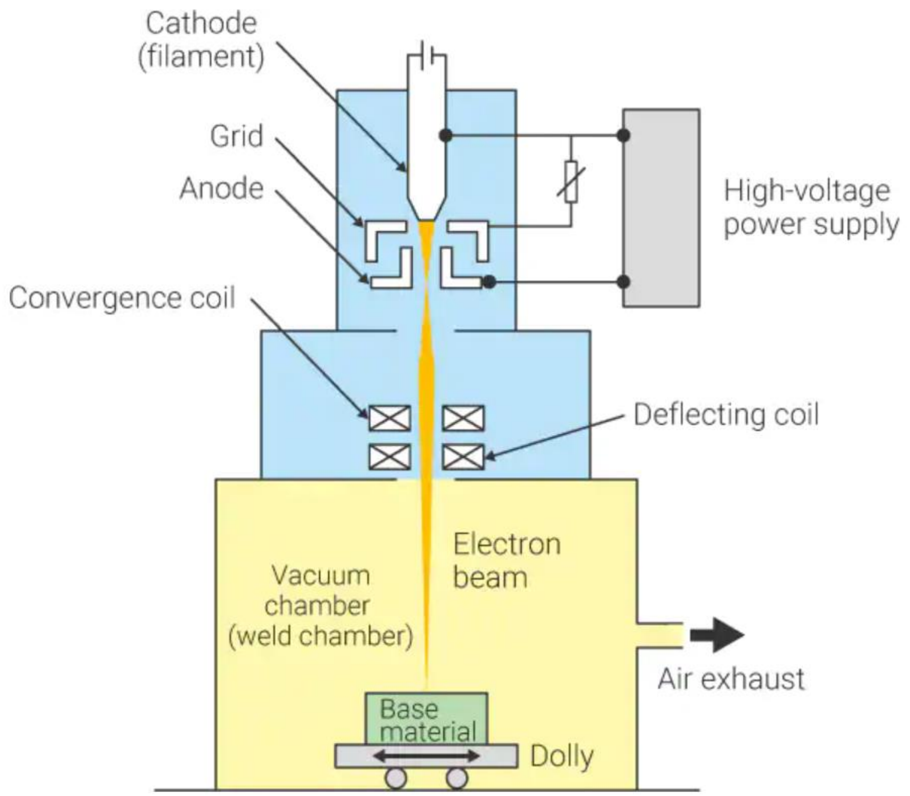
Electron Beam Welding

When a cathode in a vacuum is heated by a filament, it emits electrons. The emitted electrons are accelerated by voltage and converged by an electromagnetic coil, and generate high heat energy when they strike the base material. Electron beam welding uses this heat for welding.

The beam spot diameter of a typical electron beam welding machine is approximately 0.2 mm, and the energy density of the electron beam is about 1,000 times that obtained with an arc. The heat applied to the area around the weld is low, which allows for welding with less distortion. Controlling the output of the electron beam enables penetration adjustment, making this method applicable to a wide variety of base materials, from thick to thin plates. Electron beam welding can also be used to weld metals with high melting points (such as tungsten) as well as active metals that may oxidize during welding (such as titanium).

Electron Beam Welding

Potential applications are ship's shell plates, bridges, storage tanks, aircraft parts, and electronic components.



Differences from Laser Welding

Both electron beam welding and laser welding are capable of achieving deep penetration with a small amount of heat. With laser welding, no vacuum is required, the equipment can be smaller than electron beam welding equipment, and high welding speeds are possible.

However, laser beams have a smaller output than electron beams, so the penetration depth is shallower, making laser welding not suitable for welding thick plates. Also, if the reflectance of the base material surface is high, the energy efficiency will decrease.

	Electron beam welding	Laser welding	
		CO_2 (carbon dioxide) laser	YAG laser
Heat source device	High-voltage generator + electron gun	Optical resonator with CO_2 as the main medium	Optical resonator with a YAG rod as the medium
Output range of commercially available equipment	3 kW to 100 kW	0.5 kW to 45 kW	0.1 kW to 6 kW
Maximum melting capacity	Approx. 150 mm (100 kW)	Approx. 30 mm (45 kW)	Approx. 10 mm (6 kW)
Beam energy efficiency	Approx. 100%	Approx. 20% Significant loss due to surface reflections and plasma absorption	Slightly higher surface absorption coefficient than CO_2 with less plasma absorption
Practical maximum plate thickness	Approx. 100 mm	A few mm or less	Same as left
Welding atmosphere	Vacuum (<10^{-2} mm Hg) Welding must be performed in a vacuum	Ambient air Inert gas shielding required as with arc welding	Same as left
Weld materials	Metals only No metal materials with high vapor pressure such as zinc and magnesium	Metals, non-metals	Same as left

Accelerating voltage

The accelerating voltage significantly influences the output of the electron beam. In general, devices with an accelerating voltage of about 100 to 150 kV are considered high voltage, and devices of about 30 to 60 kV are considered low voltage.

High-voltage devices can weld steel materials between about 0.1 and 200 mm thick, and aluminum alloys between about 0.1 to 300 mm thick.

For non-specialized applications, low-voltage devices are easier to use. Such devices are used in various fields, including the electronic component industry.

Processing chamber pressure

One of the major characteristics of electron beam welders is that welding is performed in a vacuum processing chamber.

In general, processing chambers with pressures up to about 0.067 Pa are considered high-vacuum chambers, and those with pressures up to about 6.67 Pa are considered low-vacuum chambers. General-purpose high-vacuum exhaust devices include the following:

Oil diffusion pumps

Mechanical booster pumps

Oil rotary pumps

Low-vacuum devices, on the other hand, include the following:

Mechanical booster pumps

Oil rotary pumps

Principles of Deep Penetration

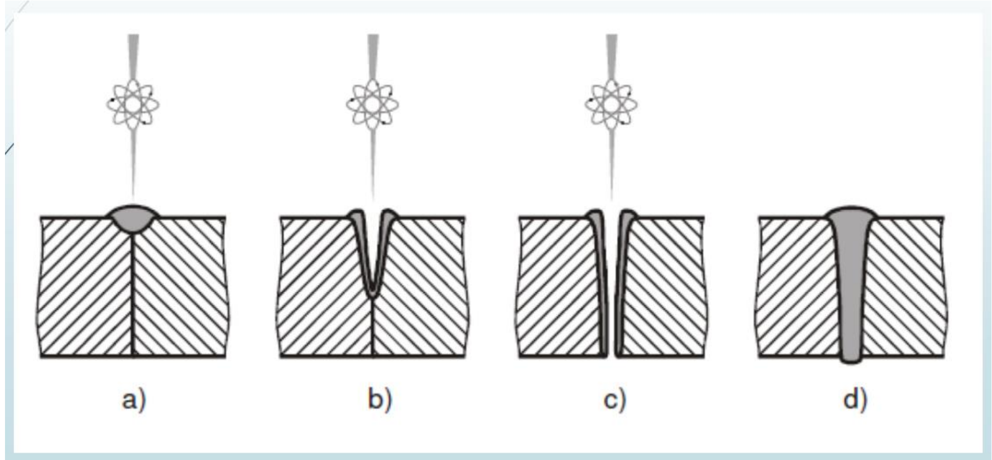
a) Impact of high energy electron beam on workpiece surface. The penetration depth into the workpiece is very low, just a few µm.

Most of the kinetic energy is released in the form of heat.

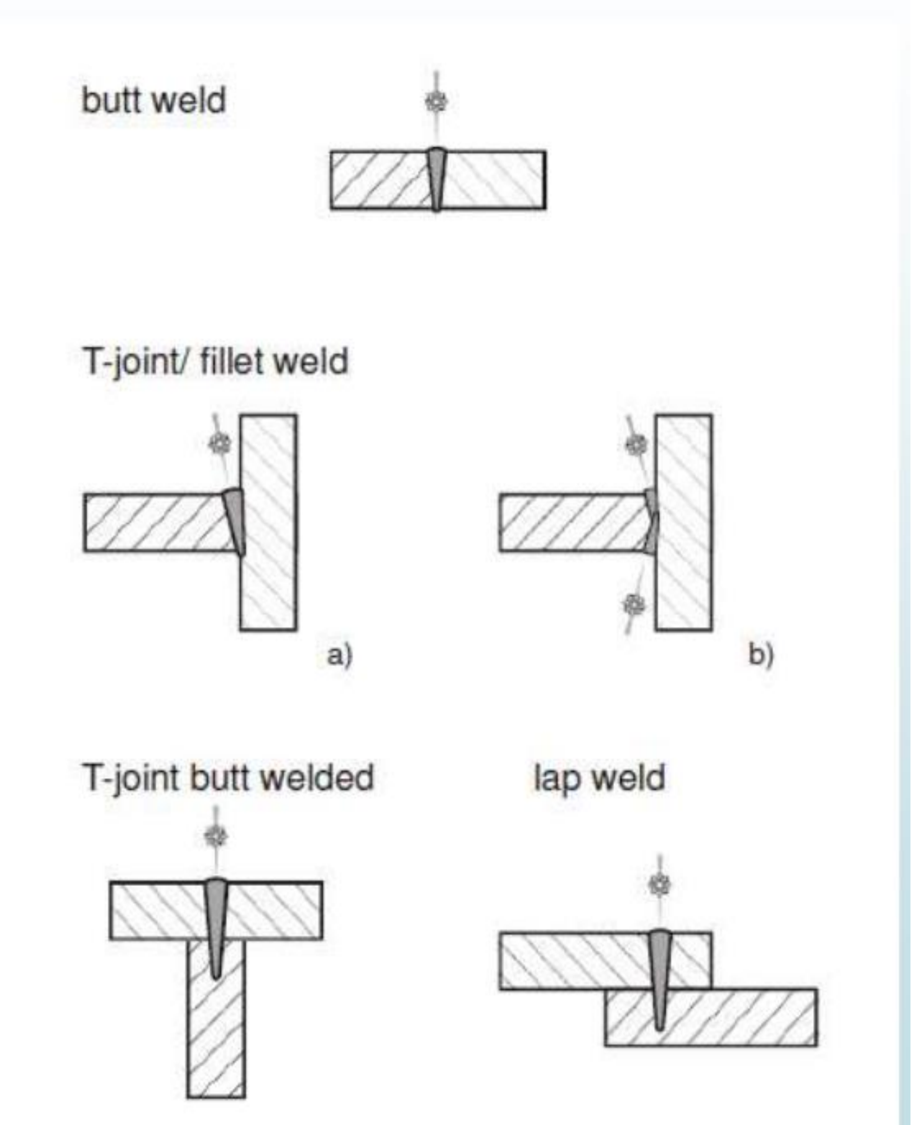
b) The high energy density at the impact point causes the metal to evaporate thus allowing the following electrons a deeper penetration.

c) This finally leads to a metal vapour cavity which is surrounded by a shell of fluid metal, covering the entire weld depth.

d) Capillary action results into formation of weld



Joint types



Advantages of EBW

Thin and thick plate welding (0,1 mm bis 300 mm).

Extremely narrow seams (t:b = 50:1).

Low overall heat input => low distortion =>Welding of completely processed components.

High welding speed is possible.

No shielding gas is required.

High process and plant efficiency.

Material dependence, is often the only welding method.

Disadvantages of EBW

Electrical conductivity of materials is required.

High cooling rates => hardening => cracks.

High precision of seam preparation.

A beam may be deflected by magnetism.

X-ray formation.

The size of the workpiece is limited by chamber size.

High investment.

Materials

Almost all steels.
Aluminium and its alloys.
Magnesium alloys.
Copper and its alloys.
Titanium.
Tungsten.
Gold.
Material combinations (e.g. Cu-steel, bronze-steel).
Ceramics (electrically conductive)

Applications of EBW

Mostly used in joining refectory materials like columbium, tungsten, and ceramics.

High precision welding of electronics components.

High-precision welding of nuclear fuel elements.

Special alloy components of jet engines.

Pressure vessels for rocket.

Joining of dissimilar metals.

Welding of Titanium medical implants.

Solid State Welding Methods

Resistance Welding

Friction Welding

Friction Stir Welding

Diffusion Welding

Diffusion Welding

Although this process was developed in the 1970s as a modern welding technology, the principle of diffusion bonding dates back centuries to when goldsmiths bonded gold over copper to create a product called filled gold. First, a thin layer of gold foil is produced and placed over copper, and a Weight is placed on top of the foil. Finally, the assembly is placed in a furnace and left until a strong bond is obtained; hence, the process is also called hot pressure welding (HPW).

Diffusion Welding

That produces solid-state coalescence between two materials under the following conditions:

1. Joining occurs at a temperature below the melting point , TM

2. Coalescence of contacting surfaces is produced with loads below those that would cause macroscopic deformation to the part.

3. A bonding aid can be used, such as an interface foil or coating ,to facilitate the bonding.

Diffusion Welding

Thus, diffusion bonding facilitates the joining of materials to produce

components with no abrupt discontinuity in the microstructure and with a minimum of deformation. It should be noted that the preferred term for this process, according to the American Welding Society, is diffusion welding. However, because diffusion bonding is used more commonly in industry.

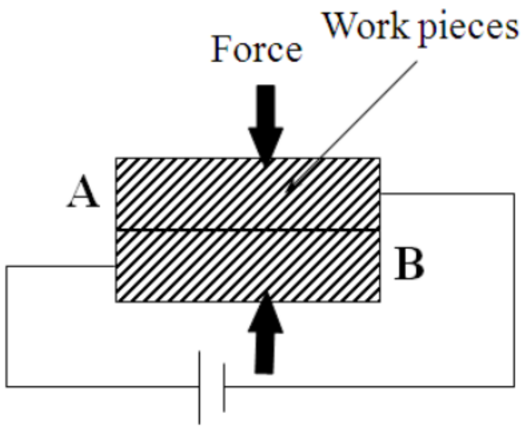


Figure (1) representation of diffusion welding using Electrical resistance for heating

Diffusion Welding

The bonded interface in diffusion welding has essentially the same physical and mechanical properties as the base metal. Its strength depends on: (a) Pressure, (b) temperature, (c) time of contact, and (d) how clean the faying surfaces are. Diffusion bonding generally is most suitable for joining dissimilar metals. It also is used for reactive metals (such as titanium, beryllium, zirconium, and refractory metal alloys) and for composite materials such as metal-matrix composites. Diffusion bonding is also an important mechanism of sintering in powder metallurgy. Because diffusion involves migration of the atoms across the joint, the process is slower than other Welding processes.

Diffusion Welding

In diffusion bonding, the nature of the joining process is essentially the coalescence of two atomically clean solid surfaces. Complete coalescence comes about through a three-stage metallurgical sequence of events. Each stage is associated with a particular metallurgical mechanism that makes the dominant contribution to the bonding process. Consequently, the stages are not discretely defined, but begin and end gradually, because the metallurgical mechanisms overlap in time. During the first stage, the contact area grows to a large fraction of the joint area by localized deformation of the contacting surface asperities. Factors such as surface roughness, yield strength, work hardening, temperature, and pressure are of primary importance during this stage of bonding. At the completion of this stage, the interface boundary is no longer a planar interface, but consists of voids separated by areas of intimate contact. In these areas of contact, the joint becomes equivalent to a grain boundary between the grains on each surface. The first stage is usually of short duration for the common case of relatively high-pressure diffusion bonding.

Diffusion Welding

During the second stage of joint formation, two changes occur simultaneously. All of the voids in the joints shrink, and most are eliminated. In addition, the interfacial grain boundary migrates out of the plane of the joint to lower-energy equilibrium. Creep and diffusion mechanisms are important during the second stage of bonding and for most, if not all, practical applications, bonding would be considered essentially complete following this stage. As the boundary moves, any remaining voids are engulfed within grains where they are no longer in contact with a grain boundary. During this third stage of bonding, the voids are very small and very likely have no impact on interface strength. Again, diffusional processes cause the shrinkage and elimination of voids, but the only possible diffusion path is now through the volume of the grains themselves. Although diffusion welding is used for fabricating complex parts in low quantities for the aerospace, nuclear, and electronics industries, it has been automated to make it suitable and economical for volume production. Unless the process is highly automated, considerable operator training and skill are required.