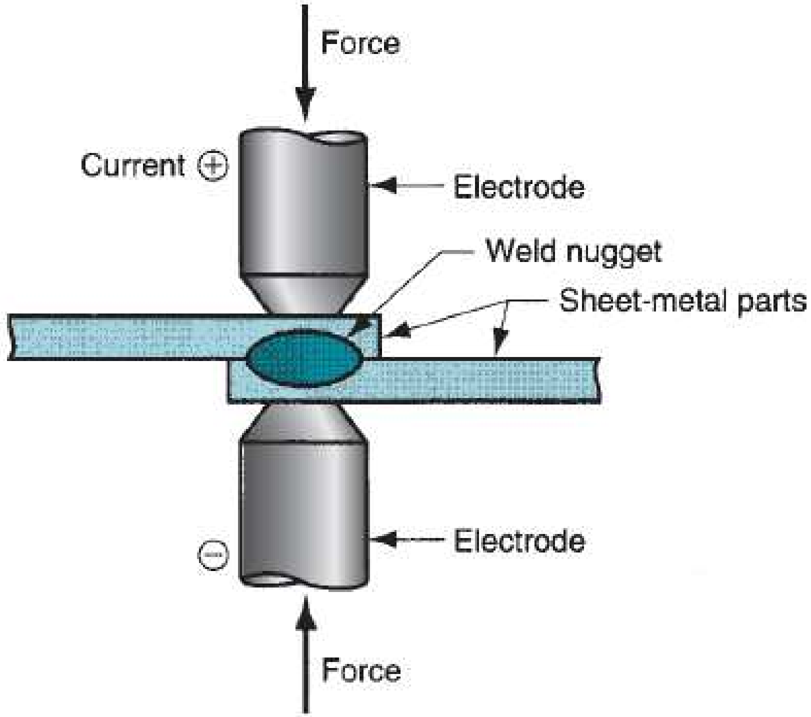
Welding Processes (Cont.)

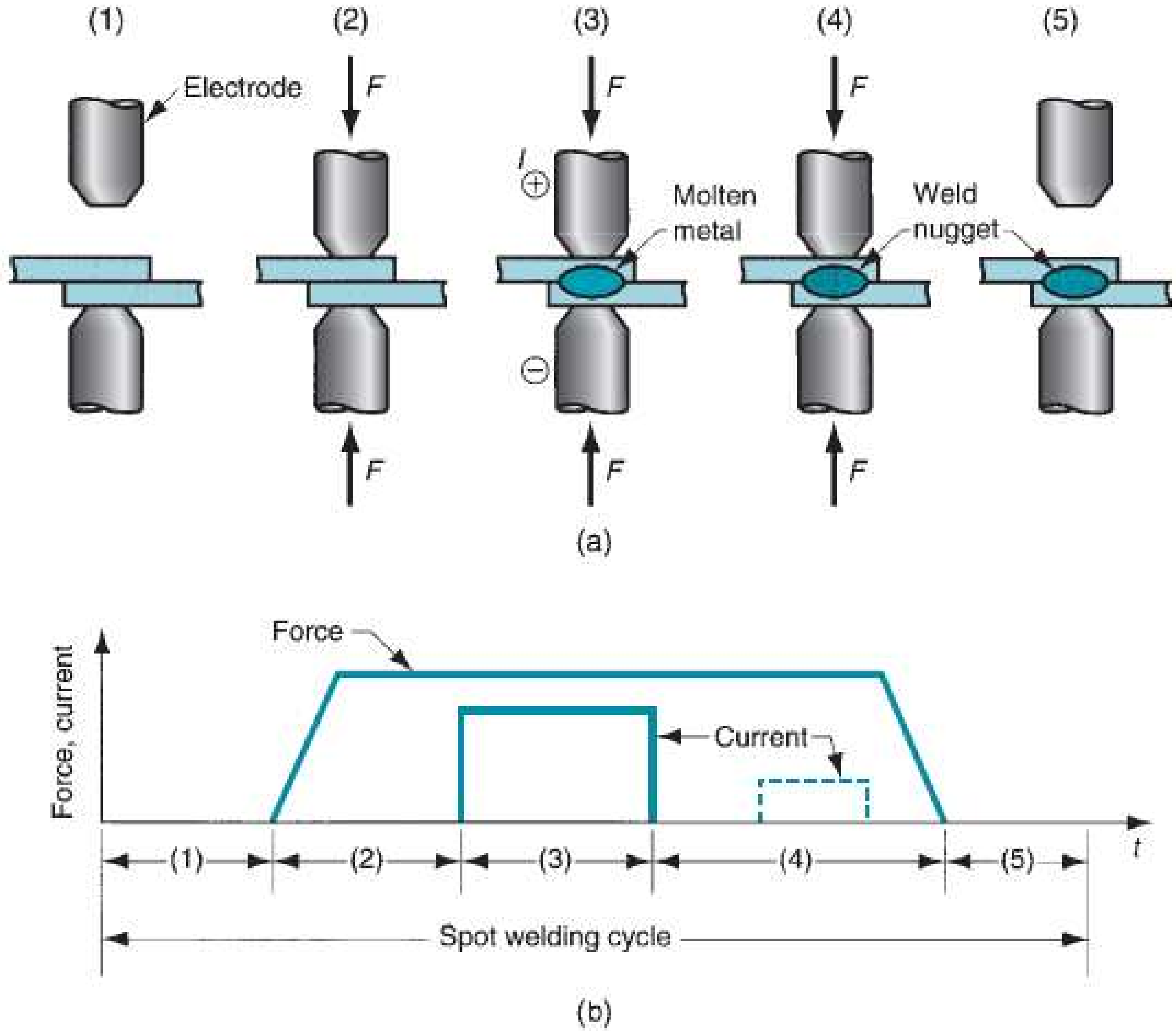
RESISTANCE WELDING

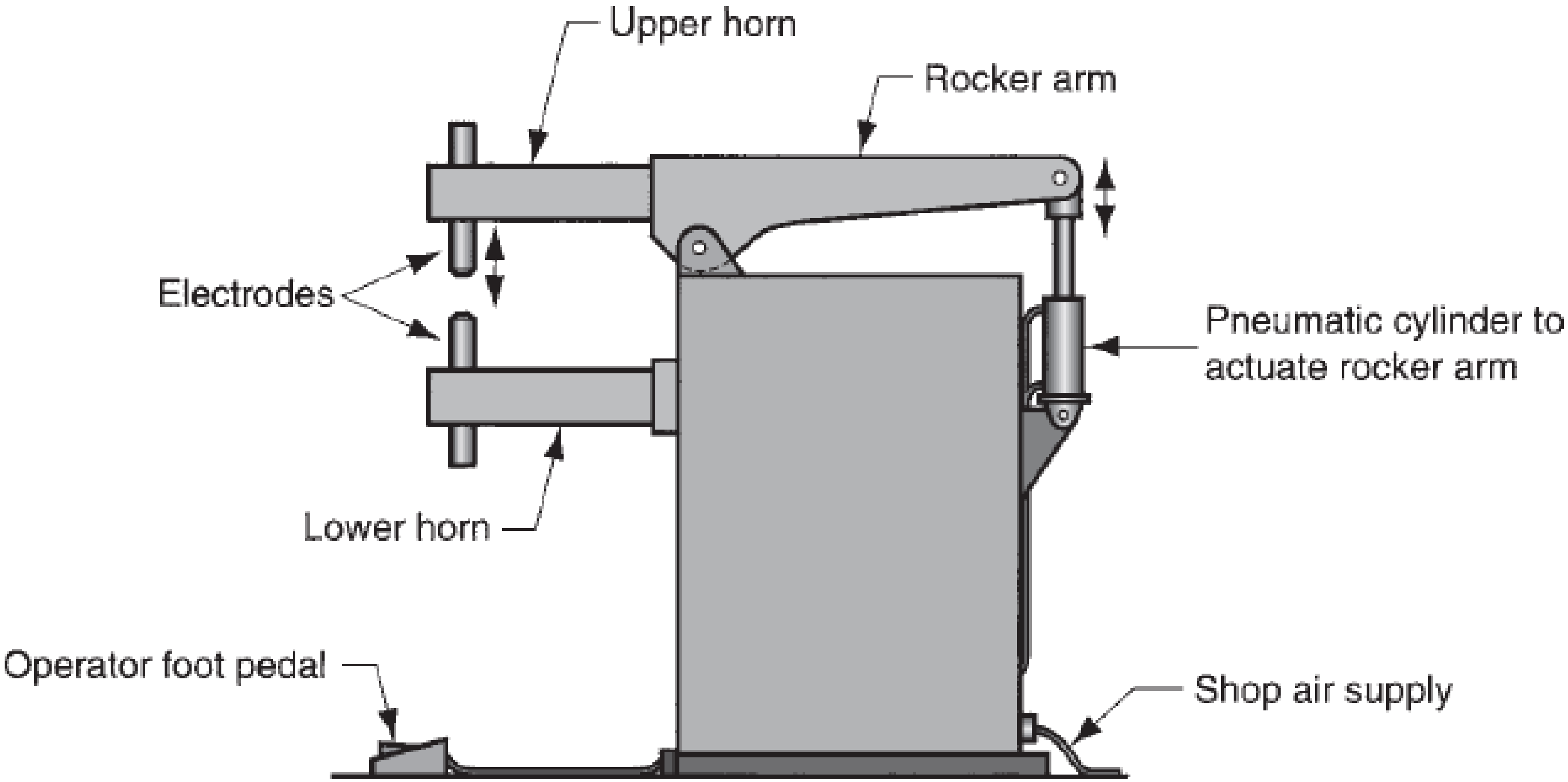
- Resistance welding is a group of fusion-welding processes that uses a combination of heat and pressure to accomplish coalescence, the heat being generated by electrical resistance to current flow at the junction to be welded.
- By comparison to arc welding, resistance welding uses no shielding gases, flux, or filler metal; and the electrodes that conduct electrical power to the process are nonconsumable.
- RW is classified as fusion welding because the applied heat almost always causes melting of the faying surfaces.



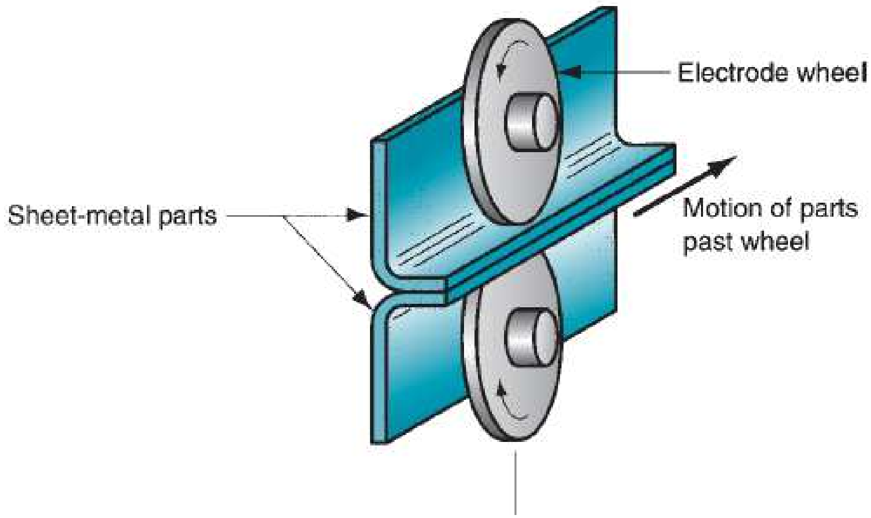
Resistance welding (RW), showing the components in spot welding, the predominant process in the RW group.

(a) Steps in a spot-welding cycle, and (b) plot of squeezing force and current during cycle. The sequence is: (1) parts inserted between open electrodes, (2) electrodes close and force is applied, (3) weld time—current is switched on, (4) current is turned off but force is maintained or increased (a reduced current is sometimes applied near the end of this step for stress relief in the weld region), and (5) electrodes are opened, and the welded assembly is removed.

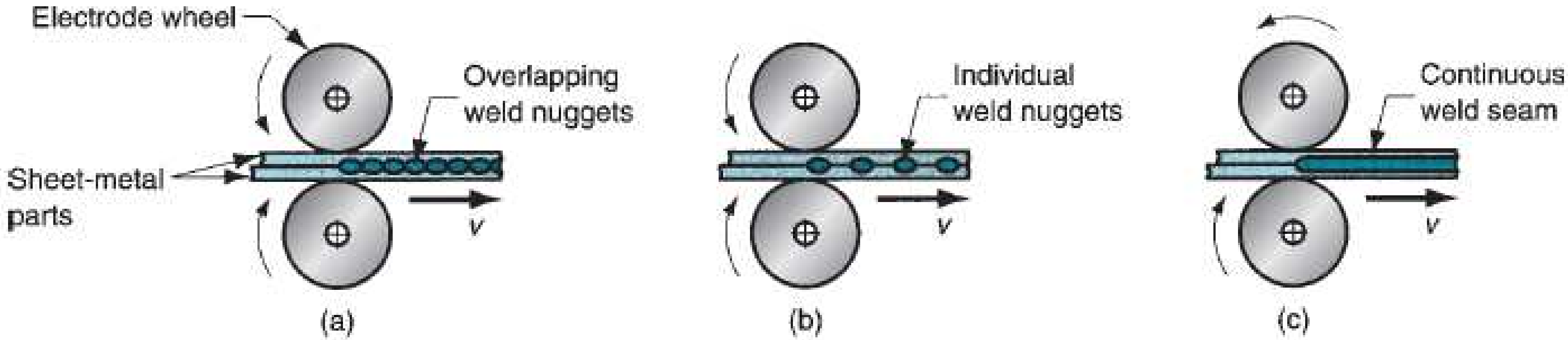




Rocker arm spot-welding machine.



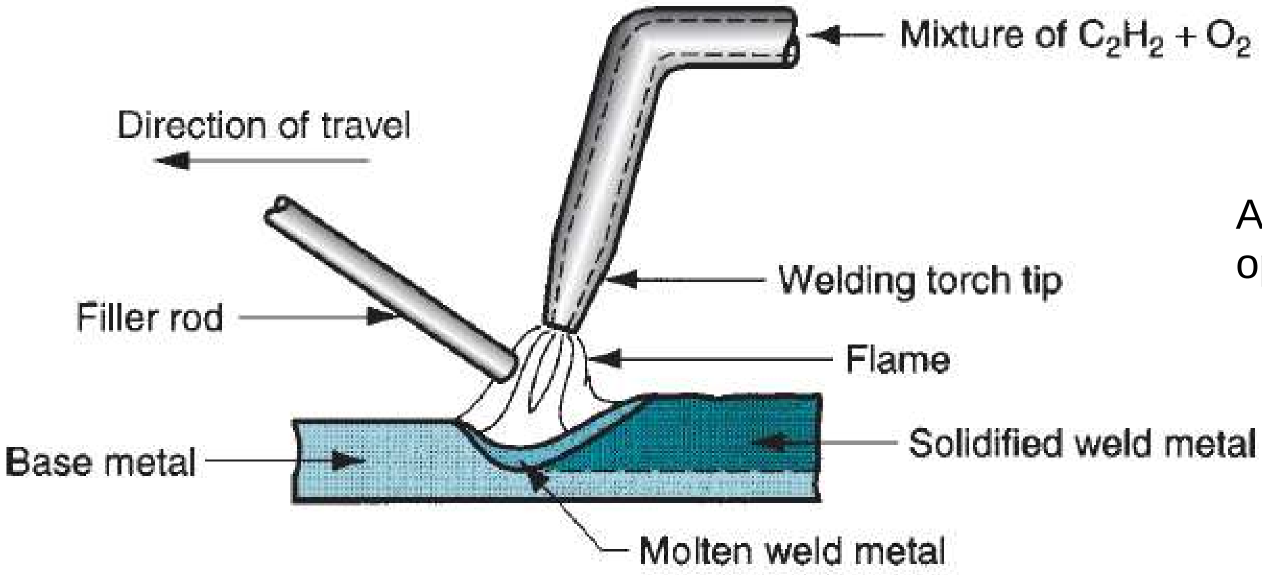
Resistance seam welding (RSEW).



Different types of seams produced by electrode wheels: (a) conventional resistance seam welding, in which overlapping spots are produced; (b) roll spot welding; and (c) continuous resistance seam.

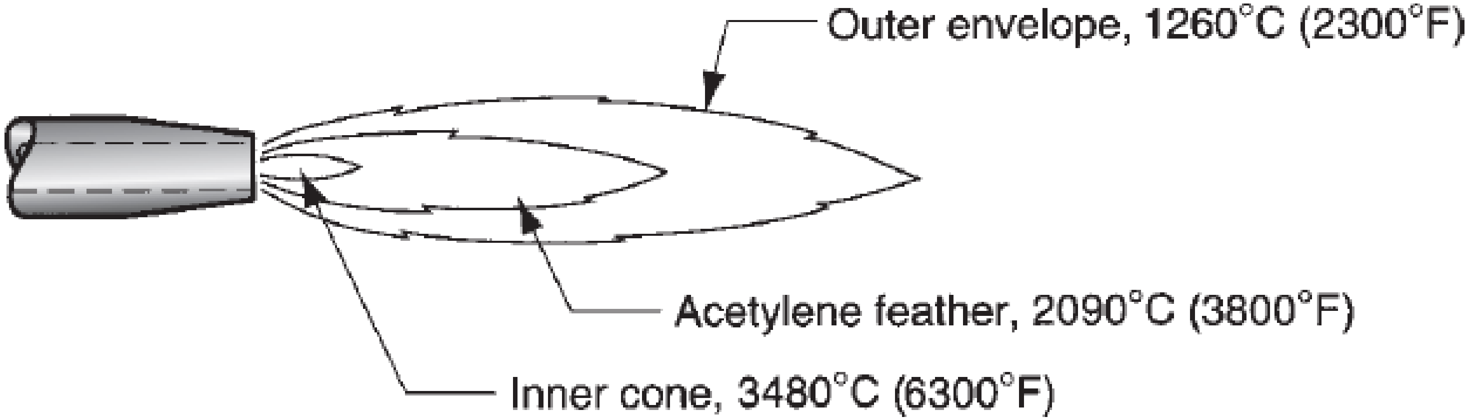
OXYFUEL GAS WELDING

- Oxyfuel gas welding (OFW) is the term used to describe the group of FW operations that burn various fuels mixed with oxygen to perform welding.
- Oxyfuel gas is also commonly used in cutting torches to cut and separate metal plates and other parts.
- The most important OFW process is oxyacetylene welding.
- Oxyacetylene welding (OAW) is a fusion-welding process performed by a high-temperature flame from combustion of acetylene and oxygen.
- The flame is directed by a welding torch.
- A filler metal is sometimes added, and pressure is occasionally applied in OAW between the contacting part surfaces.



A typical oxyacetylene welding operation (OAW).

The neutral flame from an oxyacetylene torch, indicating temperatures achieved.

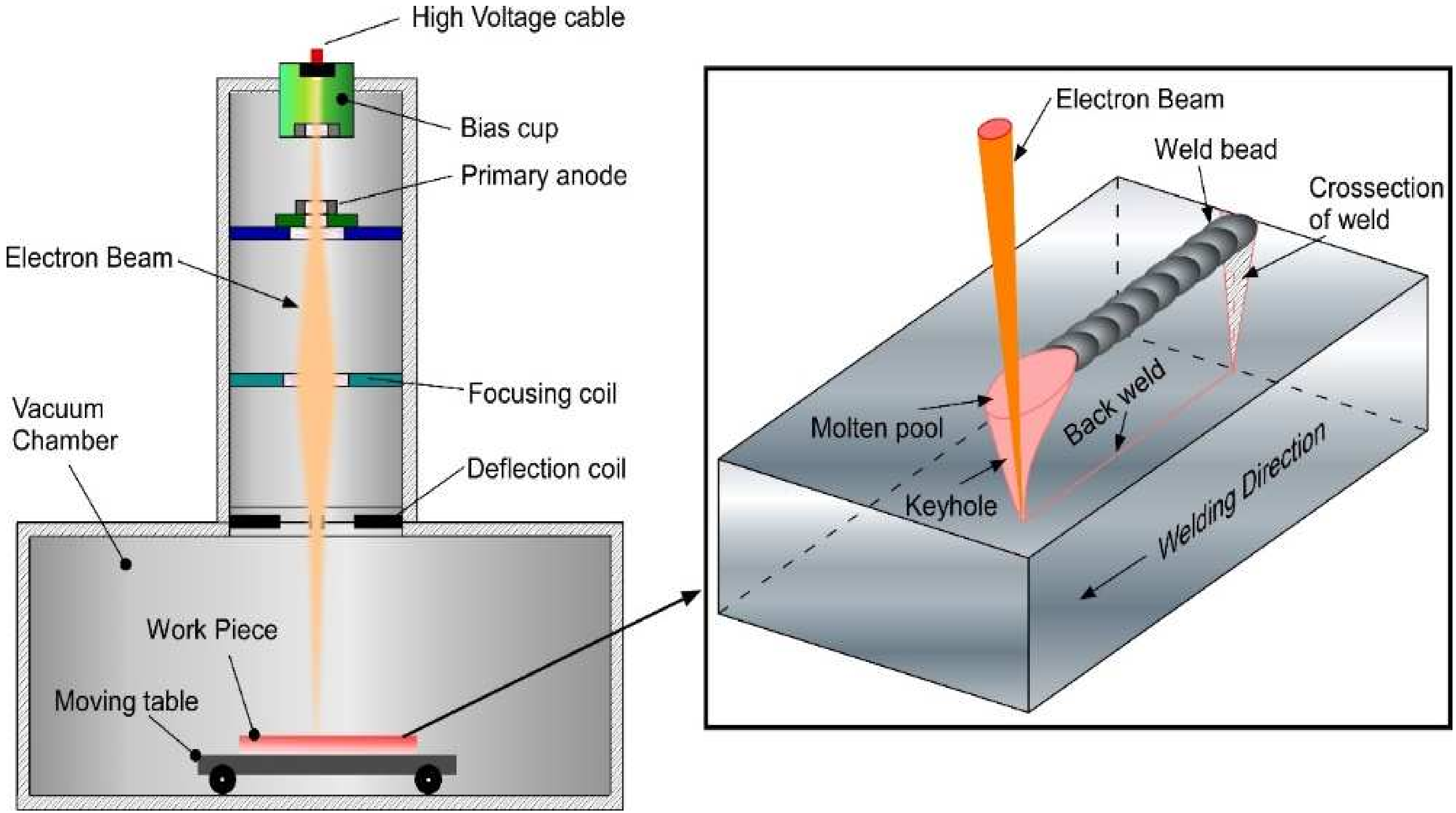


OXYFUEL GAS WELDING

- The combination of acetylene and oxygen is highly flammable, and the environment in which OAW is performed is therefore hazardous.
- Some of the dangers relate specifically to the acetylene.
- Pure C2H2 is a colorless, odorless gas.
- For safety reasons, commercial acetylene is processed to have a characteristic garlic odor.
- Although OAW can be mechanized, it is usually performed manually and is hence dependent on the skill of the welder to produce a high-quality weld joint.

OTHER FUSION-WELDING PROCESSES

- Some fusion-welding processes cannot be classified as arc, resistance, or oxyfuel welding.
- Each of these other processes uses a unique technology to develop heat for melting; and typically, the applications are unique.
- **(1) Electron-beam welding:** (EBW) is a fusion-welding process in which the heat for welding is produced by a highly focused, high-intensity stream of electrons impinging against the work surface.
- The power in EBW is not exceptional, but power density is.
- Any metals that can be arc welded by EBW, as well as certain refractory and difficult-to-weld metals that are not suited to AW.

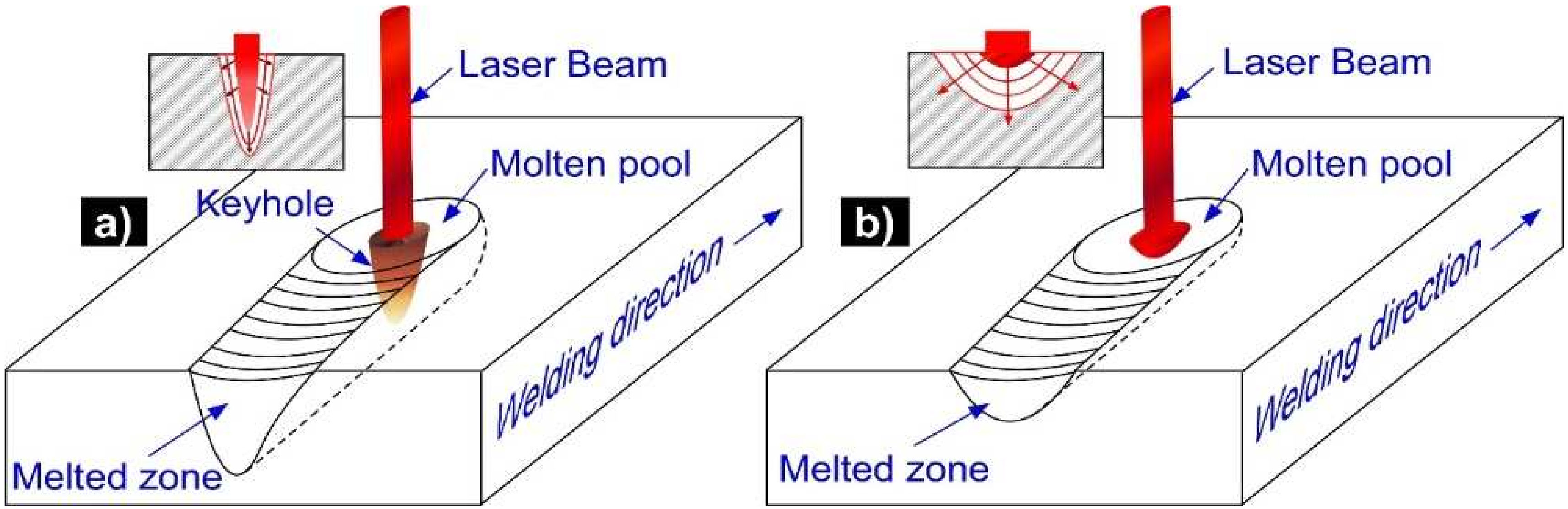


Electron beam welding, schematic explanation of keyhole mode.

(1) Electron-beam welding

- Work sizes range from thin foil to thick plate.
- EBW is applied mostly in the automotive, aerospace, and nuclear industries.
- EBW is noted for high-quality welds with deep and/or narrow profiles, limited heat-affected zone, and low thermal distortion.
- Welding speeds are high compared to other continuous welding operations.
- No filler metal is used, and no flux or shielding gases are needed.
- Disadvantages of EBW include high equipment cost, need for precise joint preparation and alignment, and the limitations associated with performing the process in a vacuum.
- In addition, there are safety concerns because EBW generates X-rays from which humans must be shielded.

(2) Laser-Beam Welding



Schematic representations of laser beam welding mechanisms. Key hole mechanism (a) and conduction mode mechanism (b).

(2) Laser-Beam Welding

- Laser-beam welding (LBW) is a fusion-welding process in which coalescence is achieved by the energy of a highly concentrated, coherent light beam focused on the joint to be welded.
- The term laser is an acronym for light amplification by stimulated emission of radiation.
- LBW is normally performed with shielding gases (e.g., helium, argon, nitrogen, and carbon dioxide) to prevent oxidation.
- Filler metal is not usually added.
- There are two types of LBW mechanisms called as keyhole mode and conduction mode.
- The difference between these two mechanisms is related with the power density.

(2) Laser-Beam Welding

- There are several advantages of LBW over EBW: no vacuum chamber is required, no X-rays are emitted, and laser beams can be focused and directed by optical lenses and mirrors.
- LBW does not possess the capability for the deep welds and high depth-to-width ratios of EBW.
- Maximum depth in laser welding is about 19 mm, whereas EBW can be used for weld depths of 50 mm or more.
- Because of the highly concentrated energy in the small area of the laser beam, the process is often used to join small parts.

SOLID-STATE WELDING

- In solid state-welding, coalescence of the part surfaces is achieved by (1) pressure alone, or (2) heat and pressure.
- For some solid-state processes, time is also a factor.
- If both heat and pressure are used, the amount of heat by itself is not sufficient to cause melting of the work surfaces.
- In other words, fusion of the parts would not occur using only the heat that is externally applied in these processes.
- In some cases, the combination of heat and pressure, or the particular manner in which pressure alone is applied, generates sufficient energy to cause localized melting of the faying surfaces.

GENERAL CONSIDERATIONS IN SOLID-STATE WELDING

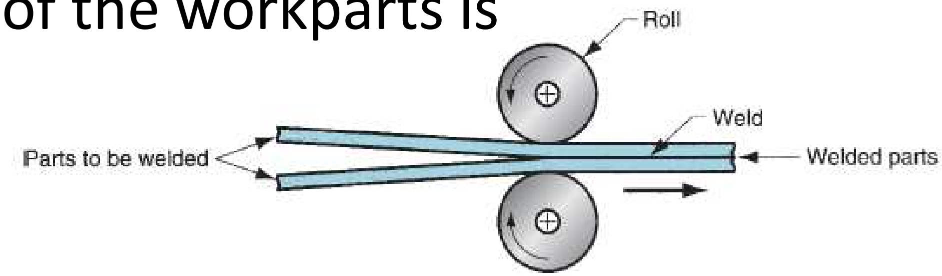
- In most of the solid-state processes, a metallurgical bond is created with little or no melting of the base metals.
- To metallurgically bond two similar or dissimilar metals, the two metals must be brought into intimate contact so that their cohesive atomic forces attract each other.
- In normal physical contact between two surfaces, such intimate contact is prohibited by the presence of chemical films, gases, oils, and so on.
- In order for atomic bonding to succeed, these films and other substances must be removed.

GENERAL CONSIDERATIONS IN SOLID-STATE WELDING

- Welding processes that do not involve melting have several advantages over fusion welding processes.
- If no melting occurs, then there is no heat-affected zone, and so the metal surrounding the joint retains its original properties.
- Many of these processes produce welded joints that comprise the entire contact interface between the two parts, rather than at distinct spots or seams, as in most fusion-welding operations.
- Also, some of these processes are quite applicable to bonding dissimilar metals, without concerns about relative thermal expansions, conductivities, and other problems that usually arise when dissimilar metals are melted and then solidified during joining.

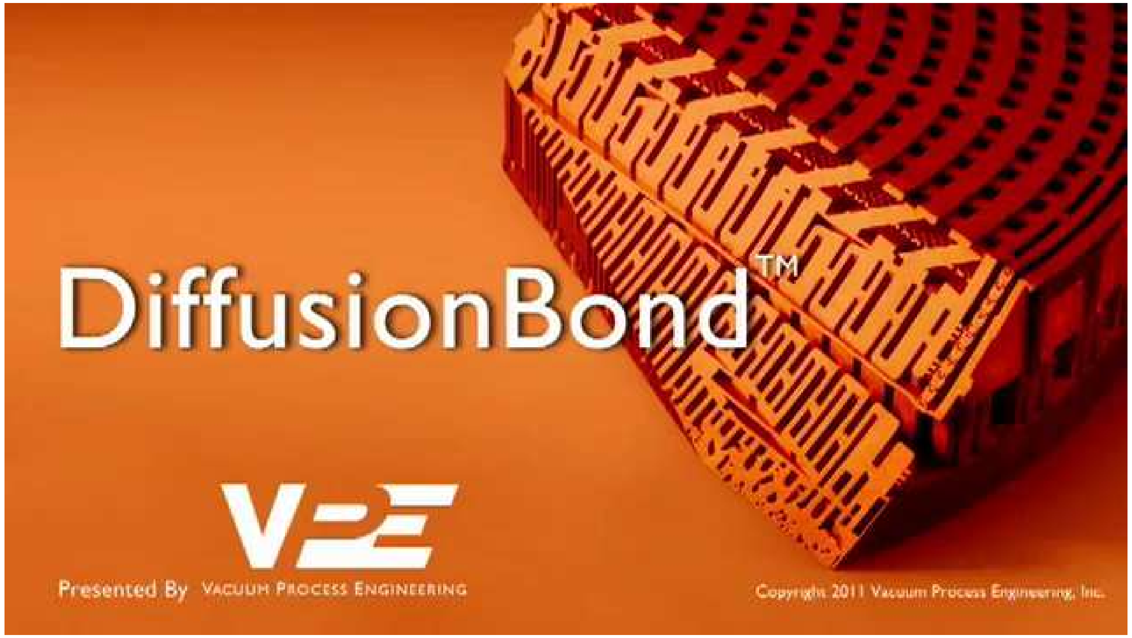
SOLID-STATE WELDING PROCESSES

- **Forge Welding** is a welding process in which the components to be joined are heated to hot working temperatures and then forged together by hammer or other means.
- **Cold welding** is a solid-state welding process accomplished by applying high pressure between clean contacting surfaces at room temperature. Also, at least one of the metals to be welded, and preferably both, must be very ductile and free of work hardening. Metals such as soft aluminum and copper can be readily cold welded.
- **Roll welding** is a variation of either forge welding or cold welding, depending on whether external heating of the workparts is accomplished prior to the process.



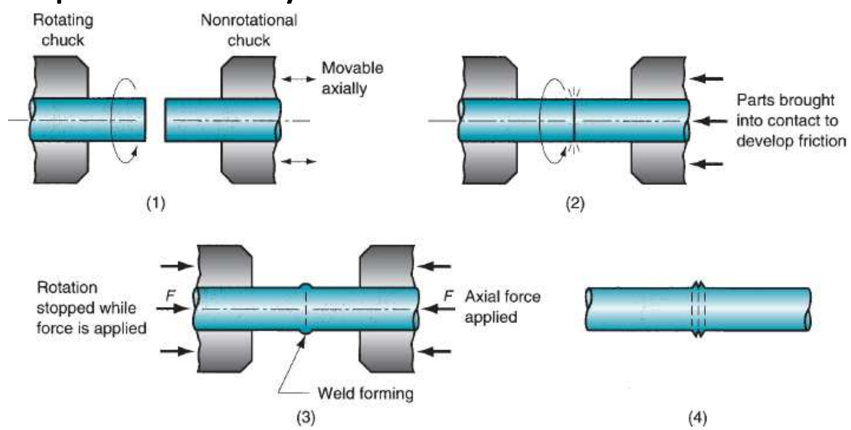
SOLID-STATE WELDING PROCESSES

- **Diffusion welding** is a solid-state welding process that results from the application of heat and pressure, usually in a controlled atmosphere, with sufficient time allowed for diffusion and coalescence to occur. Temperatures are well below the melting points of the metals (about 0.5 Tm is the maximum), and plastic deformation at the surfaces is minimal.

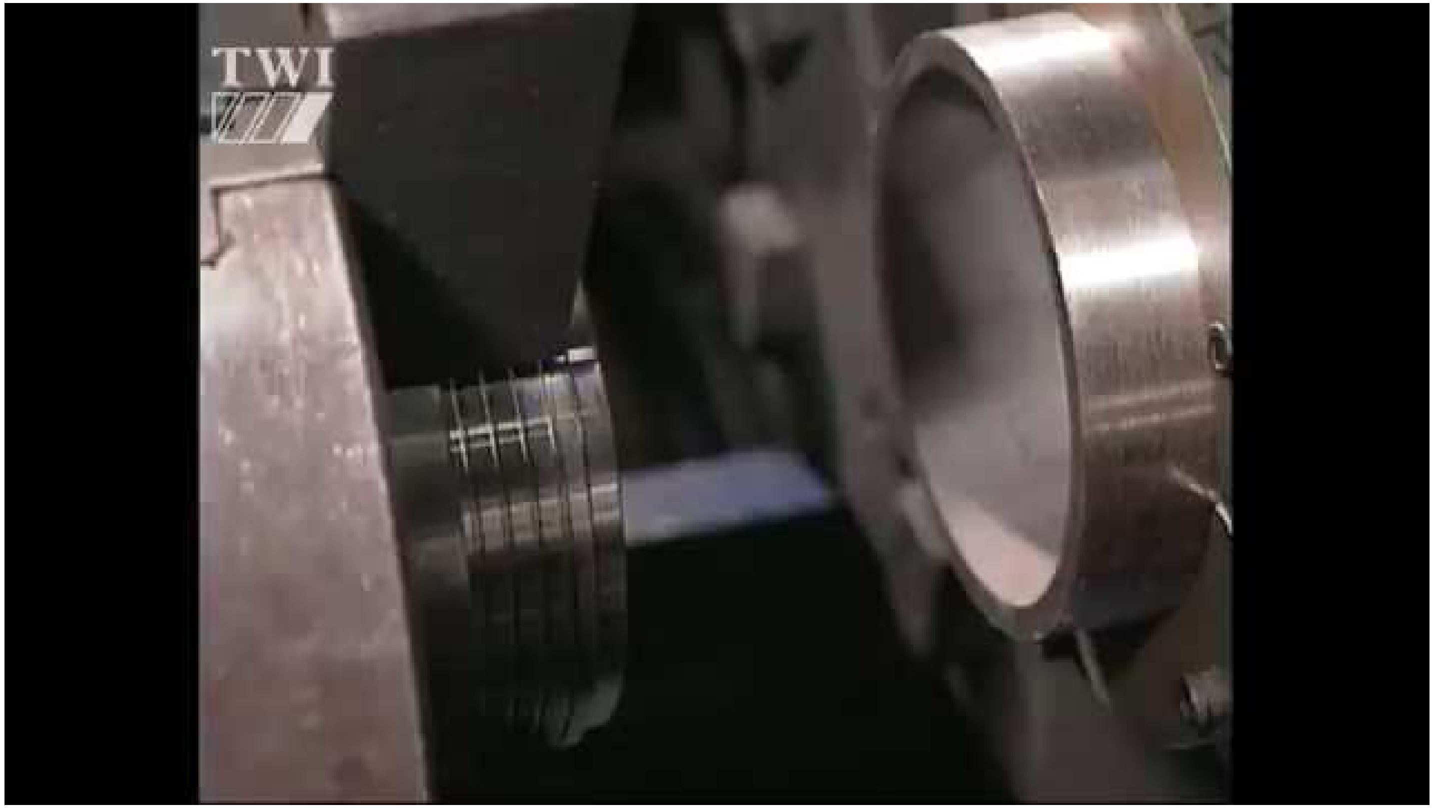


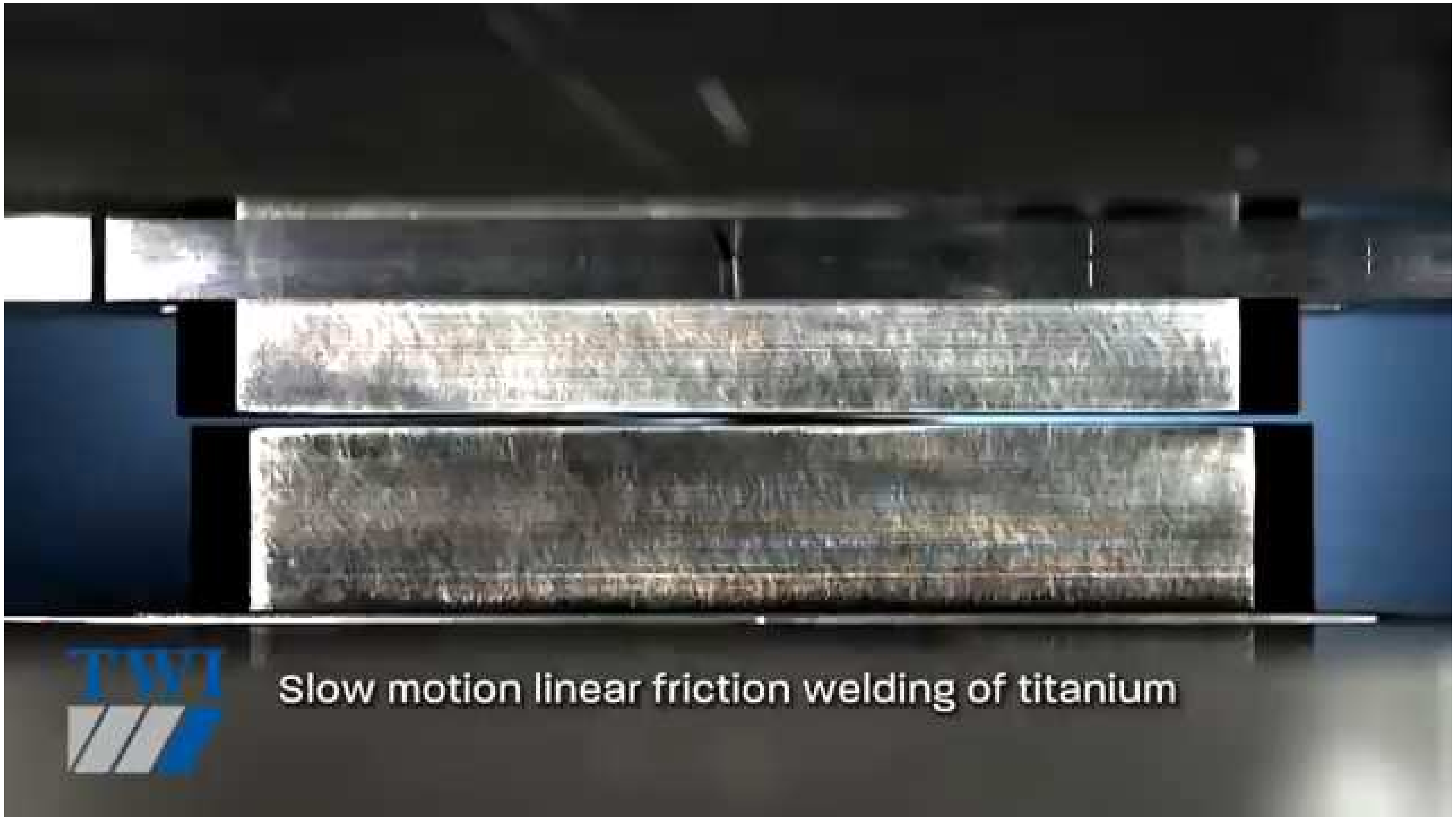
SOLID-STATE WELDING PROCESSES

- **Friction welding** is a widely used commercial process, amenable to automated production methods.
- The friction is induced by mechanical rubbing between the two surfaces, usually by rotation of one part relative to the other, to raise the temperature at the joint interface to the hot working range for the metals involved.
- Then the parts are driven toward each other with sufficient force to form a metallurgical bond.
- The axial compression force upsets the parts, and a flash is produced by the material displaced.



Friction welding (FRW): (1) rotating part, no contact; (2) parts brought into contact to generate friction heat; (3) rotation stopped and axial pressure applied; and (4) weld created.

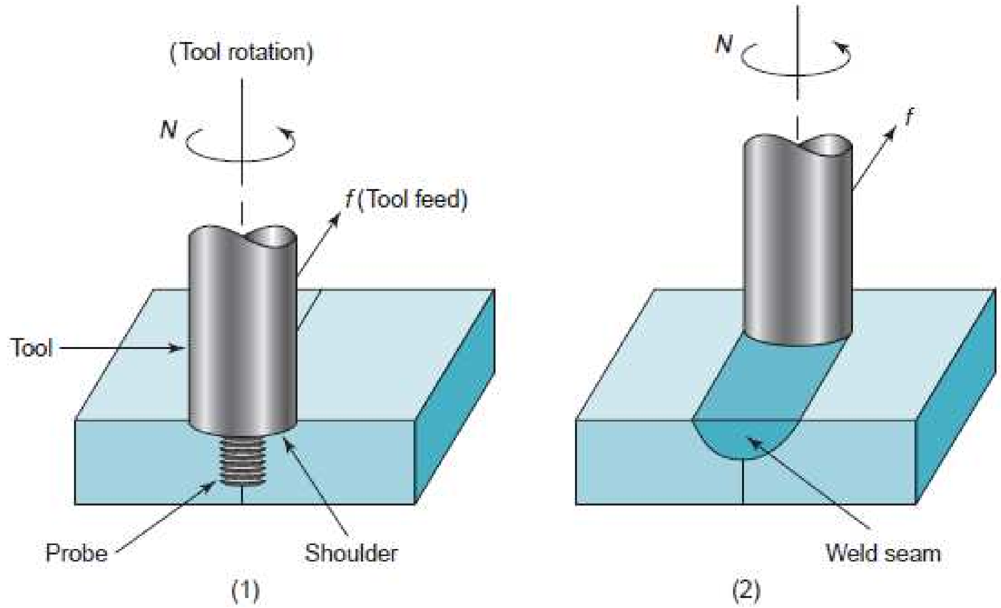



TWI
Slow motion linear friction welding of titanium

SOLID-STATE WELDING PROCESSES

- Friction stir welding is a solid state welding process in which a rotating tool is fed along the joint line between two workpieces, generating friction heat and mechanically stirring the metal to form the weld seam.
- FSW is distinguished from conventional FRW by the fact that friction heat is generated by a separate wear-resistant tool rather than by the parts themselves.

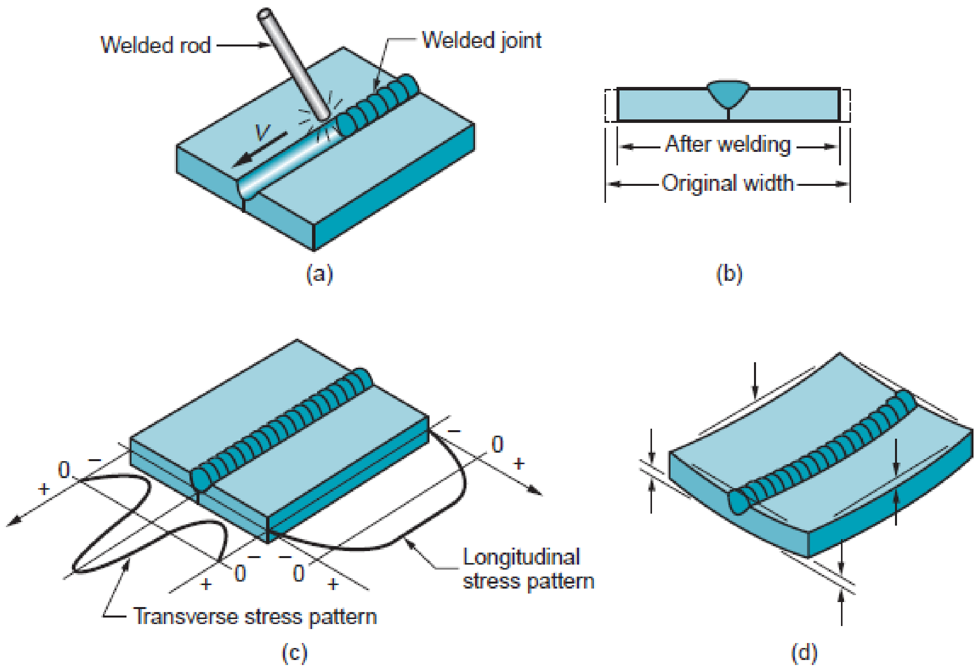
Friction stir welding (FSW): (1) rotating tool just prior to feeding into joint and (2) partially completed weld seam. N = tool rotation, f = tool feed.



[redacted]

WELD QUALITY

- **Residual Stresses and Distortion**: The rapid heating and cooling in localized regions of the work during fusion welding, especially arc welding, result in thermal expansion and contraction that cause residual stresses in the weldment. These stresses, in turn, can cause distortion and warping of the welded assembly.



(a) Butt welding two plates; (b) shrinkage across the width of the welded assembly; (c) transverse and longitudinal residual stress pattern; and (d) likely warping in the welded assembly.

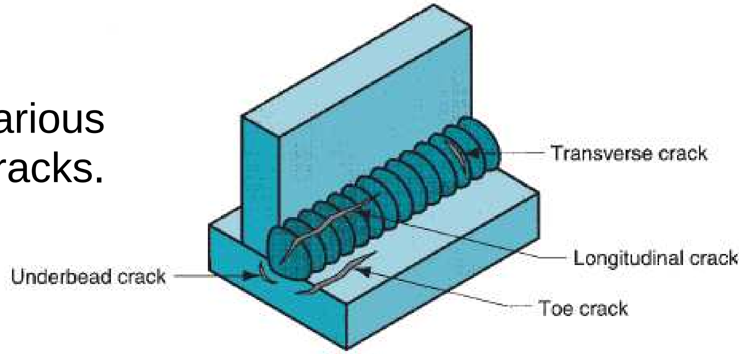
To minimize warping in a weldment:

- (1) Welding fixtures can be used to physically restrain movement of the parts during welding.
- (2) Heat sinks can be used to rapidly remove heat from sections of the welded parts to reduce distortion.
- (3) Tack welding at multiple points along the joint can create a rigid structure prior to continuous seam welding.
- (4) Welding conditions (speed, amount of filler metal used, etc.) can be selected to reduce warping.
- (5) The base parts can be preheated to reduce the level of thermal stresses experienced by the parts.
- (6) Stress relief heat treatment can be performed on the welded assembly, either in a furnace for small weldments, or using methods that can be used in the field for large structures.
- (7) Proper design of the weldment itself can reduce the degree of warping.

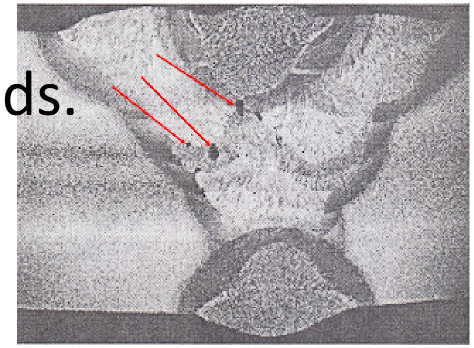
Welding Defects

- **Cracks**. Welding cracks are caused by embrittlement or low ductility of the weld and/or base metal combined with high restraint during contraction.

Various forms of welding cracks.



- **Cavities**. These include various porosity and shrinkage voids.



Welding Defects

- **Incomplete fusion** is simply a weld bead in which fusion has not occurred throughout the entire cross section of the joint

a) Desired weld profile for single V-groove weld joint. Same joint but with several weld defects: (b) undercut, in which a portion of the base metal part is melted away; (c) underfill, a depression in the weld below the level of the adjacent base metal surface; and (d) overlap, in which the weld metal spills beyond the joint onto the surface of the base part but no fusion occurs.