Chapter Five – Joining and Assembly Processes

Introduction:

- The term ***joining*** is generally used for welding, brazing, soldering, and adhesive bonding, which form a permanent joint between the parts.
- The term ***assembly*** usually refers to mechanical methods of fastening parts together. Some of these methods allow for easy disassembly, while others do not.

Welding Technology:

- Welding is joining process in which two or more parts are coalesced at their contacting surfaces by a suitable application of heat and/or pressure.
- Many welding processes are accomplished by heat alone, with no pressure applied; others by a combination of heat and pressure; and others by pressure alone.
- In some welding processes a filler material is added to facilitate coalescence.
- The assemblage of parts that are joined by welding is called a weldment.
- Welding is most commonly associated with metal parts, but the process is also used for joining plastics.

Commercial and Technological Importance of Welding:

- Welding provides a permanent joint. The welded parts become a single entity.
- The welded joint can be stronger than the parent materials if a filler metal is used that has strength properties superior to those of the parents, and if proper welding techniques are used.
- Welding is usually the most economical way to join components in terms of material usage and fabrication costs.
- Alternative mechanical methods of assembly require more complex shape alterations (e.g., drilling of holes) and addition of fasteners (e.g., rivets or bolts). The resulting mechanical assembly is usually heavier than a corresponding weldment.
- Welding is not restricted to the factory environment. It can be accomplished ‘‘in the field.’’

Limitations and Drawbacks of Welding:

- Most welding operations are performed manually and are expensive in terms of labor cost and many of them require skilled labors.
- Most welding processes are inherently dangerous because they involve the use of high energy.
- Since welding accomplishes a permanent bond between the components, it does not allow for convenient disassembly.
- The welded joint can suffer from certain quality defects that are difficult to detect, these defects can reduce the strength of the joint.

The Weld Joint:

- Welding produces a solid connection between two pieces, called a weld joint.
- A weld joint is the junction of the edges or surfaces of parts that have been joined by welding.

(1) Types of Joints

There are five basic types of joints for bringing two parts together for joining as shown if figure (5-1):

(a) Butt Joint: In this joint type, the parts lie in the same plane and are joined at their edges.

(b) Corner Joint: The parts in a corner joint form a right angle and are joined at the corner of the angle.

(c)Lap Joint: This joint consists of two overlapping parts.

(d) Tee Joint: In a tee joint, one part is perpendicular to the other in the approximate shape of the letter ''T.''

(e) Edge Joint: The parts in an edge joint are parallel with at least one of their edges in common, and the joint is made at the common edge(s).

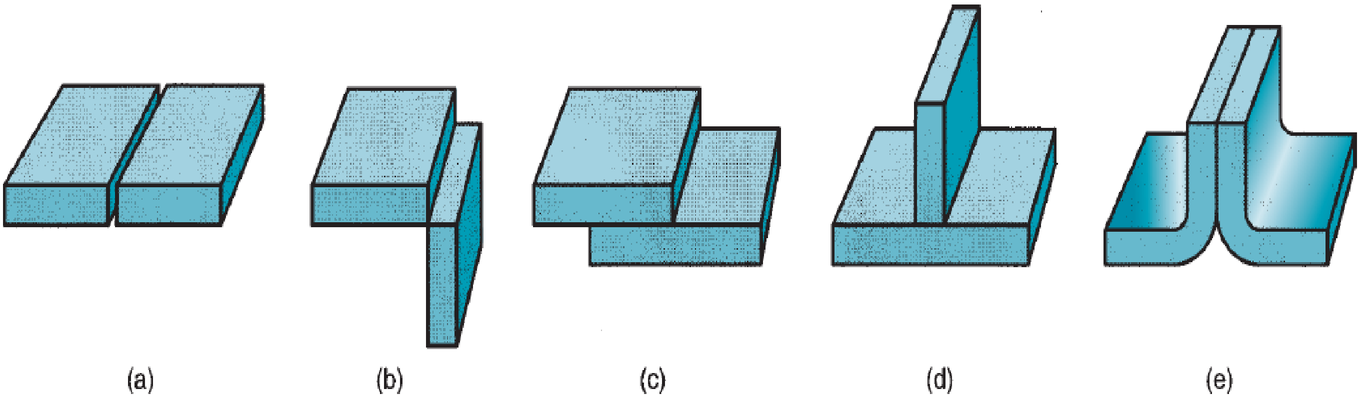


Fig. (5-1) Five basic types of joints: (a) butt (b) corner (c) lap (d) tee (e) edge

(2) Types of Welds

- It is appropriate to distinguish between the joint type and the way in which it is welded—the weld type.
- Differences among weld types are in geometry (joint type) and welding process.

(a) *Fillet weld:*

- It is used to fill in the edges of plates created by corner, lap, and tee joints, as in Figure (5-2).
- Filler metal is used to provide a cross section approximately the shape of a right triangle.
- It is the most common weld type in arc and oxyfuel welding because it requires minimum edge preparation.

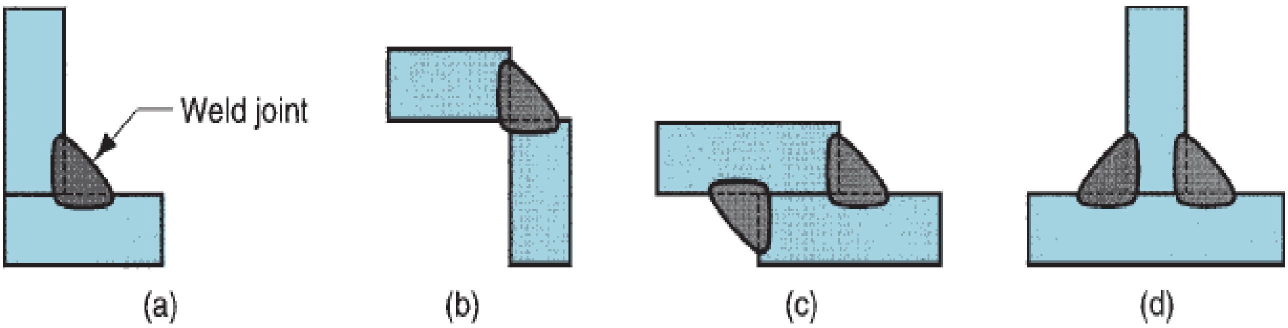


Fig. (5-2) Various forms of fillet welds: (a) inside single fillet corner joint (b) outside single fillet corner joint (c) double fillet lap joint (d) double fillet tee joint. Dashed lines show the original part edges.

(b) *Groove welds:*

- It usually require that the edges of the parts be shaped into a groove to facilitate weld penetration.
- The grooved shapes include square, bevel, V, U, and J, in single or double sides, as shown in Figure (5-3).
- Filler metal is used to fill in the joint, usually by arc or oxyfuel welding.
- Preparation of the part edges beyond the basic square edge, although requiring additional processing, is often done to increase the strength of the welded joint or where thicker parts are to be welded.

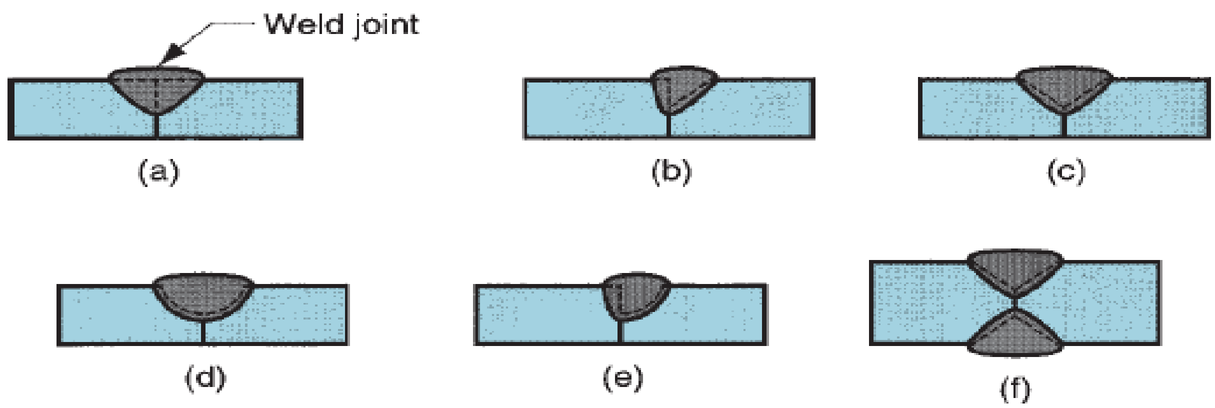


Fig. (5-3) Some typical groove welds: (a) square groove weld, one side (b) single bevel groove weld (c) single V-groove weld (d) single U-groove weld (e) single J-groove weld (f) double V-groove weld for thicker sections. Dashed lines show the original part edges.

(c) ***Plug Welds and Slot Welds:***

- They are used for attaching flat plates, as shown in Figure (5-4), using one or more holes or slots in the top part and then filling with filler metal to fuse the two parts together.

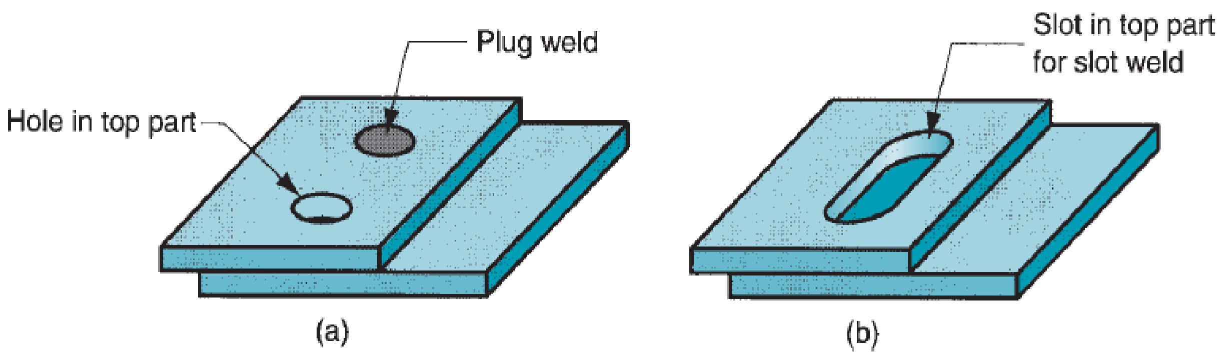
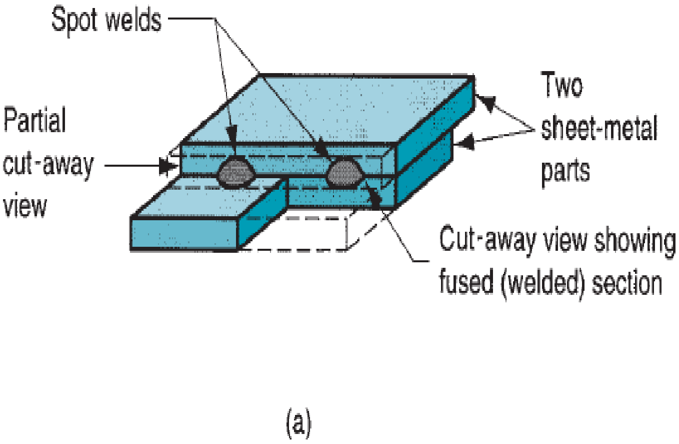


Fig. (5-4) (a) plug weld, and (b) slot weld

(d)***Spot Welds and Seam Welds:***

- Spot welds are used for lap joints, as shown in Figure (5-5).
- A spot weld is a small fused section between the surfaces of two sheets or plates.
- Multiple spot welds are typically required to join the parts.
- It is most closely associated with resistance welding.
- A seam weld is similar to a spot weld except it consists of a more or less continuously fused section between the two sheets or plates.



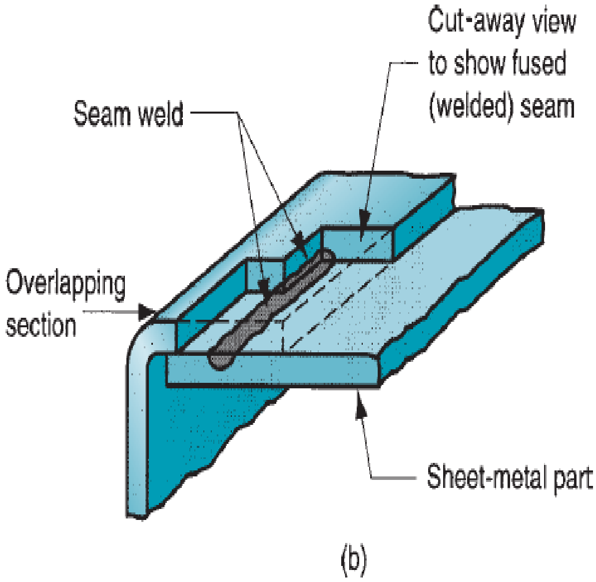
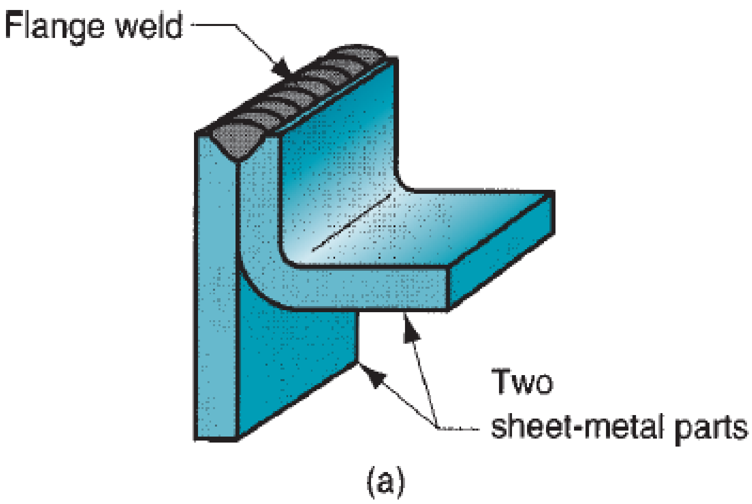


Fig. (5-5) (a) spot weld, and (b) seam weld

(e) ***Flange Welds and Surfacing Welds:***

- They are shown in Figure (5-6).
- A flange weld is made on the edges of two (or more) parts, usually sheet metal or thin plate, at least one of the parts being flanged as in Figure (5-6a).
- A surfacing weld is not used to join parts, but rather to deposit filler metal onto the surface of a base part in one or more weld beads.
- The weld beads can be made in a series of overlapping parallel passes, thereby covering large areas of the base part.
- The purpose of surface weld is to increase the thickness of the plate or to provide a protective coating on the surface.



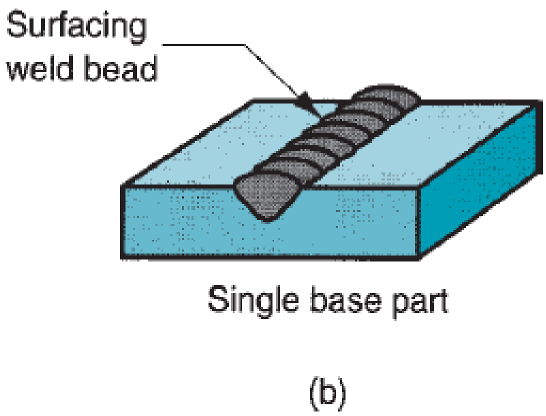


Fig. (5-6) (a) flange weld, and (b) surfacing weld

Automation in Welding:

- Because of the hazards of manual welding, and in efforts to increase productivity and improve product quality, various forms of mechanization and automation have been developed.
- The categories include **machine welding**, **automatic welding**, and **robotic welding**.

Machine welding:

- It can be defined as mechanized welding with equipment that performs the operation under the continuous supervision of an operator.
- It is normally accomplished by a welding head that is moved by mechanical means relative to a stationary w.p., or by moving the w.p. relative to a stationary welding head.
- The human worker must continually observe and interact with the equipment to control the operation.

Automatic welding:

- In which the equipment is capable of performing the operation without control by a human operator.
- A human worker is usually present to oversee the process and detect variations from normal conditions.
- In automatic welding, a weld cycle controller is used to regulate the arc movement and w.p. positioning without continuous human attention.
- Automatic welding requires a welding fixture and/or positioner to position w.p. relative to the welding head.
- It also requires a higher degree of consistency and accuracy in the component parts used in the weldment.

Robotic welding:

- In which an industrial robot or programmable manipulator is used to automatically control the movement of the welding head relative to w.p.
- The versatile reach of the robot arm permits the use of relatively simple fixtures, and the robot's capacity to be reprogrammed for new part configurations allows this form of automation to be justified for relatively low production quantities.
- A typical robotic arc welding cell consists of two welding fixtures and a human fitter to load and unload parts while the robot welds.
- In addition to arc welding, industrial robots are also used in automobile final assembly plants to perform resistance welding on car bodies.

Physics of Welding

Power Density:

- To accomplish fusion, a source of high-density heat energy is supplied to the faying surfaces, and the resulting temperatures are sufficient to cause localized melting of the base metals.
- If a filler metal is added, the heat density must be high enough to melt it also.
- Heat density can be defined as the power transferred to the w.p. per unit surface area, W/mm2 (Btu/sec-in2).
- The time to melt the metal is inversely proportional to the power density.
- It has been found that the minimum power density required to melt most metals in welding is about 10 W/mm^2 (6 $Btu/sec\text{-}in^2$).

- Power density can be computed as the power entering the surface divided by the corresponding surface area:

$$\boldsymbol{PD = \frac{P}{A}}$$

PD: power density (W/mm^2, $Btu/sec\text{-}in^2$).
P: power entering the surface (W, Btu/sec).
A: surface area over which the energy is entering (mm^2, in^2).

Example (1):
A heat source transfers 3000W to the surface of a metal part. The heat impinges the surface in a circular area, with intensities varying inside the circle. The distribution is as follows: 70% of the power is transferred within a circle of diameter=5mm, and 90% is transferred within a concentric circle of diameter=12 mm. What are the power densities in (a) the 5-mm diameter inner circle and (b) the 12-mm-diameter ring that lies around the inner circle?

Solution:
(a)

$$PD = \frac{P}{A} = \frac{0.7(3000)}{\frac{\pi}{4}(5^2)} = 106.95\ w/mm^2$$ **Answer**

(b) The area of ring around the inner circle: $A_r = \frac{\pi}{4}(12^2 - 5^2) = 93.46\ mm^2$
Power transferred to the ring area=0.9(3000) – 0.7(3000) = 600W

$$PD = \frac{P}{A} = \frac{600}{93.46} = 6.42\ w/mm^2$$ **Answer**

Heat Balance in Fusion Welding:

The quantity of heat required to melt a given volume of metal depends on:
(1) the heat to raise the temperature of the solid metal to its melting point.
(2) the melting point of the metal.
(3) the heat to transform the metal from solid to liquid phase at the melting point.

To a reasonable approximation, this quantity of heat can be estimated by:

$$U_m = KT_m^2$$

U_m: the unit energy for melting (i.e., the quantity of heat required to melt a unit volume of metal starting from room temperature), J/mm^3 (Btu/in^3).
T_m: melting point of the metal on an absolute temperature scale, ^oK (^oR).
K: constant whose value is $3.33E-6$ when the Kelvin scale is used (and K= $1.467E-5$ for the Rankine temperature scale).

Losses in Energy Generated at Heat Source:
The losses in energy generated used for welding are explained in figure (5-7).

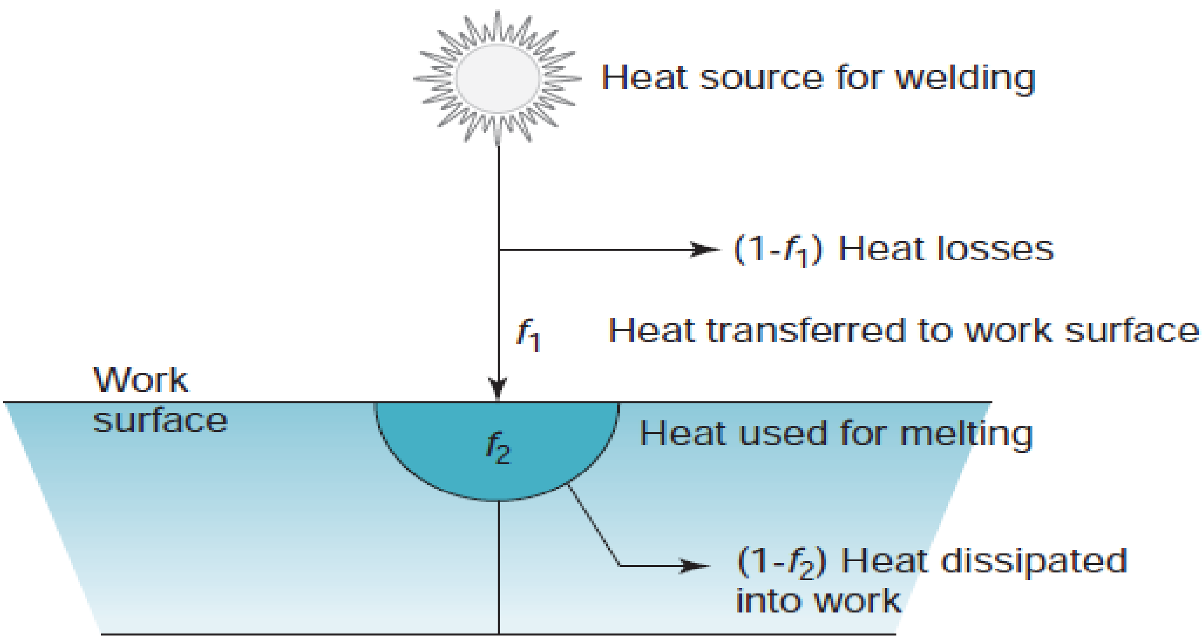


Figure (5-7) Heat transfer mechanisms in fusion welding.

f_1: heat transfer factor: the ratio of the actual heat received by the w.p. divided by the total heat generated at the source.
f_2: melting factor: the proportion of heat received at the work surface that can be used for melting.

The combined effect of $\mathbf{f_1}$ and $\mathbf{f_2}$ is to reduce the heat energy available for welding as follows:

$$H_w = f_1 f_2 H$$

H_w: net heat available for welding, J (Btu).
H: the total heat generated by the welding process, J (Btu).

- The **heat transfer factor** $\mathbf{f_1}$ is determined largely by the welding process and the capacity to convert the power source (e.g., electrical energy) into usable heat at the w.p. surface.

- The **melting factor** $\mathbf{f_2}$ depends on the welding process, but it is also influenced by the thermal properties of the metal, joint configuration, and w.p. thickness.

- The balance equation between the energy input and the energy needed for welding can be write as:

$$H_w = U_m V$$

H_w : net heat energy used by the welding operation, J (Btu).
U_m: unit energy required to melt the metal, J/mm^3 (Btu/in^3).
V: the volume of metal melted, mm^3 (in^3).

- In most welding operations, the net heat energy H_w is delivered at a given rate. This is characteristic for example of most arc-welding, many oxyfuel gas-welding operations, and even some resistance welding operations. Thus:

$$R_{Hw} = U_m R_{WV}$$

R_{HW}: rate of heat energy delivered to the operation for welding, W (Btu/min).
R_{WV}: volume rate of metal welded, mm^3/s (in^3/min).

- The volume rate of metal welded is the product of weld area A_w and travel velocity *v* in welding of a continuous bead. Thus:

$$R_{Hw} = f_1 f_2 R_H = U_m A_w v$$

R_H: rate of input energy generated by the welding power source, W (Btu/min);
A_w: weld cross-sectional area, mm^2 (in^2).
v: the travel velocity of the welding operation, mm/s (in/min).

Example (2):

The power source in a particular welding setup generates 3500W that can be transferred to the w.p. surface with a heat transfer factor f_1=0.7. The metal to be welded is low carbon steel, whose melting temperature is 1760 ^oK. The melting factor in the operation f_2=0.5. A continuous fillet weld is to be made with a cross-sectional area =20mm^2. Determine the travel speed at which the welding operation can be accomplished.

Solution:

From equation of R_{HW}:

$$R_{Hw} = f_1 f_2 R_H = U_m A_w v$$

$$U_m = K T_m^2 = 3.33(10^{-6})1760^2 = 10.32\, J/mm^3$$

$$\therefore v = \frac{f_1 f_2 R_H}{U_m A_w} = \frac{0.7(0.5)(3500)}{10.32(20)} = 5.9 mm/s$$ **Answer**

Example (3):

In a laser beam welding process, what is the quantity of heat per unit time (J/sec) that is transferred to the material if the heat is concentrated in circle with a diameter of 0.2 mm? The power density is 9000 W/mm^2.

Solution:

$$PD = \frac{P}{A} \quad \rightarrow \quad P = PD(A) = 9000\left(\frac{\pi}{4}0.2^2\right) = 282.7W$$ **Answer**

Example (4):

A welding heat source is capable of transferring 150 Btu/min to the surface of a metal part. The heated area is approximately circular, and the heat intensity decreases with increasing radius as follows: 50% of the power is transferred within a circle of diameter = 0.1 inch and 75% is transferred within a concentric circle of diameter = 0.25 in. What are the power densities in (a) the 0.1-inch diameter inner circle and (b) the 0.25-inch diameter ring that lies around the inner circle? (c) Are these power densities sufficient for melting metal?

Solution:

(a)

$$PD = \frac{P}{A} = \frac{0.5(\frac{150}{60})}{\frac{\pi}{4}(0.1^2)} = 159.2\ \frac{\frac{Btu}{s}}{in^2}$$ **Answer**

(b) The area of ring around the inner circle: $A_r = \frac{\pi}{4}(0.25^2 - 0.1^2) = 0.0412\ in^2$

Power transferred to the ring area=0.75(150) – 0.5(150) = 37.5Btu/min

$$PD = \frac{P}{A} = \frac{\frac{37.5}{60}}{0.0412} = 15.2\ \frac{\frac{Btu}{sec}}{in^2}$$ **Answer**

(c) Power densities are sufficient certainly in the inner circle and probably in the outer ring for welding.

Example (5):

A U-groove weld is used to butt weld 2 pieces of 7.0-mm-thick titanium plate. The U-groove is prepared using a milling cutter so the radius of the groove is 3.0 mm. During welding, the penetration of the weld causes an additional 1.5 mm of material to be melted. The final cross sectional area of the weld can be approximated by a semicircle with a radius of 4.5 mm. The length of the weld is 200 mm. The melting factor of the setup is 0.57 and the heat transfer factor is 0.86. (a) What is the quantity of heat (in Joules) required to melt the volume of metal in this weld (filler metal plus base metal)? Assume the resulting top surface of the weld bead is flush with the top surface of the plates. (b) What is the required heat generated at the welding source? Take: T_m for titanium is 2070°K.

Solution:

(a) $\boldsymbol{U_m = KT_m^2 = 3.3310^{-6}(2070^2) = 14.27\ J/mm^2}$

$\boldsymbol{A_w = \frac{\pi r^2}{2} = \frac{\pi 4.5^2}{2} = 31.8mm^2}$

$\boldsymbol{V = A_w L = 31.8(200) = 6360mm^3}$

$\boldsymbol{H_w = U_m V = 14.27(6360) = 90757\ J}$ **Answer**

(b) $\boldsymbol{H_w = f_1 f_2 H \quad \rightarrow \quad H = \frac{H_w}{f_1 f_2} = \frac{90757}{0.86(0.57)} = 185143\ J}$

Example (6):

In a controlled experiment, it takes 3700 J to melt the amount of metal that is in a weld bead with a cross-sectional area of 6.0 mm^2 that is 150.0 mm long. (a) What is the most likely metal? (b) If the heat transfer factor is 0.85 and the melting factor is 0.55 for a welding process, how much heat must be generated at the welding source to accomplish the weld?

Solution:

$\boldsymbol{V = A_w L = 6(150) = 900mm^3}$

$\boldsymbol{H_w = U_m V \quad \rightarrow \quad U_m = H_w/V = 3700/900 = 4.11\ J/mm^3}$

$\boldsymbol{U_m = KT_m^2 \quad \rightarrow \quad T_m = (U_m/K)^{0.5} = (4.11/3.3310^{-6})^{0.5} = 1111\ °K}$

The metal with the closest melting point to 1111° K is **Bronze (1120° K)** **Answer**

(b) $\boldsymbol{H = \frac{H_w}{f_1 f_2} = 3700/0.85(0.55) = 7914\ J}$ **Answer**