## 28 FUNDAMENTALS OF WELDING

### Review Questions

28.1 What are the advantages and disadvantages of welding compared to other types of assembly operations?

**Answer**. Advantages: (1) It provides a permanent joint, (2) joint strength is typically as high as the strength of base metals, (3) it is most economical in terms of material usage, and (4) it is versatile in terms of where it can be accomplished. Disadvantages: (1) It is usually performed manually, so labor cost is high and the skilled labor to perform it is sometimes scarce, (2) most welding operation are inherently dangerous because of the high energy involved, (3) a welded joint is difficult to disassemble, and (4) quality defects are sometimes difficult to detect.

28.2 What is meant by the term *faying surface*?

**Answer**. The faying surfaces are the contacting surfaces in a welded joint.

28.3 What is a *fusion weld*?

**Answer**. A fusion weld is a weld in which the metal surfaces have been melted in order to cause coalescence.

28.4 Name three fusion welding processes.

**Answer**. The three listed in the text are (1) arc welding, (2) resistance welding, and (3) oxyfuel welding.

28.5 What is an *autogenous weld*?

**Answer**. An autogenous weld is a fusion weld made without the addition of filler metal.

28.6 What is the fundamental difference between a fusion weld and a solid-state weld?

**Answer**. In a fusion weld, the metal is melted. In a solid state weld, the metal is not melted.

28.7 Name three solid-state welding processes.

**Answer**. The three listed in the text are (1) diffusion welding, (2) friction welding, and (3) ultrasonic welding.

28.8 What is the difference between a welding fixture and a welding positioner?

**Answer**. A welding fixture is a device for clamping and holding the components in a fixed position for welding; whereas a welding positioner is a device for holding the parts and moving and orienting them into a desirable position for welding, usually flat and horizontal.

28.9 What are the reasons why most welding operations are inherently dangerous?

**Answer**. Most welding operations are carried out at high temperatures that can cause serious burns on skin and flesh. In gas welding, the fuels are a fire hazard. In arc welding and resistance welding, the high electrical energy can cause shocks that are fatal to the worker. In arc welding, the electric arc emits intense ultraviolet radiation that can cause blinding. Other hazards include sparks, smoke, fumes, and weld spatter.

28.10 What is the difference between machine welding and automatic welding?

**Answer**. An automatic welding operation uses a weld cycle controller that regulates the arc movement and workpiece positioning; whereas in machine welding, a human worker must continuously control the arc and the relative movement of the welding head and the work part.

28.11 Name and sketch the five joint types.

**Answer**. Five joint types are (1) butt, (2) corner, (3) lap, (4) tee, (5) edge. For sketches see Figure 28.2 in the text.

28.12 Define and sketch a fillet weld.

**Answer**. A fillet weld is a weld joint of approximately triangular cross section used to fill in the edges of corner, lap, and tee joints. See Figure 28.3 in text for sketch.

28.13 Define and sketch a groove weld.

**Answer**. A groove weld is a weld joint used to fill in the space between the adjoining edges of butt and other weld types except lap. See Figure 28.4 in text for sketch.

28.14 Why is a surfacing weld different from the other weld types?

**Answer**. Because it does not join two distinct parts, but instead adds only filler metal to a surface.

28.15 Why is it desirable to use energy sources for welding that produce high power densities?

**Answer**. Because the heat is concentrated in a small area for greatest efficiency and minimum metallurgical damage.

28.16 What is the unit melting energy in welding, and what are the factors on which it depends?

**Answer**. The unit melting energy is the amount of heat energy required to melt one cubic millimeter or one cubic inch of metal. The factors on which it depends are (1) specific heat, (2) melting point, and (3) heat of fusion of the metal.

28.17 Define and distinguish the two terms *heat transfer factor* and *melting factor* in welding.

**Answer**. Heat transfer factor is the ratio of the actual heat received at the work surface divided by the total heat generated by the source. Melting factor is the ratio of heat used for melting divided by the heat received at the work surface.

28.18 What is the heat-affected zone (HAZ) in a fusion weld?

**Answer**. The HAZ is a region of base metal surrounding the fusion zone in which melting has not occurred, but temperatures from welding were high enough to cause solid state microstructural changes.

## Problems

Answers to problems labeled **(A)** are listed in an Appendix at the back of the book.

## Power Density

28.1 **(A)** (SI units) In a laser beam welding process, what quantity of heat per unit time (J/s) is transferred to the metal if the heat is concentrated in a circle with a diameter of 0.25 mm? Use the power density listed in Table 28.1.

**Solution:** *PD* from Table 28.1 is 9000 W/mm$^2$ for laser beam welding
$P = PD \times A = 9000\ \pi(0.25)^2/4 =$ **442 W = 442 J/s**

28.2 (SI units) A heat source transfers 3000 J/sec to a metal part surface. The heated area is circular, and the heat intensity decreases as the radius increases: 75% of the heat is concentrated in a circular area that = 3.5 mm in diameter. Is the resulting power density enough to melt metal?

**Solution**: Area $A = \pi(3.5)^2/4 = 9.621$ mm$^2$
Power $P = 0.75(3000) = 2250$ J/s = 2250 W
Power density $PD$ = 2250 W/9.621 = **234 W/mm$^2$**. This power density is most probably sufficient for melting the metal.

28.3 (USCS units) A heat source transfers 150 Btu/min to a metal surface for welding. 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 = 0.2 in, and 75% is transferred within a concentric circle of diameter = 0.4 in. What are the power densities in the (a) 0.2-in diameter inner circle and (b) 0.4-in diameter ring that lies around the inner circle? (c) Are these power densities sufficient for melting metal?

**Solution**: (a) Area $A = \pi(0.2)^2/4 = 0.0314$ in$^2$
200 Btu/min = 3.333 Btu/sec
Power $P = 0.50(3.333) = 1.667$ Btu/sec
Power density $PD$ = (1.667 Btu/sec)/0.0314 in$^2$ = **53 Btu/sec-in$^2$**

(b) $A = \pi(0.4^2 - 0.2^2)/4 = 0.0942$ in$^2$
Power $P = (0.75 - 0.50)(3.333) = 0.833$ Btu/sec
Power density $PD$ = (0.833 Btu/sec)/0.0942 in$^2$ = **8.85 Btu/sec-in$^2$**

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

## Unit Melting Energy

28.4 **(A)** (SI/USCS units) Compute the unit energy for melting aluminum using (a) SI units and (b) USCS units.

**Solution**: From Table 28.2, $T_m$ for aluminum = 933 K (1680 R)
(a) SI units: $U_m = 3.33(10^{-6})T_m^2$ $U_m = 3.33(10^{-6})(933)^2$ = **2.90 J/mm$^3$**

(b) USCS units: $U_m = 1.467(10^{-5})T_m^2$ $U_m = 1.467\ (10^{-5})(1680)^2$ = **41.4 Btu/in$^3$**

28.5 (SI/USCS units) Compute the unit energy for melting for plain low-carbon steel using (a) SI units and (b) USCS units.

**Solution**: From Table 28.2, $T_m$ for plain low-carbon steel = 1760 K (3160 R)

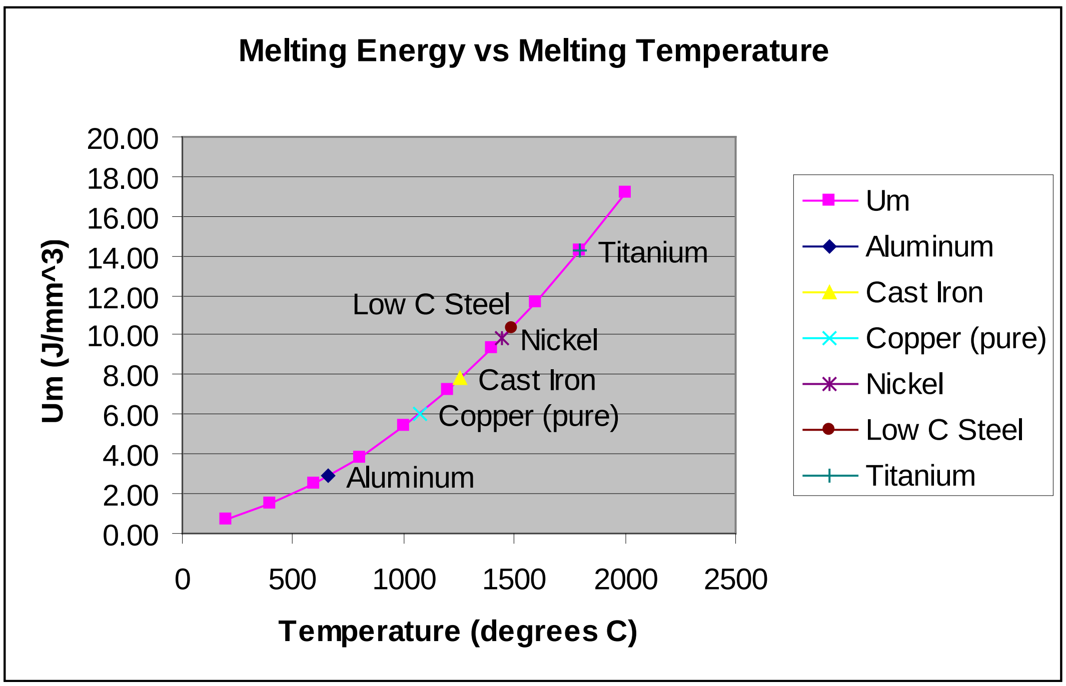
(a) SI units: $U_m = 3.33(10^{-6})T_m^2$ $U_m = 3.33(10^{-6})(1760)^2$ = **10.32 J/mm$^3$**

(b) USCS units: $U_m = 1.467(10^{-5})T_m^2$ $U_m = 1.467(10^{-5})(3165)^2$ = **146.95 Btu/in$^3$**

28.6 (SI units) Make the calculations and plot on linearly scaled axes the relationship for unit melting energy as a function of temperature. Use temperatures as follows to construct the plot: 200°C, 400°C, 600°C, 800°C, 1000°C, 1200°C, 1400°C, 1600°C, 1800°C, and

2000°C. On the plot, mark the positions of some of the welding metals in Table 28.2. It is recommended that a spreadsheet program be used for the calculations.

**Solution**: Equation (28.2) for SI units: $U_m = 3.33(10^{-6})T_m^2$. The plot is based on the following calculated values.
For $T_m$ = **200°C** = (200 + 273) = 473°K: $U_m = 3.33(10^{-6})(473)^2$ = **0.75 J/mm³**
For $T_m$ = **400°C** = (400 + 273) = 673°K: $U_m = 3.33(10^{-6})(673)^2$ = **1.51 J/mm³**
For $T_m$ = **600°C** = (600 + 273) = 873°K: $U_m = 3.33(10^{-6})(873)^2$ = **2.54 J/mm³**
For $T_m$ = **800°C** = (800 + 273) = 1073°K: $U_m = 3.33(10^{-6})(1073)^2$ = **3.83 J/mm³**
For $T_m$ = **1000°C** = (1000 + 273) = 1273°K: $U_m = 3.33(10^{-6})(1273)^2$ = **5.40 J/mm³**
For $T_m$ = **1200°C** = (1200 + 273) = 1473°K: $U_m = 3.33(10^{-6})(1473)^2$ = **7.23 J/mm³**
For $T_m$ = **1400°C** = (1400 + 273) = 1673°K: $U_m = 3.33(10^{-6})(1673)^2$ = **9.32 J/mm³**
For $T_m$ = **1600°C** = (1600 + 273) = 1873°K: $U_m = 3.33(10^{-6})(1873)^2$ = **11.68 J/mm³**
For $T_m$ = **1800°C** = (1800 + 273) = 2073°K: $U_m = 3.33(10^{-6})(2073)^2$ = **14.31 J/mm³**
For $T_m$ = **2000°C** = (2000 + 273) = 2273°K: $U_m = 3.33(10^{-6})(2273)^2$ = **17.20 J/mm³**




28.7 **(A)** (SI units) A fillet weld on low-carbon steel has a cross-sectional area of 25.0 mm² and is 300 mm long. Determine the (a) amount of heat required to perform the weld and (b) amount of heat that must be generated by the heat source, if the heat transfer factor = 0.90 and melting factor = 0.60.

**Solution**: (a) Equation (28.2) for SI units: $U_m = 3.33(10^{-6})T_m^2$
From Table 28.2, $T_m$ for low-carbon steel = 1760° K
$U_m = 3.33(10^{-6})(1760)^2 = 10.32$ J/mm³
Volume of metal melted $V = 25(300) = 7500$ mm³
$H_w = 10.32(7500)$ = **77,400 J** at weld

(b) Given $f_1 = 0.90$ and $f_2 = 0.60$, $H = 77{,}400/(0.90 \times 0.60)$ = **143,333 J** at source

28.8 (SI units) A U-groove weld is used to butt-weld two pieces of 7.0-mm-thick austenitic stainless steel plate in an arc-welding operation. The U-groove is prepared using a milling cutter so the radius of the groove is 3.0 mm; however, during welding, the penetration of the weld causes an additional 1.5 mm of metal to be melted. Thus, the final cross-sectional area of the weld can be approximated by a semicircle with radius = 4.5 mm. The length of the weld = 250 mm. The melting factor of the setup = 0.65, and the heat transfer factor = 0.90. Assuming the resulting top surface of the weld bead is flush with the top surface of the plates, determine the (a) amount of heat (in joules) required to melt the volume of metal in this weld (filler metal plus base metal) and (b) heat that must be generated at the heat source.

**Solution:** (a) From Table 28.2, $T_m$ for austenitic stainless steel = 1670°K
$U_m = 3.33(10^{-6})(1670)^2 = 9.29$ J/mm$^3$
$A_w = \pi r^2/2 = \pi(4.5)^2/2 = 31.8$ mm$^2$
$V = A_w L = 31.8(250) = 7950$ mm$^3$
$H_w = U_m V = 9.29(7950) =$ **73,856 J**

(b) $H = H_w/(f_1 f_2) = 73{,}856/(0.90 \times 0.65) =$ **126,249 J**

28.9 (USCS units) In an arc-welding operation, a groove weld has a cross-sectional area = 0.045 in$^2$ and is 14 in long. (a) What quantity of heat (in Btu) is required to accomplish the weld, if the metal to be welded is medium carbon steel? (b) How much heat must be generated at the welding source, if the heat transfer factor = 0.9 and the melting factor = 0.7?

**Solution**: (a) Equation (28.2) for USCS units: $U_m = 1.467(10^{-5})T_m^2$
From Table 28.2, $T_m$ for medium carbon steel = 3060°R
$U_m = 1.467(10^{-5})(3060)^2 = 137.4$ Btu/in$^3$
Volume of metal melted $V = 0.045(14) = 0.63$ in$^3$
$H_w = 137.4(0.63) =$ **86.6 Btu** at weld

(b) Given $f_1 = 0.9$ and $f_2 = 0.7$, $H = 86.6/(0.9 \times 0.7) =$ **98.1 Btu** at source.

28.10 (USCS units) Solve the previous problem, except that the metal to be welded is aluminum, and the corresponding melting factor is 60% of the value for steel.

**Solution**: (a) Equation (28.2) for USCS units: $U_m = 1.467(10^{-5})T_m^2$
From Table 28.2, $T_m$ for aluminum = 1680°R
$U_m = 1.467(10^{-5})(1680)^2 = 41.4$ Btu/in$^3$
Volume of metal melted $V = 0.045(14) = 0.63$ in$^3$
$H_w = 41.4(0.63) =$ **26.1 Btu** at weld

(b) Given $f_1 = 0.9$ and $f_2 = 0.70(.60) = 0.42$, $H = 26.1/(0.9 \times 0.42) =$ **69.0 Btu** at source.

### Energy Balance in Welding

28.11 **(A)** (SI units) The power developed in an arc-welding operation = 3000 W. This is transferred to the work surface with a heat transfer factor = 0.90. The metal to be welded is aluminum whose melting point is given in Table 28.2. The melting factor = 0.45. A fillet weld is to be made with a cross-sectional area = 22.0 mm$^2$. Determine the travel speed at which the welding operation can be accomplished.

**Solution**: From Table 28.2, $T_m$ = 933°K for aluminum

$U_m = 3.33(10^{-6})(933)^2 = 2.9$ J/mm$^3$
$v = f_1 f_2 R_H/U_m A_w = 0.9(0.45)(3000)/(2.9 \times 22) =$ **19.04 mm/s**

28.12 (SI units) Solve the previous problem except that the metal to be welded is medium-carbon steel, and the melting factor = 0.60.

**Solution**: From Table 28.2, $T_m = 1700$°K for medium carbon steel.
$U_m = 3.33 \times 10^{-6}(1700)^2 = 9.62$ J/mm$^3$
$v = f_1 f_2 R_H /U_m A_w = 0.9(0.6)(3000)/(9.62 \times 22) =$ **7.65 mm/s**

28.13 (SI units) An arc-welding operation on nickel performs a groove weld, whose cross-sectional area = 30.0 mm$^2$. Travel velocity = 4.0 mm/sec. Heat transfer factor = 0.82, and melting factor = 0.70. Determine the rate of heat generation required at the welding source to accomplish this weld.

**Solution**: From Table 28.2, $T_m = 1725$°K for nickel
$U_m = 3.33(10^{-6})(1725)^2 = 9.91$ J/mm$^3$
$f_1 f_2 R_H = U_m A_w v$
$R_H = U_m A_w v/f_1 f_2 = 9.91(30)(4)/(0.82 \times 0.70) =$ **2072 J/s = 2072 W**

28.14 (USCS units) The power source in an arc-welding operation on titanium generates 250 Btu/min, which is transferred to the work surface with heat transfer factor = 0.85 and melting factor = 0.6. A continuous fillet weld is to be made with a cross-sectional area = 0.05 in$^2$. Determine the travel speed at which the welding operation can be accomplished.

**Solution**: From Table 28.2, $T_m = 3725$°R for titanium
$U_m = 1.467(10^{-5})(3725)^2 = 204$ Btu/in$^3$
$v = f_1 f_2 R_H /U_m A_w = 0.85(0.6)(250)/(204 \times 0.05) =$ **12.5 in/min**

28.15 (USCS units) In an arc-welding operation on low-carbon steel to make a fillet weld, the cross-sectional area = 0.04 in$^2$ and travel speed = 12 in/min. If the heat transfer factor = 0.95 and melting factor = 0.5, determine the rate of heat generation required at the heat source to accomplish this weld.

**Solution**: From Table 28.2, $T_m = 3165$°R for low-carbon steel
$U_m = 1.467(10^{-5})(3165)^2 = 146.95$ Btu/in$^3$
$v = 12 = f_1 f_2 R_H/U_m A_w = 0.95(0.5)R_H /(146.95 \times 0.04) = 0.081\, R_H$
$R_H = 12/0.081 =$ **148.1 Btu/min**

28.16 **(A)** (USCS units) In a resistance-welding operation, two 3/32-in-thick aluminum plates are joined. The melted metal at each joint forms a disk-shaped nugget with a diameter of ¼ in. The power is on for 0.4 sec. The final nugget has a thickness = 1/8 in. Heat transfer factor = 0.80, and the melting factor = 0.50. Determine the rate of heat generation required at the heat source to accomplish this weld.

**Solution**: From Table 28.2, $T_m = 1680$°R for aluminum
$U_m = 1.467(10^{-5})(1680)^2 = 41.4$ Btu/in$^3$
$V = \pi t D^2/4 = \pi\,(0.25^2/4)(1/8) = 0.0061$ in$^3$
$H_w = U_m V = 41.4(0.0061) = 0.254$ Btu
$H = H_w /(f_1 f_2) = 0.254/(0.80 \times 0.5) = 0.635$ Btu
$R_H = H/T = 0.635/0.4 =$ **1.59 Btu/sec**