QUIZ MS102
Welding Engineering
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PROBLEMS

Problem 1

For better resistance welding, a metal must have:

P. High electrical resistivity and low melting point.
Q. High thermal conductivity.
R. High electrical resistivity and high melting point.
S. Low thermal conductivity.

A) P, Q
B) P, S
C) R, Q
D) R, S

Problem 2

Consider the following welding processes. The width of the heat-affected zone in decreasing order is:

α. Laser beam welding.
β. Submerged arc welding.
γ. Gas metal arc welding.

A) $\alpha > \beta > \gamma$
B) $\gamma > \alpha > \beta$
C) $\beta > \gamma > \alpha$
D) $\alpha > \gamma > \beta$

Problem 3

A sheet of steel 1.0-mm thick are to be spot welded. In an ordinary spot welding machine, labeled process 1, a current of 10,000 A is applied in 0.1 second, while with a capacitor discharge power source, labeled process 2, a current of 30,000 A is applied for 0.005 seconds. Assume that the fusion zone of the weld is a cylinder of 7 mm diameter and 1.5 mm height. Assume an effective resistance of 100 μΩ. Which of the following is true? Take 8.36×10^{-3} g/mm³ as the density of steel and suppose that 1380 J is necessary to melt 1 g of this metal.

A) Both processes would supply enough heat to weld the sheet.

B) Process 1 would supply enough heat to weld the sheet, whereas process 2 would not.

C) Process 2 would supply enough heat to weld the sheet, whereas process 1 would not.

D) Both processes would not supply enough heat to weld the sheet.

Problem 4

Suppose an arc weld is made on an alloyed steel with a melting temperature of 1460°C. The voltage and current in the device are 25 V and 250 A, respectively. The travel velocity is 8 mm/s, the heat transfer efficiency is 90%, and the melting efficiency is 30%. Determine the total weld metal cross-section melted in the process.

A) A_w = 21.1 mm²

B) A_w = 30.9 mm²

C) A_w = 44.5 mm²

D) A_w = 56.0 mm²

Problem 5

Calculate the heat transfer efficiency for an arc welding of metal with a current of 200 A at 20 V. The travel speed is 8 mm/s, and cross-sectional area of the joint is 18 mm². The heat required to melt the metal is 5.6 J/mm³ and the melting efficiency is 28%. With reference to the following table, answer: what welding process is being used in this case?

Process	Transfer Efficiency
Oxyfuel gas (low combustion intensity fuel)	0.25 – 0.50
Gas tungsten arc (low-current DCSP mode)	0.40 – 0.60
Plasma arc (melt-in mode)	0.70 – 0.85
Electron beam (keyhole mode)	0.85 – 0.95

A) Oxyfuel gas.

B) Gas tungsten arc.

C) Plasma arc.

D) Electron beam.

Problem 6

Regarding aspects of welding engineering, true or false?

1.( ) Shielded metal arc welding (SMAW) is a process known for its versatility, as it involves relatively cheap equipment and can be used with either DC or AC power supplies. Another asset is the possibility of conducting the weld in horizontal, inclined, or vertical positions.

2.( ) Shield metal arc welding is especially useful for welding metals with low melting and boiling temperatures such as lead, tin, and their alloys, since the low heat of the SMAW arc – in contrast to, say, GTAW – does not cause these materials to vaporize from the solid state.

3.( ) One of the advantages of gas tungsten arc welding (GTAW) over shielded metal arc welding is the high degree of protection achieved with a shielding gas directed toward the weld pool. In view of this feature, GTAW is sometimes called tungsten inert gas (TIG) welding. Since, however, a noninert gas such as carbon dioxide is deliberately added to the shielding gas mixture in some applications, the designation GTAW is a better choice.

4.( ) The flux cored arc welding technique is a welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding from the atmosphere in the form of the gases generated in the weld pool (self-shielded FCAW) or with a mixture of inert gases (gas-shielded FCAW). The inherent superiority of gas-shielded FCAW in terms of protection against contamination has led to the near abandonment of self-shielded FCAW since the early 1990s.

5.( ) The submerged arc weldng (SAW) method is one of the most productive welding techniques available; the efficiency of the process can be as high as 90% and the deposition rates can be as large as 45 kg per hour. On the other hand, limitations of this technique include its restriction to welding in thick parts (necessarily thicker than 1.5 mm), the inability to use more than a single electrode at a time, and the fact that the welding must be carried out in a flat or horizontal position.

6.( ) Electroslag welding is a highly efficient technique and can achieve extremely high deposition rates, usually in no more than two or three passes. Its main drawbacks include the relatively high angular distortion when compared to arc welding processes and the fact that, much like SAW, welding is restricted to a horizontal or flat position.

7.( ) Although the use of oxyfuel gas welding has been surpassed by the arc welding processes in most applications, oxyacethylene gas welding remains popular because it is versatile, portable, and inexpensive. In addition, the process is applicable to a wide range of metals, including reactive metals, refractory metals, and many steels (such as low-alloy steels and high-strength, heat-treatable steels).

8.( ) One of the main drawbacks of plasma arc welding (PAW) is the fact that the contact between the electrode and the workpiece may cause impurities of the ionic gas and electrode metal to infiltrate the weld, much like tungsten electrode contamination in GTAW.

9.( ) The laser welding of aluminum alloys is made difficult because of its low absorption coefficient. In this case, a YAG laser has a slight advantage compared to the CO_2 laser because of its lower wavelength, which allows for better radiation absorption.

10.( ) Continuous-voltage power supplies are particularly suitable for constantly fed continuous electrode processes such as GMAW and SAW. In a CV setting, a slight change in arc length leads to a large change in current, so melting rate changes rapidly in response. This has the effect of self-regulation, increasing the melting rate as arc length is inadvertently shortened, and vice versa. An even better control of process variables is attained if the voltage supply is short-circuited.

11.( ) Either AC or DC current patterns can be employed with shielded metal arc welding (SMAW), and each type presents advantages and disadvantages. With small-diameter electrodes and low welding currents, AC provides better operating characteristics and a more stable arc. In addition, an AC source allows for easier arc initiation and presents a lower risk of arc blow.

12.( ) Molten (or hot, solid) metal can be protected from adverse reactions with gases in the atmosphere (particularly oxygen and nitrogen) by excluding those gases. One of the most common and simplest methods is to displace atmospheric gases with inert gases. The two most common choices are helium, argon, or a mixture of both. Helium is superior to argon because it is heavier than air, and as such is easily maintained on the work during the welding procedure. Furthermore, helium has a higher ionization potential than argon.

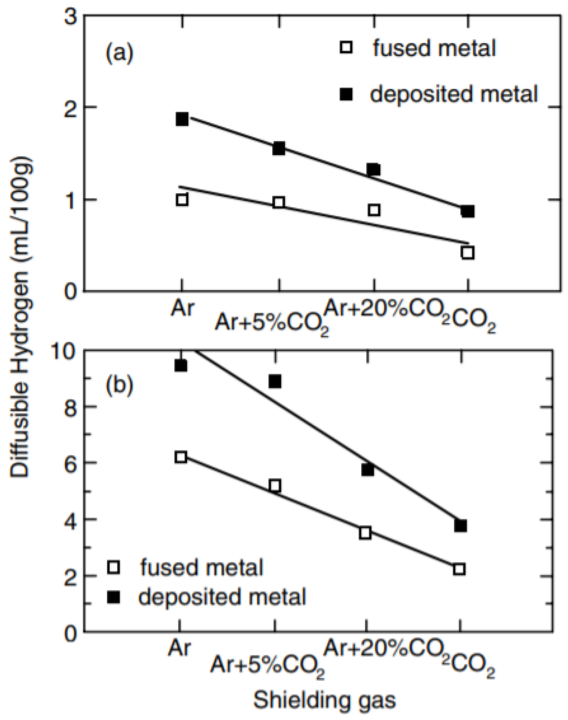
13.( ) All arc welding, electron beam, laser beam, resistance, and friction welding processes can be readily used to join stainless steels. Gas metal arc, gas tungsten arc, flux cored arc, and shielded metal arc welding are commonly used. Submerged arc welding also offers significant benefits for stainless steel, such as greater productivity and extremely low spatter levels. Benefits associated with use of SAW on stainless steel include advanced control of the chemical composition of the weld and, due to the combination of high heat input and stainless steel's low thermal expansion, formation of a mechanically outstanding microstructure.

14.( ) Preheating is generally avoided in the preparation of base metals for welding because it tends to raise shrinkage stresses and hence leads to cracking and distortion. In addition, preheating slows the cooling rate of the finished weld, with the result that the welding process duration and the hardness of the HAZ are both increased.

15.( ) One way to reduce the incidence of solidification cracking in a weld is to give preference to low linear heat input processes such as PAW and LBW and, if possible, appeal to grain refining agents (e.g., titanium and zirconium in the case of Al).

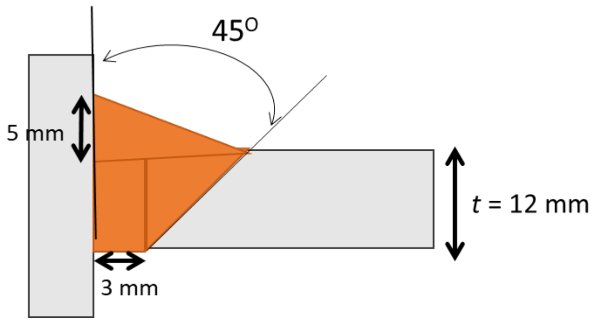
16.( ) The basicity index is used to assess the chemistry of weld fluxes in applications such as SAW. Chemically basic fluxes are normally high in manganese oxide (MgO) or calcium hydroxide (CaO) while chemically acid fluxes are normally high in silicon dioxide (SiO_2). A weld flux with basicity index lower than 1.0 is considered acidic.

17.( ) Weld hydrogen content can be reduced in several ways, including, for example, eschewing hydrogen-containing inert gases and cellulose-type electrode coverings. Controlling the composition of inert gases is another alternative. The following figure, for instance, illustrates the effect of shielding gases on weld metal hydrogen content for GMAW (figure a) and FCAW (figure b). With reference to these graphs, we surmise that the effect of adding CO_2 to shielding gases is to decrease the weld diffusible hydrogen.



Problem 7 (Khan, 2007, w/ permission)

Suppose we wish to estimate the transverse shrinkage of the butt joint illustrated below. Given the empirical factor k = 0.2, the transverse shrinkage of the weld is most nearly:



A) Δ = 0.812 mm
B) Δ = 1.25 mm
C) Δ = 1.81 mm
D) Δ = 2.43 mm

Problem 8

The maximum temperature attained in a thick sheet welding, considering two-dimensional flow of heat in a section perpendicular to the welding section, obeys which of the following proportions? Let r denote the distance to the fusion line.

A) $T_{max} \propto r^{-1}$
B) $T_{max} \propto r^{-2}$
C) $T_{max} \propto r^{-3}$
D) $T_{max} \propto r^{-4}$

Problem 9 (Khan, 2007, w/ permission)

The following parameters were obtained for a single-pass, full-penetration butt weld.

→ Initial temperature of the weldment: 30°C
→ Thickness of the base material: 6 mm
→ Melting temperature of the base material: 1530°C
→ Volume thermal capacity of the base material (steel): 0.0044 J/mm³°C
→ Net heat input: 700 J/mm

Determine the peak temperatures at distances of 3.0 and 6.0 mm from the weld fusion boundary.

A) $T_{p,3}$ = 912°C and $T_{p,6}$ = 654°C
B) $T_{p,3}$ = 912°C and $T_{p,6}$ = 807°C
C) $T_{p,3}$ = 1050°C and $T_{p,6}$ = 654°C
D) $T_{p,3}$ = 1050°C and $T_{p,6}$ = 807°C

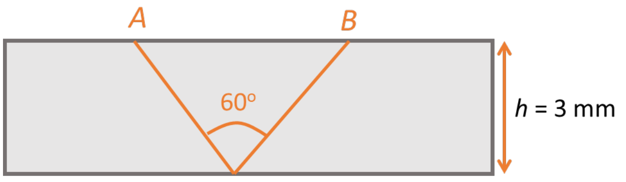
Problem 10 (Khan, 2007, w/ permission)

Find the highest welding speed to be used for the welding of 6 mm steel plates with an ambient temperature of 30°C with the welding transformer set at 20 V and current passing is 320 A. The arc efficiency is 0.9 and possible travel speeds are 7 to 10 mm/s. The limiting cooling rate for satisfactory performance is 7.5°C/s at a temperature of 500°C. Assume the volume thermal capacity of steel to be ρC_p = 0.0044 J/mm°C. Take k = 0.028 J/mm-s-°C as the thermal conductivity of steel.

A) v_{max} = 10 mm/s
B) v_{max} = 9 mm/s
C) v_{max} = 8 mm/s
D) v_{max} = 7 mm/s

Problem 11 (Khan, 2007, w/ permission)

In a butt welding process using arc welding, the arc power was found to be 2.4 kVA. The process is used to weld 2 steel plates each 3 mm thick, with 60° V-edge preparation angle, as shown. Determine the maximum possible welding speed. The metal transfer is short-circuit type and the arc is on for 90% of the time given. Take 1530°C as the melting point of steel and 30°C as room temperature. Also, use k = 40 W/m°C and α = 1.2 × 10^{-5} m^2/s as the thermal conductivity and thermal diffusivity, respectively.



A) V = 0.565 m/min
B) V = 1.08 m/min
C) V = 1.56 m/min
D) V = 2.11 m/min

Problem 12

Match the suitability of non-destructive testing methods in Group I with the defects that can be detected listed in Group II.

Group I	Group II
P. Magnetic Particle Inspection	**1.** Surface crack in martensitic stainless steels
Q. X-Ray Radiography	**2.** Surface crack in austenitic stainless steels
R. Dye Penetrant Test	**3.** Hairline crack in aluminum
S. Ultrasonic Testing	**4.** Inclusions in steels

A) P-2, Q-4, R-3, S-1
B) P-4, Q-2, R-1, S-3
C) P-3, Q-1, R-2, S-4
D) P-1, Q-4, R-2, S-3

Problem 13

In a nondestructive evaluation of a weld by radiography, an exposure of 6.5 mA-minutes was associated with a transmittance of 0.01. Determine the exposure that will produce a film density of 3.0.

A) E = 7.35 mA-min
B) E = 8.21 mA-min
C) E = 9.75 mA-min
D) E = 10.8 mA-min

Problem 14

Regarding nondestructive testing methods, true or false?

1.( ) Liquid penetrant NDT is a sensitive method for detecting discontinuities provided they are clean and open to the surface. However, the method should not be used with exceedingly porous surfaces.

2.( ) The main limitations of ultrasonic NDT are the impossibility of producing and a permanent record of the weld assessment and, perhaps more importantly, the inherent safety hazard posed by the high-frequency ultrasonic waves produced in the process.

3.( ) One of the advantages of gamma ray radiography NDT is the possibility of adjusting the wavelength, and therefore the energy output, in accordance with the depth of the weld to be inspected.

4.( ) One of the main advantages of eddy current NDT is the possibility of detecting deep flaws in the metal, especially in low-electric-conductivity metals such as stainless steel.

5.( ) Magnetic particle NDT is based on the principle that magnetic lines of force will be distorted by a change in material continuity. Unlike liquid penetrants, magnetic particle can detect some near surface discontinuities. However, the method is restricted to ferromagnetic materials.

SOLUTIONS

P.1 ■ Solution

High-electrical-resistivity metals require lower currents to produce the large amounts of heat associated with welding. A low melting point allows the engineer to liquefy the metal more easily. In addition, materials with low thermal conductivity allow heat to be contained in a small area (the HAZ) rather than being conducted away from the welding surface. Accordingly, the best combination of properties is P, S.

♦ The correct answer is **B**.

P.2 ■ Solution

Submerged arc welding produces the largest HAZ, whereas laser beam welding, with its inherent precision, produces the smallest. Gas metal arc welding produces intermediate results.

♦ The correct answer is **C**.

P.3 ■ Solution

The heat generated by a resistance welding process such as the present one is, for process 1,

$$H = I^2 \times R \times t \rightarrow H_1 = 10,000^2 \times \left(100 \times 10^{-6}\right) \times 0.1$$

$$\therefore H_1 = 1000 \text{ J}$$

whereas for process 2,

$$H_2 = 30,000^2 \times \left(100 \times 10^{-6}\right) \times 0.005$$

$$\therefore H_2 = 450 \text{ J}$$

The mass of metal melted is

$$m = \text{Volume} \times \text{Density} = \left(\frac{\pi}{4} \times 7^2 \times 1.5\right) \times \left(8.36 \times 10^{-3}\right) = 0.483 \text{ g}$$

The amount of heat required to melt this amount of steel is

$$\frac{1 \text{ g}}{1380 \text{ J}} = \frac{0.483 \text{ g}}{Q} \rightarrow Q = 667 \text{ J}$$

Accordingly, process 1 supplies enough heat to melt the steel, but process 2 does not.

♦ The correct answer is **B**.

P.4 ■ Solution

The solution is started by computing the theoretical heat required to melt a given volume of metal, which, given T_m = 1460°C, can be approximated as

$$Q = \frac{(T_m + 273)^2}{300,000} = \frac{(1460 + 273)^2}{300,000} = 10.0 \text{ J/mm}^3$$

The cross-section of metal melted in the process follows as

$$A_w = \frac{f_1 f_2 EI}{QV} = \frac{0.9 \times 0.3 \times 250 \times 25}{10 \times 8} = \boxed{21.1 \text{ mm}^2}$$

♦ The correct answer is **A**.

P.5 ■ Solution

The heat input is given by

$$H = \frac{f_1 f_2 EI}{v}$$

Here, the volume of base metal melted in each second is 8 × 18 = 144 mm³/s and the heat required for melting is H = 5.6 × 144 = 806 J. Solving for the heat transfer efficiency f_1 and substituting, we obtain

$$H = \frac{f_1 f_2 VI}{v} \rightarrow f_1 = \frac{Hv}{f_2 VI}$$

$$\therefore f_1 = \frac{806}{0.85 \times 20 \times 200} = 0.720$$

Since $f_1 \in (0.70; 0.85)$, we surmise that the weld is being executed with the plasma arc method.

♦ The correct answer is **C**.

P.6 ■ Solution

1. True. All the characteristics of SMAW mentioned in the statement are valid. Indeed, SMAW is considered one of the most versatile welding techniques. It is suitable for the welding of both low and high alloy steel, iron, and nonferrous materials such as copper and nickel.

2. False. The heat of the SMAW arc is quite high – especially if the electrode is too long or the current is too high – and can in fact produce the immediate vaporization of metals with low phase transition temperatures such as lead, tin, and zinc. In addition, SMAW should not be used with reactive metals (e.g., titanium and zirconium) and refractory metals (e.g., niobium and tantalum) because the shielding provided is not sufficient to prevent weld contamination. The most extensively used technique for welding of reactive and refractory materials is gas tungsten arc welding (GTAW).

3. True. In addition to the most usual choices of inert gases – namely, helium and argon – some noninert gases such as pure nitrogen (N_2) and pure carbon dioxide (CO_2) are sometimes added to the shielding gas mixture. These gases are introduced to improve some characteristic of the arc or weld pool, including heat intensity (from effects on ionization potential of the mixture); globular-to-spray transfer transition current (e.g. by using CO_2); and weld pool fluidity (as affected by surface-activating agents such as oxygen). The choice of gas is, among other requirements, dependent on the possibility of unwanted chemical interactions between the gas and the metal (for instance, CO_2 might react with steel to cause a degree of carburization, while N_2 might react to cause nitride formation in aluminum).

Albeit being relatively inactive at room temperature, carbon dioxide decomposes into carbon monoxide and oxygen when heated to arc temperature,

$$2\,CO_2 \rightarrow 2CO + O_2$$

In the case of steel, molten iron reacts with CO_2 and produces iron oxide and carbon monoxide according to the reaction

$$Fe + CO_2 \rightleftharpoons FeO + CO$$

At red heat temperatures, some of the carbon monoxide dissociates to carbon and oxygen, as follows,

$$2CO \rightleftharpoons 2C + O_2$$

In short, carbon dioxide, as applied in welding engineering, is anything but an inert gas.

4. False. FCAW has not at all been rejected in modern welding engineering practice. In fact, there are application contexts in which it offers superior protection against contamination, including many instances of field welding. The protection comes in the form of an inert gas (gas-shielded FCAW) or the electrode itself (self-shielded FCAW). In the case of the latter, the high-temperature decomposition of some of the electrode core ingredients provides an excellent degree of protection. In addition, the wire contains a large proportion of scavengers (deoxidizers and denitrifiers) that combine with undesirable elements that might contaminate the weld pool. A slag cover protects the metal from the air surrounding the weld.

5. False. While it is true that SAW is usually used to weld thick parts, there is nothing that hinders its application on thinner materials. Further, the process can in fact be carried out with multiple electrodes (as much as five in some applications, including with combinations of DC and AC power supplies). The statement is correct when it mentions that SAW is traditionally restricted to horizontal welds, even though companies and universities have since began devising adaptations for other directional configurations – see, for example, Sakamoto and Kobayashi (2012).

6. False. The statement is entirely wrong. For starters, a weld obtained with ESW must necessarily be carried out in a single pass. Because of the single-pass welding and very high deposition rate, distortion is minimal when compared to arc welding techniques under equivalent conditions. Lastly, electroslag welding is restricted to the vertical position because of the very large pools of molten metal and slag.

7. False. While it is true that oxyfuel welding is applicable to most metals, its scope of application certainly does not include refractory materials, reactive materials, and high-strength heat-treatable steels. In the latter case, welding quenched and tempered steels with an oxyfuel flame, which has an inherently slow heat input rate, may induce unwanted metallurgical changes in the HAZ and ruin the microstructure achieved with prior heat treatment.

8. False. Since the electrode of the plasma arc torch is normally recessed inside the arc-constricting nozzle, it is not possible for the electrode to touch the workpiece. This feature greatly reduces the possibility of contaminating the weld with electrode metal and damaging the electrode. In turn, tungsten electrode contamination is a significant source of downtime in GTAW; this emphasizes a major advantage of PAW. Plasma welding has several other advantages over GTAW; for instance, the fact that the arc in plasma welds is constricted as it passes through a small orifice gives greater directional stability to the process, whereas a gas tungsten arc under the same conditions could be easily deflected by a low-strength magnetic field.

9. True. Indeed, YAG lasers, which have wavelength ten times lower than CO_2 lasers, are known to produce reliable results in most metals. (On the other hand, the small wavelength of YAG lasers inhibits its ability to be absorbed by nonmetallic materials such as wood and plastics; CO_2 lasers are a better choice for organic materials.)

10. False. Indeed, CV power supplies allow for a fast control over process variables. However, this is not true for short-circuited conditions. Short-circuiting an electrode with such a power source would drop the arc length and the voltage to zero; this causes the current to heat by Joule heating with great rapidity and explosive force, causing severe spatter and, possibly, lengths of unmelted wire stuck in the weld pool. To prevent this from occurring, impedance is built into such power supplies to limit the rate of current change, thereby reducing the likelihood of electrode overheating and explosion, and ultimately allowing short-circuiting transfer to take place.

11. False. In reality, SMA welding with a short arc length (i.e., with a low arc voltage) is better with a DC configuration, as it provides better operating characteristics with a more stable arc. In addition, striking an arc is generally easier with DC, particularly if small diameter electrodes are used. With AC, welding current passes through zero during each half cycle, which requires periodic re-ignition of the arc; this presents problems with arc starting and arc stability. Lastly, the statement is correct when it implies that arc blow is less of a problem with an AC power supply, which is a reasonable conclusion given the fact that, with this equipment, the magnetic field imparted with the current is constantly and continuously reversing. In addition to reduced susceptibility to arc blow, the other main advantage of DC power sources is cost: an AC transformer costs less than an equivalent DC power source.

12. False. The density of helium is much lower than that of air, which makes it difficult to maintain the gas on the work when the welding is being carried out. Argon is sensibly heavier than air and hence can exclude air very effectively. Nevertheless, it is true that helium has a higher ionization potential than argon, since its two $1s^2$ electrons are more strongly confined to the atomic nucleus than the $3p^6$ subshell of argon. This allows for the achievement of hotter arcs. Lastly, the choice between the two gases is not necessarily a discrete one, as combinations of both gases can be employed to achieve intermediate levels of arc heat or intensity, lower cost, and better coverage than pure helium. Some of the properties of He and Ar at room temperature are listed below.

Gas	Molar Mass (g/mol)	Specific Gravity with Respect to Air at 1 atm	Density (g/L)	Ionization Potential (eV)
He	4.00	0.137	0.178	24.5
Ar	39.95	1.38	1.784	15.7

13. False. Due to the effect of voltage variations, control of the chemical composition of the weld is in general not a feature of submerged arc welding. Furthermore, the high heat input, slow solidification of the weld metal, stainless steel's low thermal conductivity and propensity to thermal expansion of stainless steel make for terrible microstructural results, including large grain size, low toughness, and greater sensitivity to distortion when the material is welded. Ferrite contents of at least 4% are nearly inevitable. Because of low thermal conductivity and high electric resistivity, stainless steel requires 20 to 30% less heat input than equivalent welds in carbon steels.

14. False. There is not a single correct point in this statement. For one, preheating lessens, not increases, shrinkage stresses that would otherwise increase cracking and distortion. Further, the fact that preheating slows the cooling rate is in fact an asset, as it allows for the reduction of hardness in the HAZ and leads to a more ductile weld. A slower cooling rate also allows the engineer to induce desired microstructural transformations in the HAZ – for example, in the case of steel, by enabling the formation of pearlite or bainite instead of martensite. Further, a slower cooling rate allows hydrogen to escape the weld puddle and hence minimizes hydrogen cracking.

15. True. Indeed, solidification cracking can be prevented with use of low linear heat input, high-energy-density processes such as PAW, LBW, and EBW, and use of grain-refining agents (including Ti in Zr in the case of aluminum).

16. True. A basicity index lower than unity is considered acidic; a basicity index between 1.0 and 1.2 is considered neutral; a basicity index greater than 1.2 is considered basic. It has been found that low values of BI are associated with better control of weld pool and covering slag, better bead shape, and higher deposition rate.

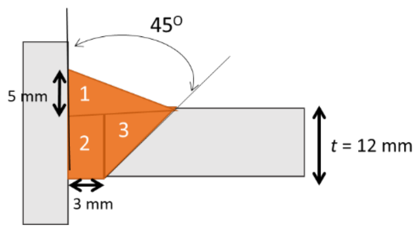
17. True. All it takes is a quick inspection of the graphs: increasing the shield gas composition from pure argon to a mixture of Ar and CO_2 causes the diffusible hydrogen level to decrease correspondingly, be it in GMAW or FMAW.

P.7 ■ Solution

The transverse shrinkage is given by

$$\Delta = k\frac{A}{t}$$

where k = 0.2 is an empirical factor, A is the cross-sectional area of the weld, and t = 12 mm is the thickness of plate. Suppose we divided the cross-sectional area of the weld as shown.



It follows that

$$A = A_1 + A_2 + A_3 = \frac{1}{2}\times 5\times(12+3)+3\times 12+\frac{1}{2}\times 12\times 12 = 146\ \text{mm}^2$$

and, backsubstituting in the equation for Δ,

$$\Delta = 0.2\times\frac{146}{12} = \boxed{2.43\ \text{mm}}$$

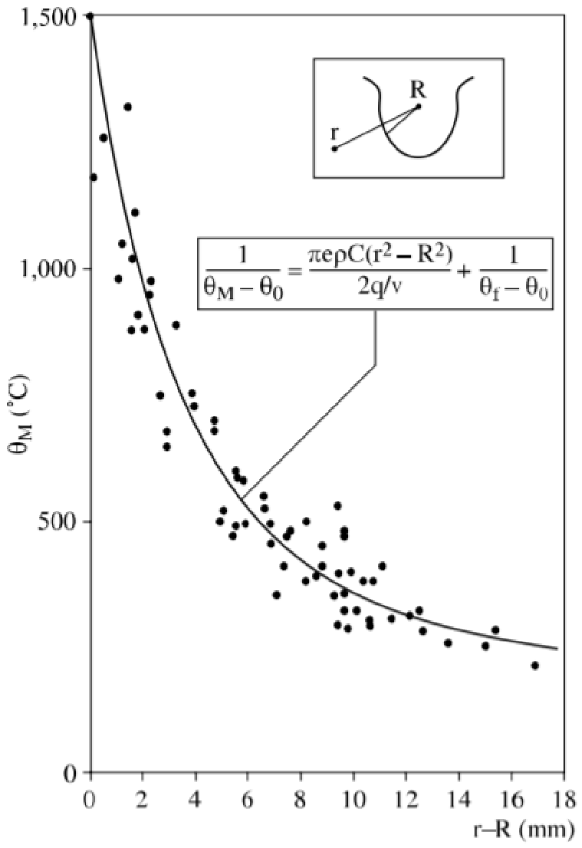
♦ The correct answer is **D**.

P.8 ■ Solution

It can be shown that the maximum temperature attained for a thick sheet welding, considering two-dimensional flow of heat in a section perpendicular to the welding section, is given by

$$\frac{1}{T_{\max}-T_0} = \frac{\pi e\rho C_p\left(r^2-R^2\right)}{2q/v}+\frac{1}{T_f-T_0}$$

Accordingly, we can infer the proportion $T_{\max} \propto r^{-2}$, i.e., the maximum temperature in the HAZ varies with the inverse square of the distance r from the fusion line. This trend is illustrated in the following graph, which shows analytically calculated and empirical results.



In contrast, the maximum temperature attained in the case of a thin sheet welding (unidirectional flow of heat in a section perpendicular to the welding direction) is given by

$$\frac{1}{T_{\max}-T_0} = \frac{\sqrt{2\pi e}\rho C_p hr}{q/v}+\frac{1}{T_f-T_0}$$

Thus, the maximum temperature in the HAZ varies in approximately inverse proportion to the distance r to the fusion line (i.e., in thin materials) or to its square (i.e., in thick materials).

♦ The correct answer is **B**.

P.9 ■ Solution

The peak temperature is given by

$$\frac{1}{T_p-T_0} = \frac{\sqrt{2\pi e}\rho C_p hy}{H_{\text{net}}}+\frac{1}{T_m-T_0}$$

Substituting T_0 = 30°C, ρC_p = 0.0044 J/mm°C, h = 6 mm, H_{net} = 700 J/mm, T_m = 1530°C, and a distance from the fusion boundary of y = 3.0 mm yields

$$\frac{1}{T_p - 30} = \frac{\sqrt{2\pi e} \times 0.0044 \times 6 \times 3.0}{700} + \frac{1}{1530 - 30}$$

$$\therefore \boxed{T_{p,3} = 912^\circ\mathrm{C}}$$

Likewise, for a distance from the fusion boundary y = 6.0 mm, we obtain

$$\frac{1}{T_p - 30} = \frac{\sqrt{2\pi e} \times 0.0044 \times 6 \times 6.0}{700} + \frac{1}{1530 - 30}$$

$$\therefore \boxed{T_{p,6} = 654^\circ\mathrm{C}}$$

♦ The correct answer is **A**.

P.10 ■ Solution

Assume first a travel speed of 10 mm/s. Given the arc efficiency f_1 = 0.9 and other variables, the heat input is calculated as

$$H_{\text{net}} = \frac{f_1 VI}{v} = \frac{0.9 \times 20 \times 320}{10} = 576 \text{ J/mm}$$

The equation to be used in the calculation of cooling rate depends on the value of parameter τ, which is given by

$$\tau = h\sqrt{\frac{\rho C_p (T_c - T_0)}{H_{\text{net}}}}$$

If τ < 0.75, the plate is considered thin and the cooling rate R is given by

$$R = \frac{2\pi k (T_c - T_0)^3}{H_{\text{net}}}$$

If, on the other hand, τ > 0.75, the plate is considered thick and the cooling rate R is determined with the relation

$$R = 2\pi k \rho C_p \left(\frac{t}{H_{\text{net}}}\right)^2 (T_c - T_0)^3$$

Accordingly, to check whether the plate is considered thin or thick, we must compute parameter τ, namely

$$\tau = h\sqrt{\frac{\rho C_p (T_c - T_0)}{H_{\text{net}}}} = 6 \times \sqrt{\frac{0.0044 \times (500 - 30)}{576}} = 0.360$$

Since τ < 0.75, the plate is considered thin. The cooling rate is calculated as

$$R = 2\pi k \rho C_p \left(\frac{t}{H_{\text{net}}}\right)^2 (T_c - T_0)^3 = 2\pi \times 0.028 \times 0.0044 \times \left(\frac{6}{576}\right)^2 \times (500 - 30)^3 = 8.72^\circ\mathrm{C/s}$$

This is greater than the limiting cooling rate of 7.5°C/s. Another iteration is in order. Let the travel speed be 9 mm/s. The heat input now becomes

$$H_{\text{net}} = \frac{f_1 VI}{v} = \frac{0.9 \times 20 \times 320}{9} = 640 \text{ J/mm}$$

The updated value of τ is

$$\tau = 6 \times \sqrt{\frac{0.0044 \times (500 - 30)}{640}} = 0.341$$

The plate is considered thin. The cooling rate now becomes

$$R = 2\pi \times 0.028 \times 0.0044 \times \left(\frac{6}{640}\right)^2 \times (500 - 30)^3 = 7.06^\circ\mathrm{C/s}$$

Since R < 7.5°C/s, this is a satisfactory cooling rate; thus, the welding can be finalized at a speed of 9 mm/s.

♦ The correct answer is **B**.

P.11 ■ Solution

Given C = 0.90 (the fraction of time the arc is on) and VI = 2.4 kVA, the rate of heat input is determined as

$$Q = CVI = 0.90 \times 2400 = 2160 \text{ W}$$

The minimum weld width to be maintained is $w = \overline{AB} = 2 \times \sqrt{3} = 3.46$ mm. The heat input rate is approximated as

$$Q = 8k\theta_m h\left(0.2 + \frac{Vw}{4\alpha}\right)$$

Here, Q = 2160 W as computed above, thermal conductivity k = 40 W/m°C, $h = 3 \times 10^{-3}$ mm, $w = 3.46 \times 10^{-3}$ mm, and thermal diffusivity $\alpha = 1.2 \times 10^{-5}$ m²/s. In addition, temperature difference θ_m = 1530 − 30 = 1500°C. Substituting and solving for the velocity V brings to

$$2160 = 8 \times 40 \times 1500 \times \left(3 \times 10^{-3}\right) \times \left[0.2 + \frac{V \times \left(3.46 \times 10^{-3}\right)}{4 \times \left(1.2 \times 10^{-5}\right)}\right]$$

$$\therefore V = 0.0180 \text{ m/sec} = \boxed{1.08 \text{ m/min}}$$

♦ The correct answer is **B.**

P.12 ■ Solution

The correct association is P-1, Q-4, R-2, S-3. The magnetic particle method, for instance, cannot be used in a paramagnetic material such as aluminum, and does not lend itself to detection of deep flaws such as inclusions in steels; however, it is a viable method for assessment of surface cracks in most steels. The X-ray radiography method, in turn, yields the deepest penetration of all four methods, and as such can be used to assess inclusions in steels. Ultrasonic testing is a viable choice for detection of hairline cracks in aluminum.

♦ The correct answer is **D.**

P.13 ■ Solution

Given the transmittance I_t/I_0 = 0.01, the initial film density is calculated as

$$FD_1 = \log_{10}\left(\frac{I_0}{I_t}\right) = \log_{10}\left(\frac{1}{0.01}\right) = 2.0$$

The following equation can be used to estimate the change in exposure needed to produce a change in film density,

$$\frac{E_1}{FD_1} = \frac{E_2}{FD_2} \rightarrow E_2 = FD_2 \times \frac{E_1}{FD_1}$$

$$\therefore E_2 = 3.0 \times \frac{6.5}{2.0} = \boxed{9.75 \text{ mA-min}}$$

♦ The correct answer is **C.**

P.14 ■ Solution

1. True. Liquid penetrant NDT should not be used with porous surfaces because the bleed out of liquid from porous surfaces can mask defects. This technique can in fact be used with nonferrous metals so long as the surface is clean and not exceedingly rough.

2. False. The frequency, and therefore the energy, of the ultrasonic waves used in the NDE method in question are far too low to be considered a health hazard, unlike, say, the dangerous ionizing radiation produced in gamma ray radiography. Nevertheless, ultrasonic NDT does have its limitations, such as the requirement of skilled labor, the need for a couplant (liquid) for adequate wave transmission, and the difficult resolution of small defects near the surface.

3. False. Gamma sources have a constant energy output and cannot be adjusted. X-ray radiography is somewhat superior in this regard as it allows for adjustable energy levels and generally provides higher quality radiographs. Nevertheless, both methods share the safety hazards associated with use of radiation, such as control of facilities where the technique will be used and special monitoring of exposure levels and dosages to personnel. Another drawback is the relatively long time, compared to other methods, between the exposure process and the availability of results. The main advantage of radiography over, say, ultrasonic testing is the fact that it provides a permanent record of the weld test for future reference.

4. False. Eddy current relies on the flow of current through a material and as such is very much dependent on a high electrical conductivity. Further, it generally offers a low depth of penetration even when used to assess highly conductive metals; the depth of examination is generally limited to 6 mm for nonferromagnetic materials and 0.25 mm for ferromagnetic materials. The main limitation of this technique, however, has to do with positioning: ECT current always runs parallel to the surface, which means that a defect that does not come in direct contact with the current cannot be detected.

5. True. Indeed, magnetic particle NDT is capable near surface discontinuities that may go unnoticed in dye penetrant testing. The technique is indeed limited to ferromagnetic materials (i.e., iron, cobalt, nickel, and some of their alloys). Another limitation is that, in some applications, parts may have to be demagnetized after inspection.

ANSWER SUMMARY

Problem 1	B
Problem 2	C
Problem 3	B
Problem 4	A
Problem 5	C
Problem 6	T/F
Problem 7	D
Problem 8	B
Problem 9	A
Problem 10	B
Problem 11	B
Problem 12	D
Problem 13	C
Problem 14	T/F

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