Production & Industrial Engineering

Manufacturing Process - I

Comprehensive Theory

with **Solved Examples** and **Practice Questions**

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Manufacturing Process - I

First Edition : 2020

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CHAPTER 02

Welding

INTRODUCTION

Welding which is the process of joining two metallic components for the desired purpose, can be defined as the process of joining two similar or dissimilar metallic components with the application of heat, with or without the application of pressure and with or without the use of filler metal. Heat may be obtained by chemical reaction, electric arc, electrical resistance, frictional heat, sound and light energy. If no filter metal is used during welding then it is termed as 'Autogenous Welding Process'.

- Welding is a process by which two materials, usually metals, are permanently joined together by coalescence, which is induced by a combination of temperature, pressure, and metallurgical conditions.
- The particular combination of these variables can range from high temperature with no pressure to high pressure with no increase in temperature.
    - Welding (positive process)
    - Machining (negative process)
    - Forming, casting (zero process)

Advantages

1. A large number of metals/alloys both similar and dissimilar can be joined by welding.
2. Welding can join workpieces through, spots, as continuous pressure tight seams, end-to-end and in a number of other configurations.
3. A good weld is as strong as the base metal.
4. Welding permits considerable freedom in design.
5. General welding equipment is not very costly.
6. Portable voiding equipments are available.
7. Welding results in a good saving of material and reduced labour content of production.
8. Low manufacturing costs.
9. Welding is also used as a method for repairing broken, worn or defective metal parts. Due to this, the cost of reinvestment can be avoided.

Disadvantages

1. Welding results in residual stresses and distortion of the workpieces.
2. Welding heat produces metallurgical changes. The structure of the welded joint is not same as that of parent metal.
3. Jigs and fixtures are generally required to hold and position the parts to be welded.

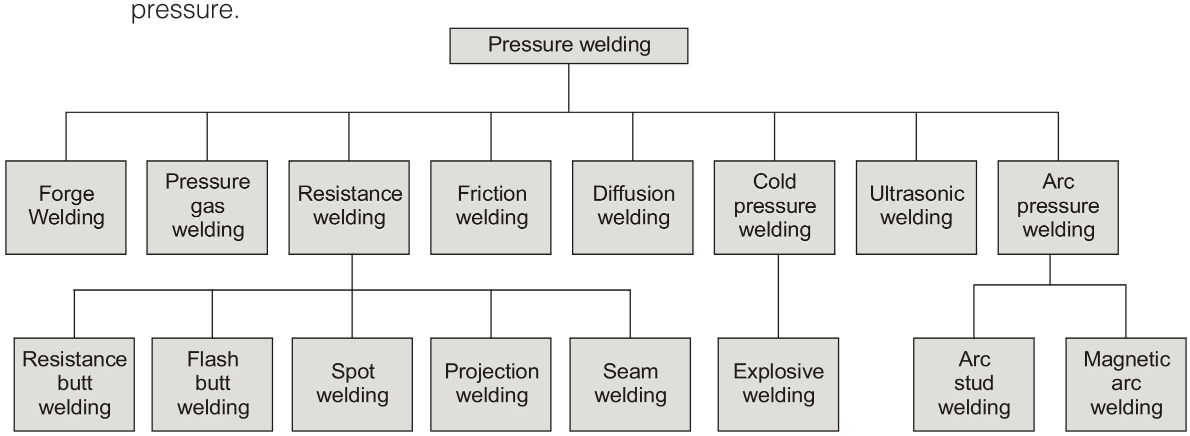
4. A wielded joint, for many reasons, needs stress-relief heat treatment.
5. Welding results in residual stresses and distortion of die workpieces.
6. Welding gives out harmful radiations (light), fumes and spatter.
7. For producing a good welding job, a skilled worker is a must.

Classification of welding process

- A welding process can be defined as follows:

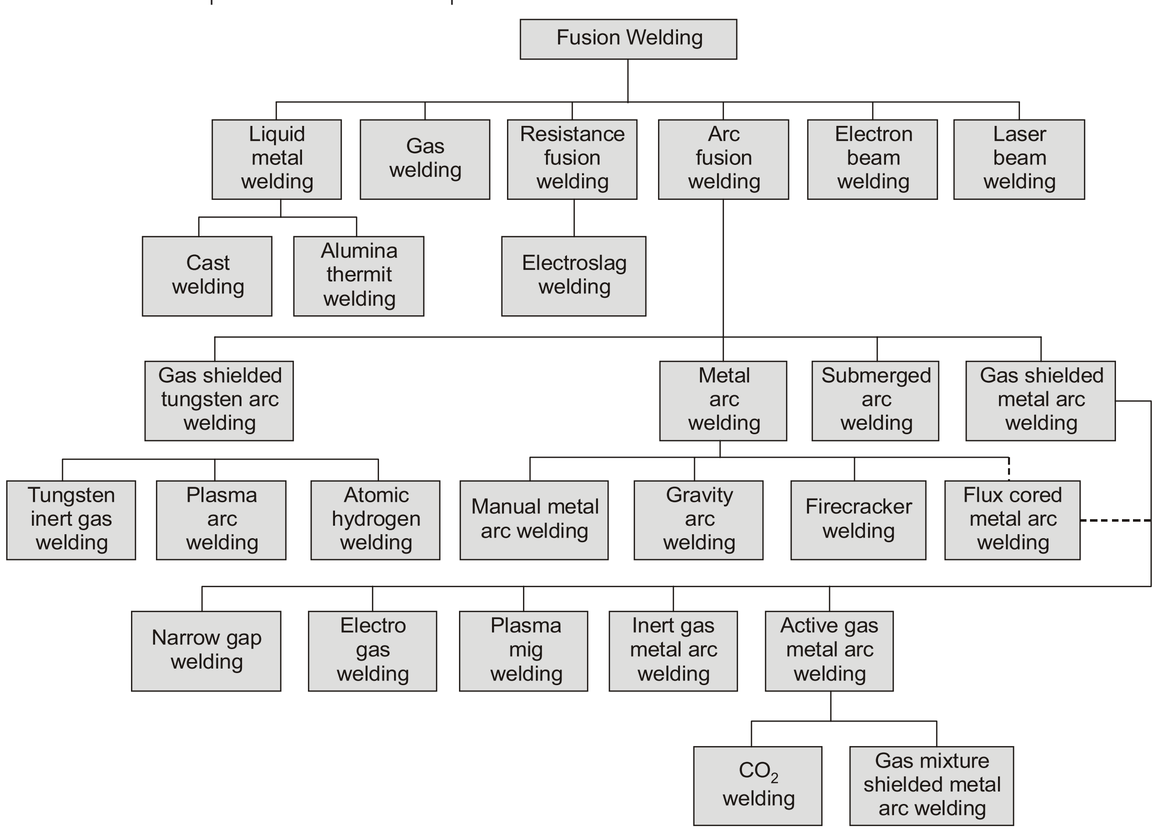
I. Pressure welding

- The characteristics of a pressure weld is that the metal joined is never brought to a molten stage, it is heated to a welding temperature and the actual union is brought about by application of pressure.



II. Fusion welding

- The characteristic of a fusion weld is that the material being joined is a actually melted and the union is produced on subsequent solidification.



III. Allied welding process

- Soldering
- Brazing
- Braze welding

2.1 Weldability of Metals

- The weldability of a material will depend on the specific welding or joining process being considered.
- For resistance welding of consistent quality, it is usually necessary to remove the oxide immediately before welding.
- Fabrication weldability test is used to determine mechanical properties required for satisfactory performance of welded joint.
- The correct sequence of the given materials in ascending order of their weldability is

Aluminum < copper < cast iron < MS

Case of Aluminum

- The oxide coating on aluminum alloys causes some difficulty in relation to its weldability.
- It also has high thermal conductivity and a very short temperature range between liquidus and solidus and when liquid its viscosity is very low.
- Aluminium is poor absorber of laser light.
- During fusion welding, the aluminum would oxidize so readily that special fluxes or protective inert-gas atmospheres must be employed.
- Friction welding and TIG welding is good for aluminium.
- For aluminium AC current plus high frequency is must.

Case of Cast Iron

- Cast iron is more difficult to weld because of its high carbon content and brittleness (poor ductility)
- Massive carbon deposits have a tendency to form in the areas adjacent to the weld, and high-carbon martensite tends to form in the heat-affected zones. These microstructures are very brittle and may crack spontaneously while welding is in progress or later when load is applied to the workpiece.
- Cast iron can be joined by the oxyacetylene brazing process and shielded metal-arc welding (stick) process.
- Some cases preheating and/or post heating is required.

Weldability: Nodular CI> Malleable CI > Gray CI > White CI

Case of stainless steel

- Stainless steel is a difficult metal to weld because it contains both nickel and chromium.
- The best method for welding stainless steel is TIG welding.
- The electric arc is also preferred for welding stainless steels. A heavily coated welding rod, which produce a shielded arc, is employed.
- You must do a better job of pre-cleaning.
- Using a low arc current setting with faster travel speeds is important when welding stainless steel, because some stainless steels are subject to carbide precipitation.
- The ferritic stainless steels are generally less weldable than the austenitic stainless steel and require both preheating and postweld heat treatments.
- Welds of ferritic stainless steel can be by
  (i) autogenously (i.e. without the addition of filler metal)
  (ii) with an austenitic stainless steel
  (iii) using a high nickel filler alloy.
  (iv) Type 405 filler (low 11% Cr, low carbon and small 0.2% Al)
- Welding process: TIG, MIG, Shielded-metal arc welding and Plasma arc welding

ILLUSTRATIVE EXAMPLES

Example 2.1 In arc welding of a butt joint, the welding speed is to be selected such that the highest cooling rate is achieve. Melting efficiency and heat transfer efficiency are 0.6 and 0.8 respectively. The area of the weld cross section is 6 mm^2 and the unit energy required to melt the metal is 12 J/mm^3. If the welding power is 4 kW. What is the welding speed in mm/s.

Solution :

$$\eta_{melting} = 0.6$$

$$\eta_{HT} = 0.8$$

$$\text{Area of cross section (A)} = 6 \text{ mm}^2$$

$$\text{Welding power} = 4 \text{ kW}$$

$$\text{Unit energy require to melt} = 12 \text{ J/mm}^3$$

$$\text{Let the welding speed} = V \text{ mm/s}$$

$$\eta_{melting} = \frac{\text{Heat require to melt the joint}}{\text{Net heat supplied}}$$

$$\text{HRMJ} = \text{Volume of joint} \times \text{rate of melting}$$

$$\text{Volume of joint} = \text{Area of joint} \times \text{Welding speed.}$$

$$\text{Net heat supply} = \eta_{HT} \times V \times I = 0.8 \times 4 \times 10^3 = 3.2 \times 10^3$$

$$\eta_{melting} = \frac{6 \times 12 \times V}{3.2 \times 10^3}$$

$$V = \frac{0.6 \times 3.2 \times 10^3}{6 \times 12} = 26.67 \text{ mm/s}$$

Example 2.2 The arc length voltage characteristic is given by

$V = 24 + 4L$ (L = length (arc) in mm)

The volt ampere characteristic of a power source can be approximated by a straight line with open circuit voltage 80 V and short circuit current is 600 A. Determine optimum arc length for maximum power?

Solution :

$$V_1 = 24 + 4L \quad \text{...(i)}$$

We know

$$V = OCV - \left(\frac{OCV}{SCC}\right) I$$

$$V_2 = 80 - \left(\frac{80}{600}\right) I \quad \text{...(ii)}$$

From (i) & (ii) we can say

$$24 + 4L = 80 - \left(\frac{80}{600}\right) I$$

$$\frac{8}{60} I = 80 - 24 - 4L = 56 - 4L$$

$$I = (56 - 4L)\left(\frac{60}{8}\right)$$

We know
$$P = VI = (24+4L)\times\left\{(56-4L)\left(\frac{60}{8}\right)\right\}$$
$$= \frac{60}{8}\{(56\times 24) - 96L + 244L - 16L^2\}$$
$$= \frac{60}{8}[(56\times 24) - 128L - 16L^2]$$

For maximum power, $\frac{dP}{dL} = 0$
$$128 - 32L = 0$$
$$32L = 128$$
$$L = \frac{128}{32} = 4 \text{ mm}$$

Example 2.3 For resistance spot welding of two aluminium sheets, each 2 mm thick, a current of 5000 A was passed for 0.15 sec. The total resistance was estimated to be 75 μΩ and the nugget diameter and thickness were measured to be 5 mm and 2.5 mm respectively. What would be the proportion of heat energy utilized for welding if the melting energy per unit volume for aluminium is taken as 2.9 J/mm^3?

Solution :

Thickness of each plate = 2 mm; Current (I) = 5000 A

Time (t_1) = 0.15 sec; Resistance = 75 μΩ = 75 × 10^{-6} Ω

Nugget diameter (d_n) = 5 mm; Nugget thickness (t_n) = 2.5 mm

Total energy supplied = I^2RT

$\Rightarrow$ $H_s = 5000^2 \times 75 \times 10^{-6} \times 0.15 = 281.25$ J

$$\text{Volume of Nugget} = \frac{\pi}{4}\times d_n^2 \times h_n = \frac{\pi}{4}\times 5^2 \times 2.5 = 49.0.87 \text{ mm}^3$$

$\therefore$ Melting energy require for nugget = volume × 2.9

$\Rightarrow$ $49.087 \times 2.9 = 142.353$ J

Heat energy lost = 281.25 – 142.353 = 138.903 J

$$\text{Proportion of heat utilized} = \frac{\text{Heat rerquired to melt}}{\text{Total Heat supply}} = \frac{138.903}{281.25}\times 100 = 49.38\%$$

Example 2.4 The DC power source for arc welding has the characteristic $3V + I = 240$, where V = voltage and I = current in ampere. For maximum arc power at the electrode, voltage should be set at

(a) 20 V (b) 40 V (c) 60 V (d) 80 V

Ans : (b)

Given, Power source = $3V + I = 240$

$$\text{Power} = VI$$
$$3V + I = 240$$
$$\boxed{I = 240 - 3V}$$
$$P = V(240-3V) = 240V - 3V^2$$

$$\text{for max arc power} = \frac{dp}{dv} = 0 = \frac{d(240V - 3V^2)}{dv}$$
$$240 - 6V = 0$$

Student's Assignments 2

Q.45 During resistance welding, the resistance in welding circuit is sum of
P. Resistance of electrodes.
Q. Resistance of sheet parts.
R. Contact resistance of the forging surfaces.
S. Resistannce of wires that carry electricity from source to welding equipment.
(a) P, Q (b) Q, R
(c) P, Q, R (d) P, Q, R, S

Q.46 The quantity of heat required to melt a given volume of metal from room temperature is given as $U_m = kT_m^2$, where U_m is J/mm³, $k = 3.33 \times 10^{-6}$ (a constant), T_m = Melting point of metal in kelvin. If for welding of steel with T_m as 1530 K, heat transfer factor of 0.8, cross section area of 10 mm² and welding speed of 7 mm/sec, the rate of energy required to be delivered by welding equipment is _____ J/s. (Correct upto 3 decimal)

Q.47 The flow strength of alloy of aluminium is given as 230 MPa. This alloy is extruded from an initial diameter of 180 mm to 60 mm. Length of the billet is 400 mm. The coefficient of friction is 0.15 and assume a die angle of 450°. The magnitude of extrusion pressure is ______ MPa.

Q.48 A disk 40 cm in diameter and 5 cm thick is to be casted of pure aluminium in an open mold operation. The melting temperature of aluminium is 660°C and the pouring temperature will be 800°C. Assume that the amount of aluminium heated will be 15% more than needed to fill the mold cavity. The amount of heat that must be added to the metal to heat it to the pouring temperature, starting from a room temperature of 25°C is ______ MJ. The heat of fusion of aluminium = 389.3 J/g, density = 2.7 g/cm³ and specific heat = 0.88 J/g°C. Assume the specific heat has same value for solid and molten metal.

Q.49 Seam welding is carried out on 1.8 mm thick copper tube at 4 welds per cm by circular electrods of 200 mm diameter. Welding cycle consists of 2 cycles 'on' and 2 cycles 'off'. Power supply is at 60 Hz. RPM of circular electrode will be _________.

Q.50 During an arc welding, the peak temperature reached at any point in material is calculated as

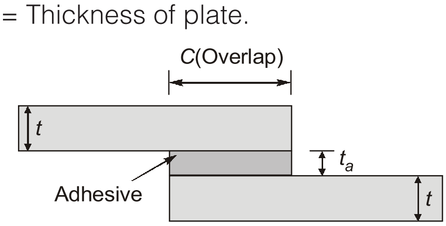
$$\frac{1}{T_P - T_O} = \frac{\sqrt{2\pi e}(\rho c)hy}{H_{net}} + \frac{1}{T_M - T_O} \text{ where,}$$

T_P = Temperature reached at a distance y mm from fusion boundary (°C)
T_0 = Initial plate temperature (°C)
e = Base of natural logarithm = 2.718
ρ = Density of base metal (g/mm³)
c = Specific heat of base metal (J/g°C)
h = Thickness of base metal, (mm)
H_{net} = Net heat available at weld joint (J/mm)
T_M = Melting temperature of base metal
Given following parameters:
T_0 = 30°C, Heat transfer efficiency, η_1 = 0.9, Voltage = 25 volts, Current = 300 amperes, Welding speed, v = 7 mm/sec, ρc = 0.0044 J/mm³ °C, Plate thickness, h = 6 mm, melting temperature, T_M = 1510°C. The temperature (in °C) at a distance of 8 mm from fusion zone for arc welding of steel is ________. (Upto 3 decimal)

Q.51 A joint is made between two aluminium sheets of 1.2 mm thickness each with an adhesive thickness of 0.25 mm. The overlapped length is 12 mm. Given, E_{Al} = 703 N/mm², G_a = 11.9 N/mm², and ultimate shear stress of the adhesive τ_a = 0.6 N/mm². The stress concentration factor can be given as

$$k = \left(\frac{C^2 G_a}{2Ett_a}\right)^{1/2},$$

where G_a = Shear modulus of adhesive
E = Young's modulus of metal
C = Overlap length
t_a = Thickness of adhesive
t = Thickness of plate.



The maximum shear stress in the lap joint as shown is figure, to which the joint can withstand (in N/mm²) is ________.