APPLIED MARINE ENGINEERING

Attempt ALL questions
Marks for each part question are shown in brackets

1. (a) Construct a horizontal axis for carbon content of steel 0 to 2.5% using 0.1% increments. Place the following materials on this axis in their appropriate percentage carbon content bandwidth:
   - Mild Steel
   - Cast Iron
   - Wrought Iron
   - High Carbon Steel
   - Medium Carbon Steel

   (5)

   (b) Name a typical component that it would be used on a vessel for each of the metals detailed in part (a), stating the reason why it is best suited for this application. (5)

2. (a) Define the term *stainless steel,* making reference the percentage quantities of its TWO main constituents. (4)

   (b) With reference to EACH of the following grades of stainless steel, list ONE of its unique properties and a common use that utilises this property:

   (i) ferritic; (2)

   (ii) austenitic; (2)

   (iii) martensitic. (2)

3. With reference to manufacturing components from aluminium:

   (a) explain why it may be necessary to anneal aluminium; (2)

   (b) describe the problems encountered when working with annealed aluminium; (4)

   (c) describe how it could be annealed on board a vessel. (4)

4. Explain EACH of the following engineering terms, stating ONE material that exhibits EACH property:

   (a) brittleness; (2)

   (b) ductility; (2)

   (c) hardness; (2)

   (d) malleability; (2)

   (e) toughness. (2)

5. With reference to TIG welding:

(a) describe the process; (3)

(b) explain why an ac current is preferred when welding aluminium; (2)

(c) explain the advantages compared to other methods. (5)

6. With reference to marine corrosion:

(a) list EIGHT factors that influence the rate of corrosion for an unprotected metal surface; (4)

(b) explain the process of galvanic corrosion; (4)

(c) state TWO major factors influencing the severity of galvanic corrosion. (2)

7. With reference to glass reinforced plastic (GRP) hulls:

(a) state THREE causes for EACH of the following defects to occur:

(i) de-lamination; (3)

(ii) osmotic blisters; (3)

(iii) stress cracking; (3)

(b) state the part of the underwater section of the hull on which osmotic blisters most commonly occur. (1)

8. List FIVE different methods of remotely monitoring the content level of a fuel oil service tank, explaining their operating principle. (10)

9. (a) Explain the limitation of a proportional controller. (2)

(b) Explain, with the aid of diagrams, how the limitation explained in part (a) may be overcome. (8)

10. (a) Define EACH of the following terms:

(i) cascade control; (4)

(ii) split range control. (3)

(b) Describe possible problems associated with *split range control* used for the control of a main engine cooling system. (3)

1. (a) Construct a horizontal axis for carbon content of steel 0 to 2.5% using 0.1% increments. Place the following materials on this axis in their appropriate percentage carbon content bandwidth:
- Mild Steel
- Cast Iron
- Wrought Iron
- High Carbon Steel
- Medium Carbon Steel

(5)

(b) Name a typical component that it would be used on a vessel for each of the metals detailed in part (a), stating the reason why it is best suited for this application. (5)

(a) Place these on a 0–2.5% C axis (bands)

- **Wrought iron: ~0.00–0.08 %C** (essentially pure Fe with slag stringers) – far left.
- **Mild (low-carbon) steel: ~0.05–0.25 %C** – left-of-centre.
- **Medium-carbon steel: ~0.30–0.60 %C** – mid range.
- **High-carbon steel: ~0.60–1.00(≈1.2–1.4) %C** – right of mid (within your 0–2.5% axis mark **0.6–1.0%**).
- **Cast iron: ~2.0–4.0 %C** – at the **far right**; on the 0–2.5% axis show **about 2.0–2.5%** (note it extends beyond to ~4%).

(On your line: left→right order is Wrought iron → Mild steel → Medium C steel → High C steel → Cast iron.)

(b) One typical shipboard component for each, with reason

- **Wrought iron:** *Older vessels: anchor chain links / rivets / handrails* — very **tough, malleable**, good **corrosion resistance**; easy to forge (historical use).
- **Mild steel:** *Hull plating/frames, bulkheads* — good **weldability**, **ductility**, adequate strength, **low cost**.
- **Medium-carbon steel:** *Propeller shaft / gears / crankshafts* — higher **strength & toughness**; can be **heat-treated** (normalize/temper).
- **High-carbon steel:** *Springs (valve/governor), cutting tools* — can be **hardened** to high **hardness/wear resistance**.
- **Cast iron:** *Engine blocks, pump/valve bodies, pipe fittings* — excellent **castability**, good **compressive strength**, **damping** and fair corrosion resistance in many services.

). (a) Define the term *stainless steel,* making reference the percentage quantities of its TWO main constituents. (4)

(b) With reference to EACH of the following grades of stainless steel, list ONE of its unique properties and a common use that utilises this property:

(i) ferritic; (2)

(ii) austenitic; (2)

(iii) martensitic. (2)

(a) Define stainless steel with its two main constituents (4 marks)

- Stainless steel is an **iron–carbon alloy** containing a **minimum of 10.5–12% chromium** by mass.
- **Carbon content** is typically **less than 1.2%**.
- Chromium forms a stable **oxide film** on the surface, giving stainless steel its corrosion resistance.

(b) Grades of stainless steel

(i) Ferritic stainless steel (2 marks)

- **Property:** Magnetic, good resistance to stress corrosion cracking, relatively inexpensive.
- **Use:** Exhaust systems, kitchen equipment, decorative trim (good corrosion resistance and formability).

(ii) Austenitic stainless steel (2 marks)

- **Property:** Excellent corrosion resistance, non-magnetic, good ductility (common grade 316).
- **Use:** Ship side valves, tanks, pipelines exposed to seawater (marine grade).

(iii) Martensitic stainless steel (2 marks)

- **Property:** Can be heat treated for high hardness and wear resistance.
- **Use:** Propeller shafts, turbine blades, pumps, cutlery (where hardness and strength are essential).

3. With reference to manufacturing components from aluminium:

(a) explain why it may be necessary to anneal aluminium; (2)

(b) describe the problems encountered when working with annealed aluminium; (4)

(c) describe how it could be annealed on board a vessel. (4)

(a) Why it may be necessary to anneal aluminium (2 marks)

- Aluminium work-hardens during processes like rolling, bending, or forming.
- Annealing **restores ductility and softness**, relieving internal stresses, making further forming/machining easier.

(b) Problems when working with annealed aluminium (4 marks)

- **Reduced strength and hardness** → may deform under load.
- **Lower wear resistance** → more prone to surface damage.
- **Risk of distortion** during machining or service due to its softness.
- **Welding issues** → annealed aluminium may lose temper strength and become weaker in heat-affected zones.

(c) How it could be annealed on board a vessel (4 marks)

- Heat the aluminium component evenly to about **350–400 °C**.
- This can be judged by applying a **soap film**: when the soap turns **black** (carbonises), correct temperature is reached.
- Hold the component at that temperature for sufficient time (depends on thickness).
- Allow to **cool slowly in air** (furnace cooling not usually possible onboard).

4. Explain EACH of the following engineering terms, stating ONE material that exhibits EACH property:

(a) brittleness; (2)

(b) ductility; (2)

(c) hardness; (2)

(d) malleability; (2)

(e) toughness. (2)

(a) Brittleness (2 marks)

- **Definition:** The tendency of a material to fracture or break suddenly without significant plastic deformation.
- **Example material: Glass** or **cast iron**.

(b) Ductility (2 marks)

- **Definition:** The ability of a material to be stretched or drawn out into a wire without breaking.
- **Example material: Copper** (used in electrical wiring).

(c) Hardness (2 marks)

- **Definition:** The ability of a material to resist indentation, scratching, or wear.
- **Example material: Hardened steel** (used for cutting tools).

(d) Malleability (2 marks)

- **Definition:** The ability of a material to be hammered, rolled, or pressed into thin sheets without cracking.
- **Example material: Gold** or **aluminium** (sheet forming).

(e) Toughness (2 marks)

- **Definition:** The ability of a material to absorb energy and resist fracture under sudden impact.
- **Example material: Mild steel** (used in ship hulls and structures).

5. With reference to TIG welding:

(a) describe the process; (3)

(b) explain why an ac current is preferred when welding aluminium; (2)

(c) explain the advantages compared to other methods. (5)

(a) Describe the process (3 marks)

- TIG (Tungsten Inert Gas) welding uses a **non-consumable tungsten electrode** to create an electric arc.
- The arc melts the base metal, and a separate **filler rod** may be added if required.
- An **inert shielding gas** (argon or helium) protects the molten weld pool from atmospheric contamination.

(b) Why AC current is preferred for aluminium (2 marks)

- Aluminium has a tough **oxide layer (Al_2O_3)** with a very high melting point.
- AC provides a **cleaning action** during the positive half-cycle, breaking down the oxide layer, while the negative half-cycle provides **deep penetration**.

(c) Advantages compared to other methods (5 marks)

1. Produces **high-quality, precise, clean welds** with minimal spatter.
2. Allows welding of **thin materials** and **non-ferrous metals** (aluminium, copper, stainless steel).
3. **No flux required** → no slag inclusions.
4. Excellent control of **heat input and weld pool**, reducing distortion.
5. Can weld in a variety of positions and is suitable for **aerospace, marine, and critical applications**.

6. With reference to marine corrosion:

(a) list EIGHT factors that influence the rate of corrosion for an unprotected metal surface; (4)

(b) explain the process of galvanic corrosion; (4)

(c) state TWO major factors influencing the severity of galvanic corrosion. (2)

(a) Eight factors influencing corrosion rate of an unprotected metal surface (4 marks)

(½ mark each = 4 total)

1. **Oxygen concentration** – more oxygen accelerates corrosion.
2. **Salinity (chloride content)** – higher salt increases conductivity and corrosion.
3. **Temperature** – higher temperatures increase reaction rates.
4. **pH of seawater** – acidic conditions accelerate corrosion.
5. **Flow rate of seawater** – turbulence increases oxygen supply and erosion–corrosion.
6. **Presence of biological activity** – marine growth can concentrate corrosive areas.
7. **Impurities and pollutants** – e.g., sulphates, industrial contaminants.
8. **Surface condition of metal** – rough or stressed areas corrode faster; coatings or passive films slow corrosion.

(b) Process of galvanic corrosion (4 marks)

- Occurs when **two dissimilar metals** are electrically connected and immersed in an electrolyte (e.g., seawater).
- The more **anodic (less noble) metal** becomes the **sacrificial anode** and corrodes preferentially.
- The more **cathodic (noble) metal** is protected and corrodes less.
- Electron flow occurs from anode → cathode, with metal loss at the anode.

(c) Two major factors influencing severity of galvanic corrosion (2 marks)

1. **Potential difference between the two metals** – greater difference = faster corrosion.
2. **Relative surface area of cathode to anode** – small anode coupled to a large cathode corrodes very rapidly.

7. With reference to glass reinforced plastic (GRP) hulls:

(a) state THREE causes for EACH of the following defects to occur:

(i) de-lamination; (3)

(ii) osmotic blisters; (3)

(iii) stress cracking; (3)

(b) state the part of the underwater section of the hull on which osmotic blisters most commonly occur. (1)

(a) Causes of defects

(i) De-lamination (3)

1. Poor bonding between successive laminate layers during manufacture (e.g., contamination, inadequate curing).
2. Mechanical impact or shock loading causing separation of fibre layers.
3. Water ingress leading to weakening of the resin–fibre bond.

(ii) Osmotic blisters (3)

1. Water permeation through the gel coat into voids or resin pockets.
2. Presence of unreacted resins, salts, or contaminants in laminate forming concentrated solutions.
3. Osmotic pressure builds up, forcing the gel coat to blister.

(iii) Stress cracking (3)

1. Excessive mechanical loads beyond design limits (e.g., grounding, heavy slamming).
2. Incorrect lay-up orientation leading to weak spots in laminate.
3. Cyclic fatigue stresses over time (vibration, wave impact, engine stresses).

(b) Location of osmotic blisters (1)

- Most commonly occur on the **underwater hull bottom and bilge areas**, especially where water stagnates or where resin-rich layers exist.

8. List FIVE different methods of remotely monitoring the content level of a fuel oil service tank, explaining their operating principle. (10)

Five methods and their principles (10 marks, 2 each)

1. **Hydrostatic pressure gauge system**
    - Measures the **head pressure** exerted by the liquid at the base of the tank.
    - Pressure is proportional to liquid height → converted to level indication remotely.
2. **Pneumatic (bubble tube) system**
    - Air is bubbled into a dip tube reaching the bottom of the tank.
    - Back pressure in the tube corresponds to liquid head → measured and displayed remotely.
3. **Float and transmitter system**
    - A **float** rises and falls with the fuel level.
    - Motion is transmitted mechanically, magnetically, or electrically to a remote gauge.
4. **Capacitance probe system**
    - Uses a probe forming a capacitor with the tank wall.
    - Capacitance changes as the fuel level rises or falls (due to changing dielectric constant).
    - Signal is converted to a remote level indication.
5. **Ultrasonic or radar level gauge**
    - A transducer sends ultrasonic or microwave pulses towards the liquid surface.
    - Time taken for the reflected signal (echo) to return is measured.
    - Calculated distance gives liquid level.

9. (a) Explain the limitation of a proportional controller. (2)

(b) Explain, with the aid of diagrams, how the limitation explained in part (a) may be overcome. (8)

(a) Limitation of a proportional controller (2 marks)

- A proportional controller **cannot completely eliminate the steady-state error (offset)**.
- For the controlled variable to remain at setpoint, the output must adjust; this requires a finite error to exist (called **proportional offset or droop**).

(b) How the limitation may be overcome (8 marks)

Solution: introduce Integral action (making a PI or PID controller).

- The integral term sums the error over time, driving the error to zero.
- As long as a steady error exists, the integral keeps adjusting the controller output until the setpoint is achieved.
- This eliminates the offset that proportional control alone cannot remove.

With diagram explanation (if drawn in exam):

1. **Proportional-only system:**
    - Show a setpoint vs process variable curve → steady error remains.
    - Indicate “droop” or offset at equilibrium.
2. **PI controller:**
    - Add integral action, curve rises to reach setpoint (error = 0).

Alternative methods (less common but acceptable):

- Adding **reset wind-up correction**.
- Using **cascade control** to improve accuracy.

10. (a) Define EACH of the following terms:

(i) cascade control; (4)

(ii) split range control. (3)

(b) Describe possible problems associated with *split range control* used for the control of a main engine cooling system. (3)

(a) Definitions

(i) Cascade control (4 marks)

- A control strategy where **two controllers are used in series**:
  - The **primary (master) controller** controls the main process variable (e.g., cooling water outlet temperature).
  - The **secondary (slave) controller** controls a faster-responding variable (e.g., cooling water flow or valve position).
- The output of the master controller becomes the setpoint for the slave controller.
- **Advantage:** improves accuracy and response by dealing with disturbances quickly in the secondary loop before they affect the main process.

(ii) Split range control (3 marks)

- A single controller output signal is divided into **two or more actuators** (valves) that operate over different parts of the control range.
- Example: One valve opens (cooling water bypass) for lower controller outputs, while another valve opens (cooling water to cooler) at higher outputs.
- Ensures smooth control across a wide operating range.

(b) Problems with split range control in main engine cooling (3 marks)

1. **Overlap or dead band** between valve operations – can cause instability or poor control.
2. **Incorrect calibration** → one valve opens too early/late, leading to hunting or uneven cooling.
3. **Unequal valve characteristics** – different response times may cause surging or oscillation in cooling water flow.