AME MAY 2022

APPLIED MARINE ENGINEERING

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

1. Detail the changes in the properties of steel by the addition of EACH of the following elements:

 (a) nickel; (2)

 (b) chromium; (2)

 (c) molybdenum; (2)

 (d) silicon; (2)

 (e) manganese. (2)

2. (a) List FIVE different desirable properties of aluminium. (5)

 (b) In modern vessels identify parts that utilises EACH of the properties listed in part (a). (5)

3. With reference to the heat treatment of steel:

 (a) explain which steels this process is best suited to; (2)

 (b) explain EACH of the following processes, making reference to mechanical properties and internal structure:

  (i) hardening; (4)

  (ii) tempering. (4)

4. Describe, with the aid of load extension graphs, EACH of the following engineering terms:

   (a) limit of proportionality; (2)

   (b) yield point; (2)

   (c) Ultimate Tensile Strength; (2)

   (d) 0.1% Proof Stress. (4)

5. (a) Explain the process of *brazing* for the joining of metals and alloys. (4)

   (b) State TWO methods by which a cracked aluminium alloy pump casting might be repaired. (2)

   (c) List the FOUR functions that the flux performs in the brazing process. (4)

6. With reference to the protection of aluminium from corrosion:

   (a) explain the naturally occurring process and it's limitations; (4)

   (b) explain the process of anodising, stating its advantages. (6)

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. With reference to the flowrate measuring device shown in the figure, describe the principle of operation, explaining how an analogue remote reading may be obtained. (10)

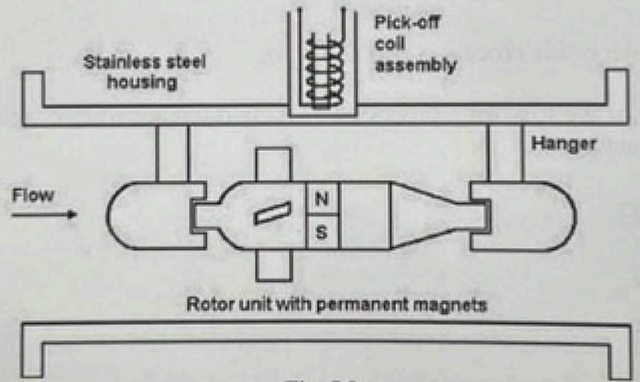

Fig Q8

9. With reference to *Discontinuous* or *On Off* control systems:

(a) sketch the response of a basic heater control, showing temperature against time and labelling the key points; (4)

(b) state THREE methods of improving the accuracy/speed of response. (6)

10. With reference to a main engine lubricating oil system, explain, with the aid of a sketch, the principle of a *closed loop* temperature control system. (10)

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Alloying Elements and their Impact on Steel Properties:

Adding specific elements to steel, known as alloying, significantly alters its properties, making it suitable for diverse applications. Here's how each element you mentioned influences steel:

(a) Nickel:

- **Strength & Toughness:** Increases, especially at low temperatures, making nickel steels ideal for cryogenic applications.

- **Corrosion Resistance:** Improves, particularly against chloride-induced corrosion, making it valuable for marine and chemical environments.
- **Weldability:** Reduces due to the formation of brittle phases during welding, requiring special techniques.

(b) Chromium:

- **Hardenability:** Increases significantly, allowing deeper penetration of hardening effects during heat treatment.
- **Wear Resistance:** Enhances due to the formation of hard chromium carbides, making it suitable for wear-resistant components.
- **Corrosion Resistance:** Improves considerably, especially when exceeding 11%, creating stainless steel with excellent corrosion resistance.
- **Ductility:** Reduces, making the steel less formable but enhancing its strength.

(c) Molybdenum:

- **Hardenability:** Increases, similar to chromium, enabling deeper hardening and higher strength potential.
- **High-Temperature Strength:** Improves, making it valuable for components operating at elevated temperatures.
- **Creep Resistance:** Enhances, resisting deformation under stress at high temperatures, crucial for boiler components.
- **Weldability:** Reduces due to the formation of hard and brittle phases during welding, requiring specific welding techniques.

(d) Silicon:

- **Deoxidation:** Aids in removing oxygen during steelmaking, improving internal cleanliness and preventing defects.
- **Strength & Wear Resistance:** Increases moderately, offering a balance between cost and performance.
- **Ductility & Weldability:** Reduces slightly, requiring adjustments in fabrication techniques.

(e) Manganese:

- **Strength, Toughness & Hardenability:** Increases, making it a versatile and cost-effective alloying element.
- **Deoxidation & Desulfurization:** Plays a crucial role in removing oxygen and sulfur during steelmaking, improving internal quality.
- **Weldability:** Reduces slightly due to the formation of hard manganese sulfides, requiring controlled welding practices.

Important Note:

The specific effects of each element depend on the **amount added** and the **presence of other elements** in the steel. Additionally, there can be trade-offs between different properties – for example, increasing strength might come at the cost of reduced ductility. Selecting the right alloying elements and their concentrations is crucial for achieving the desired properties for a specific application.

2. (a) List FIVE different desirable properties of aluminium. (5)

(b) In modern vessels identify parts that utilises EACH of the properties listed in part (a). (5)

Desirable Properties of Aluminum and their applications in modern vessels:

(a) Five Desirable Properties of Aluminum:

1. **Lightweight:** Aluminum has a low density, making it about three times lighter than steel for the same volume. This is crucial for weight-sensitive applications like airplanes, ships, and vehicles, optimizing fuel efficiency and performance.
2. **Corrosion resistant:** Aluminum forms a thin, naturally occurring oxide layer that protects it from corrosion, even in saltwater environments. This makes it ideal for marine applications like boat hulls, masts, and deck components.
3. **Good conductor of heat and electricity:** Aluminum efficiently conducts heat, making it suitable for heat exchangers, engine components, and electrical wiring in vessels. This facilitates heat management and efficient power distribution.
4. **Durable and formable:** Aluminum is strong and resistant to damage, yet easily shaped into complex designs. This allows for lightweight yet sturdy structures and components like lifeboats, railings, and interior panels.
5. **Recyclable:** Aluminum is highly recyclable, with a recycling rate exceeding 70%. This contributes to sustainability and reduced environmental impact, making it an eco-friendly choice for vessel construction.

(b) Examples of Applications in Modern Vessels:

Property	**Example**
Lightweight	**Superstructure, bulkheads, lifeboats, masts, railings**
Corrosion resistant	**Hulls, deck components, propellers, rudders**

Good conductor of heat	**Heat exchangers, engine components, fuel tanks**
Good conductor of electricity	**Electrical wiring, cables, bus bars**
Durable and formable	**Lifeboats, davits, hatches, interior panels, furniture**

Additional Notes:

- The specific applications of aluminum vary depending on the type and size of the vessel.
- Alloys of aluminum with other elements like magnesium or copper can further enhance specific properties for tailored applications.
- While steel remains dominant in some areas due to its high strength, aluminum finds increasing use in modern vessels due to its combination of desirable properties and sustainability benefits.

3. With reference to the heat treatment of steel:

    (a) explain which steels this process is best suited to; (2)

    (b) explain EACH of the following processes, making reference to mechanical properties and internal structure:

    (i) hardening; (4)

    (ii) tempering. (4)

Heat Treatment of Steel: Suits and Processes

(a) Steels Best Suited for Heat Treatment:

Heat treatment is particularly beneficial for specific types of steel, primarily those with medium to high carbon content (0.2-1.0%). These steels experience significant changes in their mechanical properties due to the heat-driven transformations in their internal structure. Some examples include:

- Hypoeutectoid steels (carbon content < 0.77%): These steels can achieve significant hardening through quenching, forming martensite with high strength and hardness.
- Eutectoid steel (0.77% carbon): This steel readily transforms into pearlite (a mixture of ferrite and cementite) during slow cooling, achieving a good balance of strength and ductility.
- Hypereutectoid steels (carbon content > 0.77%): These steels can achieve high wear resistance due to the presence of cementite (iron carbide). However, their weldability and ductility are limited.

Steels with very low carbon content (< 0.2%) and high-alloy stainless steels generally benefit less from heat treatment due to their inherent properties or limited transformation potential.

(b) Heat Treatment Processes Explained:

(i) Hardening:

- Process: Steel is heated above its critical temperature (around 723°C), austenitizing its microstructure (transforming it into austenite, a high-carbon phase). This is followed by rapid quenching (usually in water or oil), which traps the high-carbon austenite structure as a metastable phase called martensite.
- Mechanical Properties: Hardening significantly increases the strength and hardness of the steel but at the expense of ductility and toughness. Martensite is very strong and hard but also brittle and prone to cracking.
- Internal Structure: The rapid quenching prevents carbon atoms from diffusing and forming equilibrium phases like pearlite. Instead, austenite transforms into martensite, a distorted tetragonal lattice structure with high carbon content, leading to high strength and hardness.

(ii) Tempering:

- Process: Hardened steel is reheated to a lower temperature (typically between 150°C and 500°C) and then cooled slowly. This allows some of the martensite to transform back into less brittle phases like ferrite and cementite, depending on the tempering temperature.
- Mechanical Properties: Tempering reduces the hardness and strength of the steel compared to the hardened state but significantly improves its ductility and toughness. This makes the steel more resistant to cracking and failure under stress.
- Internal Structure: Tempering allows carbon atoms to diffuse and form more stable phases like ferrite and cementite. The specific phases formed and the degree of transformation depend on the tempering temperature, influencing the final balance of strength, ductility, and toughness.

Therefore, hardening and tempering are complementary processes. Hardening provides high strength and hardness, while tempering improves ductility and toughness, allowing for a tailored balance of properties for specific applications.

4. Describe, with the aid of load extension graphs, EACH of the following engineering terms:

(a) limit of proportionality; (2)

(b) yield point; (2)

(c) Ultimate Tensile Strength; (2)

(d) 0.1% Proof Stress. (4)

(a) Limit of Proportionality:

Imagine pulling a rubber band gently. Initially, it stretches proportionally to the pulling force. This linear relationship between stress and strain defines the elastic region. The limit of proportionality, represented by a point on the graph, marks the transition from this linear region to a slightly curved region. Beyond this point, the material starts to deform slightly more than expected for the applied stress.

(b) Yield Point:

Continue pulling the rubber band harder. At some point, it suddenly stretches significantly even with a small increase in force. This abrupt jump on the graph is the yield point. It signifies the onset of plastic deformation, where the material begins to deform permanently even after the stress is removed.

(c) Ultimate Tensile Strength (UTS):

Keep pulling the rubber band relentlessly. It continues to stretch, but at a slower rate as its internal resistance builds up. Eventually, it reaches a peak point on the graph, the ultimate tensile strength (UTS). This represents the maximum stress the material can withstand before finally breaking.

(d) 0.1% Proof Stress:

Not all materials have a distinct yield point. In such cases, we use the 0.1% proof stress. Imagine pulling the rubber band slightly again and measuring its length after releasing the force. If the permanent elongation reaches 0.1% of its original length, the stress at that point is called the 0.1% proof stress. It serves as a practical measure of the material's yield strength in the absence of a clear yield point.

Visualizing the Graph:

Think of the graph as a mountain trail. We start walking on a flat (elastic) path, then encounter a slight incline (limit of proportionality), followed by a steeper climb (yield point), reaching the peak (UTS), and finally, the trail drops off before we fall (fracture). The 0.1% proof stress would be like stopping at a certain point on the slope and checking how far down the path we've permanently slid.

Understanding these terms and their visual representations is crucial for selecting materials appropriate for different engineering applications. Knowing their limits helps us design components that can safely handle expected loads and deformations without compromising their integrity or performance.

5. (a) Explain the process of *brazing* for the joining of metals and alloys. (4)

(b) State TWO methods by which a cracked aluminium alloy pump casting might be repaired. (2)

(c) List the FOUR functions that the flux performs in the brazing process. (4)

Brazing and Aluminium Alloy Repair:

(a) Brazing Process:

Brazing is a metal joining process where a filler metal with a lower melting point than the base metals is used to create a strong bond. Here's how it works:

1. **Preparation:** The surfaces to be joined are cleaned and fitted closely together, with a small gap (0.002-0.005 inches). Flux is applied to aid cleaning and promote wetting.
2. **Heating:** The joint is heated using various methods like torches, induction heating, or furnaces, reaching the brazing temperature of the filler metal (typically above 450°C but below the base metal melting point).
3. **Filler Metal Application:** The filler metal, in the form of wire, rod, or paste, is introduced to the heated joint.
4. **Capillary Action:** Due to surface tension and wetting properties, the molten filler metal flows into the gap by capillary action, filling it completely.
5. **Solidification:** As the heat source is removed, the filler metal solidifies, joining the base metals together.

(b) Repairing a Cracked Aluminium Alloy Pump Casting:

1. **Brazing:** This is a common method for repairing small cracks and leaks. The brazing process described above can be used with an aluminium brazing filler metal. However, careful selection of the filler metal and brazing technique is crucial to ensure compatibility with the specific aluminium alloy and avoid distortion.
2. **Welding:** For larger cracks or when high strength is required, welding might be an option. However, due to the lower melting point of aluminium and its sensitivity to heat, special techniques like TIG welding with appropriate filler metals are necessary to minimize distortion and maintain casting integrity.

(c) Functions of Flux in Brazing:

1. **Cleaning:** Flux removes oxides and impurities from the metal surfaces, improving wetting and adhesion of the filler metal.
2. **Deoxidation:** Fluxes often contain deoxidizers that neutralize oxides during heating, further promoting wetting and flow of the filler metal.
3. **Protection:** Flux can provide a protective atmosphere around the joint, preventing oxidation and contamination during heating.
4. **Wetting:** Some fluxes contain wetting agents that enhance the surface tension of the molten filler metal, allowing it to flow more easily into the joint gap.

Important Note: Repairing cracked castings requires expertise and proper selection of materials and techniques. Consulting a qualified welding or brazing professional is essential for a successful and safe repair.

6. With reference to the protection of aluminium from corrosion:

(a) explain the naturally occurring process and it's limitations; (4)

(b) explain the process of anodising, stating its advantages. (6)

Protecting Aluminium from Corrosion:

(a) Naturally Occurring Process and its Limitations:

Aluminium naturally develops a thin, hard, and adherent oxide layer on its surface when exposed to oxygen. This layer, known as aluminium oxide (Al2O3), acts as a barrier, impeding the penetration of corrosive elements like chlorine or salt. This self-healing process provides inherent corrosion resistance to aluminium and makes it suitable for many applications.

However, this natural protection has limitations:

- **Porosity:** The oxide layer is not entirely perfect and can have microscopic pores, allowing corrosive agents to reach the underlying metal.
- **Thickness:** The naturally formed oxide layer is relatively thin and can be worn away by abrasion or mechanical wear, exposing fresh metal to corrosion.
- **Alkaline and Acidic Environments:** The oxide layer is less effective in highly alkaline or acidic environments, where it can dissolve or degrade, compromising its protective ability.

(b) Anodizing Process and its Advantages:

Anodizing is an electrochemical process that thickens and strengthens the natural oxide layer on aluminium. Here's how it works:

1. **Preparation:** The aluminium component is cleaned and degreased.
2. **Electrolyte Bath:** The component is immersed in an electrolytic bath containing an acidic or alkaline solution.
3. **Anode:** The component acts as the anode, while the cathode is typically made of inert material like stainless steel.
4. **Voltage Application:** A direct current (DC) voltage is applied between the anode and cathode, causing oxidation of the aluminium at the anode.
5. **Oxide Layer Growth:** The oxidation process thickens and strengthens the existing oxide layer, creating a controlled and more robust barrier.
6. **Sealing (Optional):** The anodized aluminium can be further treated with hot water or a sealing solution to close any remaining pores in the oxide layer, enhancing its corrosion resistance.

Advantages of Anodizing:

- **Increased Corrosion Resistance:** The thicker and more uniform oxide layer significantly improves the aluminium's resistance to corrosion, even in harsh environments.
- **Enhanced Hardness:** The anodized layer is harder than the natural oxide, offering additional wear and scratch resistance.
- **Decorative Finishes:** By controlling the voltage and electrolyte, various colors and finishes can be achieved on the anodized aluminium, providing an aesthetic appeal.
- **Environmentally Friendly:** Anodizing uses water-based solutions and emits fewer harmful fumes compared to some other metal finishing processes.

Important Note:

- The specific type of anodizing process and electrolyte chosen depend on the desired properties and application of the aluminium component.
- While anodizing significantly improves corrosion resistance, it may not be sufficient for highly corrosive environments or require additional protective measures.

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:

1. Improper resin mixing: Incorrect resin-to-hardener ratio can lead to incomplete curing, weakening the bond between layers.
2. Insufficient resin application: Not enough resin between layers can create air pockets and weak bonds.
3. Contamination: Dirt, grease, or moisture trapped between layers can prevent proper adhesion.
4. Uneven pressure during layup: Inconsistent pressure can lead to voids and weak areas.
5. Excessive sanding: Removing too much material can thin layers and reduce overall strength.

(ii) Osmotic Blisters:

1. Water permeation: Diffusion of water molecules through the GRP laminate.
2. Presence of salts: Dissolved salts in the water attract more water, creating osmotic pressure.
3. Imperfect laminate: Micro-cracks, voids, or poor adhesion points allow water ingress.
4. Lack of protective barrier: Inadequate gelcoat or anti-osmosis coating allows water contact.
5. Temperature cycling: Expansion and contraction due to temperature changes can stress the laminate, exacerbating existing weaknesses.

(iii) Stress Cracking:

1. Mechanical overload: Excessive loads exceeding the design limits of the hull.
2. Impact damage: Punctures, dents, or other forceful impacts can initiate cracks.
3. Poor design: Stress concentrations due to sharp corners, inadequate reinforcement, or improper load distribution.
4. Fatigue: Repeated loading and unloading cycles can weaken the material and lead to crack propagation.
5. Environmental factors: UV exposure, chemical attack, or temperature extremes can degrade the mechanical properties of GRP.

(b) Osmotic Blister Location:

Osmotic blisters most commonly occur on the underwater sections of the hull exposed to prolonged water contact. This includes the keel, bilge areas, garboards, and lower portions of the transom. These areas experience constant immersion and higher salt concentrations, making them more susceptible to water permeation and osmotic pressure buildup.

8. With reference to the flowrate measuring device shown in the figure, describe the principle of operation, explaining how an analogue remote reading may be obtained. (10)

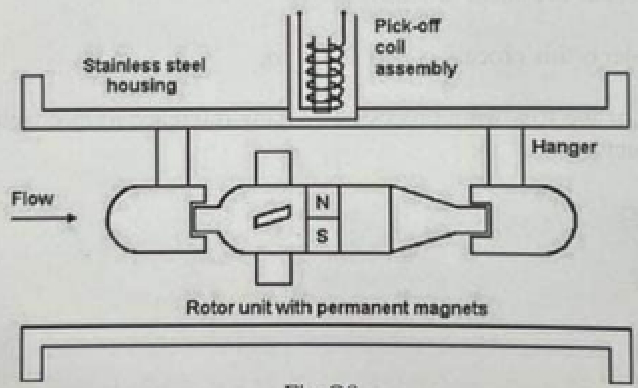


Fig Q8

9. With reference to *Discontinuous* or *On Off* control systems:

(a) sketch the response of a basic heater control, showing temperature against time and labelling the key points; (4)

(b) state THREE methods of improving the accuracy/speed of response. (6)

a) Response Sketch:

Here's the response sketch of a basic heater control showing temperature against time:

```
  |         / / / \ \      |
  |      /\/\/\/\/\        |
  |    /\/\/\/\/\/\/\      |
  |  /\/\/\/\/\/\/\/\      |
--|--------------------|--
  |___/ \___/ \___/ \___|
    Setpoint    Time
```

Key Points:

- Horizontal line: Desired temperature (setpoint).

- Sawtooth waveform: Actual temperature fluctuates around the setpoint.

- Peaks: Heater turns on, increasing temperature rapidly.

- Valleys: Heater turns off, temperature drops until the setpoint is reached and the cycle repeats.

- Hysteresis: Dead zone around the setpoint where the heater remains off (below) or on (above).

(b) Improving Accuracy/Speed of Response:

1. Proportional Band Reduction: Decrease the hysteresis band to reduce the temperature swing and improve accuracy. However, too small a band can lead to frequent switching and increased wear on the heater.
2. Rate Limiting: Limit the rate of temperature change by delaying heater activation or deactivation based on the rate of previous changes. This prevents large overshoots and improves stability.
3. Pulse Width Modulation (PWM): Instead of full on/off cycles, rapidly switch the heater on and off at a high frequency. By varying the "on" time per cycle (duty cycle), the average power delivered can be controlled, providing more precise temperature control compared to simple on/off cycles.
4. Feedback Controller: Introduce a simple feedback loop with a sensor measuring the actual temperature. The controller compares it to the setpoint and adjusts the heater state (on/off) based on the difference, aiming for a more continuous and accurate response.

Remember, each method has its advantages and limitations. Choosing the best approach depends on specific requirements for accuracy, speed, complexity, and cost.

10. With reference to a main engine lubricating oil system, explain, with the aid of a sketch, the principle of a *closed loop* temperature control system. (10)

Here's an explanation of a closed loop temperature control system for a main engine lubricating oil system, along with a sketch:

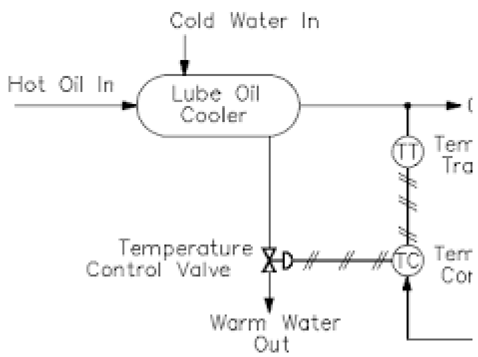
Components:

- **Lubricating Oil Pump:** Circulates oil throughout the engine for lubrication and cooling.
- **Oil Cooler:** Transfers heat from the oil to a cooling medium (usually water or seawater).
- **Temperature Sensor:** Measures the oil temperature at the outlet of the engine or cooler.
- **Temperature Controller:** Analyzes the sensor data and compares it to the desired oil temperature (setpoint).
- **Control Valve:** Regulates the flow of cooling medium through the oil cooler based on the temperature controller's output.
- **Bypass Valve:** Allows oil to bypass the cooler if the measured temperature is below the setpoint.

Principle:

1. The lubricating oil pump circulates oil through the engine, absorbing heat due to friction and combustion.
2. The hot oil flows through the oil cooler, where the heat is transferred to the cooling medium through the tubes.
3. The temperature sensor measures the oil temperature at the outlet of the engine or cooler.
4. The temperature controller receives the sensor data and compares it to the setpoint.
5. If the measured temperature is higher than the setpoint, the controller sends a signal to the control valve.
6. The control valve opens, increasing the flow of cooling medium through the oil cooler, which removes more heat from the oil.
7. As the oil cools down, the sensor detects the decrease in temperature, and the controller adjusts the control valve accordingly.
8. If the measured temperature is below the setpoint, the controller opens the bypass valve, allowing some oil to bypass the cooler and maintain the desired temperature.

Sketch:



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closed loop temperature control system for main engine lubricating oil

Advantages:

- Maintains a consistent oil temperature, which is crucial for optimal engine performance and wear reduction.
- Prevents overheating, which can damage engine components and lead to breakdowns.
- Improves engine efficiency by regulating oil temperature within the optimal range.

Additional Notes:

- The specific design and components of the system may vary depending on the engine size and operating conditions.
- Alarms and safety features are typically incorporated to detect and respond to malfunctions or unexpected temperature changes.
- Regular maintenance of the system, including cleaning the oil cooler and checking sensor accuracy, is crucial for optimal performance.