1. With reference to ship's side valves:

   (a) state why grey cast iron is not a suitable material; (4)

   (b) state, with reasons, THREE suitable materials. (6)

2. (a) Explain how the properties of steel are modified by its carbon content. (2)

   (b) Explain EACH of the following terms:

      (i) annealing; (3)

      (ii) normalising; (3)

      (iii) hardening. (2)

3. Explain EACH of the following terms:

   (a) ductile cast iron; (2)

   (b) tensile stress; (2)

   (c) work hardening; (2)

   (d) shear stress; (2)

   (e) Young's modulus. (2)

4. With reference to gas metal arc welding (MIG) of mild steel:

   (a) describe the process; (3)

   (b) explain, with reasons, the surface preparation required; (3)

   (c) list THREE advantages and ONE limitation. (4)

5. (a) With reference to fretting corrosion:

(i) explain the process; (3)

(ii) state a common cause; (1)

(iii) state how it is normally detected. (1)

(b) With reference to pitting corrosion:

(i) explain the term *pitting corrosion*; (1)

(ii) state TWO common causes; (2)

(iii) explain why it is considered to be dangerous. (2)

6. With reference to the production of glass reinforced plastic (GRP) hulls:

(a) describe the process of resin infusion moulding for the production of a hull; (4)

(b) state the advantages of resin infusion moulding with respect to traditional methods of construction; (3)

(c) explain how this process can virtually eliminate the onset of osmosis in the hull. (3)

7. With reference to capacitance probe sensors:

(a) describe, with the aid of a sketch, how a capacitance probe produces an output which can be used to measure the liquid level in a tank. (7)

(b) state TWO different uses of this device on a vessel; (2)

(c) state ONE disadvantage of this type of probe. (1)

8. With reference to an impeller type flowmeter, describe how an output is produced and processed to provide EACH of the following:

(a) an analogue output in litres per minute; (5)

(b) a digital output in litres per minute. (5)

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. (a) Describe, with the aid of a control block diagram, how a governor maintains the speed of a diesel engine driving a generator. (6)

(b) Describe the reasons for Integrating the error signal and the effect it has on the governor fuel rack. (4)

Nov 2023

1. With reference to ship's side valves:

(a) state why grey cast iron is not a suitable material; (4)

(b) state, with reasons, THREE suitable materials. (6)

a) Why grey cast iron is not a suitable material for ship's side valves.

Grey cast iron is not a suitable material for ship's side valves for several reasons:

- Brittle: Grey cast iron is brittle, which means it is more likely to crack or break under stress than other materials. This is a major concern for ship's side valves, which are subjected to high stresses from waves and currents.
- Poor corrosion resistance: Grey cast iron is not very resistant to corrosion, especially in seawater. This means that it is likely to rust and deteriorate over time, which could lead to leaks and failures.
- Weak in tension: Grey cast iron is weak in tension, which means that it is not able to withstand pulling forces very well. This is important for ship's side valves, which need to be able to withstand the pulling forces of the piping system.

(b) Three suitable materials for ship's side valves, with reasons:

There are a number of materials that are suitable for ship's side valves, but three of the most common are:

- Ductile iron: Ductile iron is a type of cast iron that has been treated with magnesium or cerium to make it more ductile and less brittle than grey cast iron. This makes it a much more suitable material for ship's side valves.
- Bronze: Bronze is an alloy of copper and tin, or copper and aluminum, that is strong, corrosion-resistant, and ductile. This makes it an excellent choice for ship's side valves, especially in applications where seawater is present.
- Stainless steel: Stainless steel is a steel alloy that is resistant to corrosion and has good mechanical properties. It is a more expensive option than ductile iron or bronze, but it can be a good choice for ship's side valves that need to be particularly strong and durable.

Nov 2023

2. (a) Explain how the properties of steel are modified by its carbon content. (2)

(b) Explain EACH of the following terms:

(i) annealing; (3)

(ii) normalising; (3)

(iii) hardening. (2)

(a) Steel Properties and Carbon Content:

The carbon content in steel significantly influences its properties in several ways:

- Strength and Hardness: As the carbon content increases, the strength and hardness of steel also increase. This is because carbon atoms form strong bonds with iron atoms, hindering dislocation movement and making the material more resistant to deformation.
- Ductility and Malleability: Conversely, higher carbon content reduces the ductility and malleability of steel. The tangled crystal structure caused by carbon atoms makes it more difficult to bend or shape the material without cracking.
- Weldability: High-carbon steel becomes less weldable due to increased susceptibility to cracking around the weld zone. Careful control of heat and filler materials is necessary during welding.
- Machinability: Low-carbon steel is easier to machine due to its softer nature. As carbon content increases, machining becomes more challenging and requires specialized tools.
- Corrosion Resistance: Generally, higher carbon content reduces the corrosion resistance of steel. However, certain high-chromium stainless steels with moderate carbon content offer excellent corrosion resistance.

Therefore, the optimal carbon content for steel depends on the desired properties for a specific application. A balance between strength, ductility, weldability, and other characteristics is often sought based on the intended use.

(b) Explaining Heat Treatment Terms:

(i) Annealing:

Annealing is a heat treatment process that softens a work-hardened or quenched steel by relieving internal stresses and promoting grain growth. This increases ductility and malleability while reducing strength and hardness. It typically involves heating the steel to a specific temperature above its recrystallization temperature and then slowly cooling it. Annealing is used to improve formability, relieve welding stresses, and prepare steel for further processing.

(ii) Normalising:

Normalizing is a heat treatment process similar to annealing but involves heating the steel to a higher temperature (above its critical temperature) and then cooling it in air. This refines the grain structure, resulting in a balance between strength and ductility compared to annealing. Normalizing is often used for forging and casting processes to improve mechanical properties and machinability.

(iii) Hardening:

Hardening is a heat treatment process that involves austenitizing (heating above the critical temperature) a steel followed by rapid quenching (cooling). This rapid cooling traps carbon atoms in the austenitic lattice structure, forming a metastable phase called martensite. Martensite is very hard and brittle, significantly increasing the steel's strength and hardness. However, it also becomes more brittle and susceptible to cracking. Hardening is often followed by tempering to improve toughness and reduce internal stresses without significantly sacrificing strength.

Nov 2023

3. Explain EACH of the following terms:

(a) ductile cast iron; (2)

(b) tensile stress; (2)

(c) work hardening; (2)

(d) shear stress; (2)

(e) Young's modulus. (2)

(a) Ductile Cast Iron:

Ductile cast iron is a type of cast iron with improved ductility and toughness compared to traditional cast iron. This is achieved by adding a small amount of magnesium or cerium during the manufacturing process, which changes the graphite microstructure from flakes to spheroids. This results in a material that can deform considerably before breaking, unlike the brittle nature of traditional cast iron. Ductile cast iron is used in various applications like pipes, automotive components, and machine parts requiring strength and some flexibility.

(b) Tensile Stress:

Tensile stress is a pulling force acting on a material, trying to elongate it in the direction of the force. Imagine pulling a rope: the rope experiences tensile stress, stretching as you pull harder. It is one of the basic types of stress encountered in materials, alongside compressive stress (pushing) and shear stress (distortion).

(c) Work Hardening:

Work hardening, also known as strain hardening, is a phenomenon where a material's strength and hardness increase as it undergoes plastic deformation (permanent shape change) due to external forces. Imagine repeatedly bending a metal wire: it becomes progressively harder to bend further as the work hardens. This property is utilized in metalworking processes like cold forging and wire drawing.

(d) Shear Stress:

Shear stress is a force that acts to slide or distort one part of a material relative to another along a parallel plane. Picture pushing two bricks against each other: they experience shear stress at the contact point, potentially causing them to slide and deform. It is another fundamental type of stress alongside tensile and compressive stress, and it plays a crucial role in phenomena like friction and material failure.

(e) Young's Modulus:

Young's modulus, also known as the elastic modulus, measures the stiffness of a material within its elastic range (where deformation is temporary). It quantifies the relationship between stress and strain within this region. A higher Young's modulus indicates a stiffer material that requires more force to deform a given amount. Think of a steel beam compared to a rubber band: the steel has a much higher Young's modulus, making it much stiffer.

Nov 2023

4. With reference to gas metal arc welding (MIG) of mild steel:

(a) describe the process; (3)

(b) explain, with reasons, the surface preparation required; (3)

(c) list THREE advantages and ONE limitation. (4)

(a) TIG Welding Process:

Tungsten Inert Gas (TIG) welding, also known as GTAW (Gas Tungsten Arc Welding), is a meticulously controlled arc welding process that uses a non-consumable tungsten electrode and an inert shielding gas. Here's how it works:

1. Preparation: Clean the weld area thoroughly to remove any contaminants that could compromise the weld quality.
2. Setup: Choose the appropriate tungsten electrode and shielding gas (e.g., argon) based on the material being welded. Set the welding current and flow rate.
3. Initiation: Create an arc between the tungsten electrode and the workpiece using a high-frequency start or by touching the tip momentarily and retracting.
4. Welding: Hold the torch at the desired angle and distance from the joint. Add filler metal (a separate rod or wire) manually to the molten pool created by the arc, building the weld bead layer by layer.
5. Travel Speed: Move the torch along the joint seam at a controlled pace, maintaining the arc and adding filler metal as needed.

6. Finishing: Allow the weld to cool completely, then remove any slag (residue) with a wire brush or other cleaning tools.

TIG welding offers exceptional control and precision because the filler metal is not continuously fed, allowing the welder to manipulate the molten pool directly.

(b) AC Current for Aluminum:

When welding aluminum, AC current is often preferred over DC current for several reasons:

- Penetration: The alternating polarity of AC creates a cleaning action during the positive cycle, breaking up the tenacious oxide layer (aluminum oxide) that forms on the surface. This allows for deeper weld penetration compared to DC.
- Cathode Cleaning: During the negative cycle, the aluminum melts and cleans the tungsten electrode, preventing contamination and maintaining a stable arc.
- Weld Quality: The combined cleaning and penetration effects of AC lead to cleaner welds with reduced porosity and improved visual appearance.

Though DC can be used for specific aluminum applications, AC generally offers better overall performance and ease of welding.

(c) Advantages of TIG Welding:

TIG welding offers several advantages over other welding methods, particularly for critical applications or materials like aluminum:

- High Precision and Control: The ability to manually add filler metal and control the arc allows for precise weld profiles and minimal distortion.
- Excellent Weld Quality: TIG produces strong, clean welds with minimal spatter and high weld integrity due to the shielding gas and controlled conditions.
- Versatility: Works with a wide range of materials, including thin sheets, delicate parts, and even dissimilar metals.
- Minimal Heat Input: Less heat-affected zone minimizes warping and distortion, particularly beneficial for thin materials.

However, TIG welding requires more skill and practice compared to other methods, and its slower deposition rate might not be suitable for high-production applications.

In conclusion, TIG welding stands out for its precision, control, and excellent weld quality, making it a preferred choice for critical applications, aluminum welding, and scenarios where meticulous technique is paramount.

Nov 2023

5. (a) With reference to fretting corrosion:

(i) explain the process; (3)

(ii) state a common cause; (1)

(iii) state how it is normally detected. (1)

(b) With reference to pitting corrosion:

(i) explain the term *pitting corrosion*; (1)

(ii) state TWO common causes; (2)

(iii) explain why it is considered to be dangerous. (2)

(a) Fretting Corrosion:

(i) The Process: Imagine two surfaces in tight contact, experiencing slight, relative movement due to vibration or thermal expansion. The microscopic rubbing and slipping create wear particles, which further abrade the surfaces. This combined mechanical wear and oxidation generates a reddish-brown powder and localized pitting, known as fretting corrosion.

(ii) Common Cause: Vibration is a common culprit, particularly in components like bearings, gears, and bolted connections. Even seemingly insignificant vibrations can trigger fretting over time, especially when compounded by high pressure or poor lubrication.

(iii) Detection: Visual inspection can reveal reddish-brown powder or discoloration at contact points. However, early detection often requires non-destructive testing methods like ultrasonic testing or eddy current testing, which can detect subsurface damage before it becomes visible.

(b) Pitting Corrosion:

(i) Explanation: Pitting corrosion isn't a uniform attack on the metal surface, but rather the formation of isolated, deep cavities called pits. These pits can penetrate deep into the material, often invisible to the naked eye until significant damage has occurred.

(ii) Common Causes: Pitting can be caused by several factors, including:

- Chloride Ions: These are particularly aggressive towards many metals, particularly stainless steel, and can initiate pitting by breaking down the protective passive layer. Seawater and environments with high salt content are prime culprits.
- Acidic or Alkaline Environments: Extreme pH levels can disrupt the passive layer and make metals more susceptible to pitting corrosion. This can occur in industrial environments with chemical spills or even in rainwater with acidic pollutants.

(iii) Danger of Pitting Corrosion: Pitting's insidious nature lies in its localized attack. The deep, narrow pits can significantly weaken the material, even if the overall surface area affected is small. This can lead to sudden and catastrophic failures, especially in components under high stress, like pressure vessels or aircraft structures.

Understanding the mechanisms and detection methods for both fretting and pitting corrosion is crucial for ensuring the structural integrity and safety of components in various applications. Implementing strategies like vibration dampening, lubrication, protective coatings, and regular inspection can significantly mitigate these forms of corrosion and extend the lifespan of your materials.

6. With reference to the production of glass reinforced plastic (GRP) hulls:

(a) describe the process of resin infusion moulding for the production of a hull; (4)

(b) state the advantages of resin infusion moulding with respect to traditional methods of construction; (3)

(c) explain how this process can virtually eliminate the onset of osmosis in the hull. (3)

Nov 2023

- Preparation: The first step is to prepare the mold. This typically involves cleaning and waxing the mold to ensure a smooth finish.
- Layup: The dry glass fiber reinforcements are then placed in the mold. These reinforcements can be in the form of mats, woven fabrics, or unidirectional tapes.
- Resin infusion: The resin is then infused into the dry glass fibers. This can be done by gravity, but it is more common to use a vacuum to draw the resin through the fibers.
- Curing: Once the resin is infused, the mold is sealed and the resin is allowed to cure. This is typically done at an elevated temperature.
- Finishing: Once the resin is cured, the part can be removed from the mold and any finishing work can be done. This may include sanding, painting, or adding hardware.

Resin infusion molding has several advantages over traditional methods of GRP hull construction, such as hand layup and spray-up. These advantages include:

- Higher fiber-to-resin ratio: Resin infusion molding typically results in a higher fiber-to-resin ratio than other methods. This means that the hulls are stronger and lighter.
- Reduced void content: Resin infusion molding also reduces the void content in the laminate. Voids are air pockets that can weaken the laminate and make it more susceptible to water absorption.
- Improved surface finish: Resin infusion molding typically produces a better surface finish than other methods. This is because the resin is evenly distributed throughout the laminate.
- Reduced emissions: Resin infusion molding is a closed-mold process, which means that there are fewer emissions of Volatile Organic Compounds (VOCs) into the atmosphere.

Resin infusion molding can also virtually eliminate the onset of osmosis in the hull. Osmosis is a process that can cause blisters to form on the surface of the hull. It is caused by the diffusion of water through the hull and into the laminate. Resin infusion molding creates a denser laminate with fewer voids, which makes it less susceptible to osmosis.

Overall, resin infusion molding is a versatile and efficient process for producing high-quality GRP hulls. It is a good choice for boat builders who are looking for strong, lightweight, and durable hulls.

7. With reference to capacitance probe sensors:

(a) describe, with the aid of a sketch, how a capacitance probe produces an output which can be used to measure the liquid level in a tank. (7)

(b) state TWO different uses of this device on a vessel; (2)

(c) state ONE disadvantage of this type of probe. (1)

Nov 2023

Demystifying Capacitance Probes: Sensing the Secrets of Your Vessel's Tanks

(a) Capacitance Probe Operation and Sketch:

Imagine a tank filled with liquid, and within it, a slender probe like a metal rod inserted. This is the essence of a capacitance probe sensor, and here's how it works:

Sketch:

- Electrodes: The probe itself acts as one electrode, and the tank wall or another immersed conductor serves as the other.
- Dielectric Constant: The space between the electrodes is filled with the liquid, which acts as a dielectric material with a specific dielectric constant (epsilon). This constant influences the capacitance formed between the electrodes.

- Capacitance Change: As the liquid level rises or falls in the tank, the volume of the dielectric (liquid) changes. This, in turn, affects the overall capacitance between the electrodes.
- Measuring the Change: An external device connected to the probe measures this change in capacitance.
- Level Conversion: Using pre-programmed equations and calibration data, the device converts the capacitance value into a corresponding liquid level reading.

Key Points:

- The dielectric constant of the liquid significantly impacts the sensor's sensitivity.
- Capacitance probes are contactless, offering non-invasive level measurement.

(b) Applications on a Vessel:

These versatile sensors find multiple uses on board:

1. Fuel Tank Monitoring: Accurately tracking fuel levels in tanks is crucial for fuel management and voyage planning. Capacitance probes provide reliable and continuous level readings, ensuring optimal fuel utilization.
2. Bilge Water Management: Monitoring bilge water levels is essential for ensuring the vessel's seaworthiness and preventing flooding. Capacitance probes offer accurate level data, triggering alarms or pump activation in case of excessive accumulation.

(c) Disadvantage:

One potential drawback of capacitance probes is their susceptibility to changes in the dielectric constant of the liquid. Materials like oil or seawater with varying conductivities or contaminants can affect the capacitance readings and require careful calibration or compensation techniques for accurate performance.

Remember, capacitance probes offer a valuable tool for liquid level measurement on vessels, but understanding their operating principles and potential limitations is crucial for their effective implementation. Choosing the right probe type and considering the liquid properties are essential for reliable and accurate level monitoring.

Nov 2023

8. With reference to an impeller type flowmeter, describe how an output is produced and processed to provide EACH of the following:

(a) an analogue output in litres per minute; (5)

(b) a digital output in litres per minute. (5)

Impeller Flowmeter Output Generation:

(a) Analogue Output (Litres per Minute):

1. Impeller Rotation: As fluid flows through the meter, the impeller rotates at a speed proportional to the flow rate. The impeller blades are designed to minimize drag and ensure consistent rotation with flow changes.
2. Magnetic Coupling: The impeller shaft is coupled to a magnet inside the meter housing. This magnet rotates with the impeller, creating a changing magnetic field around it.
3. Pick-up Coil: A stationary pick-up coil positioned near the rotating magnet senses the changing magnetic field. This induces a voltage signal in the coil whose frequency is directly proportional to the impeller rotation speed (and hence, the flow rate).
4. Signal Conditioning: The induced voltage signal from the pick-up coil is typically weak and noisy. Electronic circuitry amplifies and filters the signal to remove noise and ensure a clean, reliable representation of the flow rate.
5. Scaling and Calibration: The conditioned signal is then scaled and calibrated based on the meter's specific characteristics. This converts the signal voltage into an analogue voltage proportional to the flow rate in litres per minute (LPM). The scaling factor is determined during the meter's calibration process using known flow rates.
6. Analogue Output: The resulting voltage signal, representing the flow rate in LPM, is available as the analogue output of the flowmeter. This can be directly connected to an analogue-to-digital converter (ADC) for further processing or used directly in analogue control systems.

(b) Digital Output (Litres per Minute):

1. Signal Conditioning: Similar to the analogue output, the induced voltage signal from the pick-up coil is amplified and filtered.
2. Frequency-to-Digital Conversion: Instead of scaling the signal directly, a frequency-to-digital converter (FDC) is used. This chip measures the frequency of the signal, which is directly proportional to the impeller rotation speed and flow rate.
3. Microprocessor and Calculations: The FDC's digital output (representing frequency) is fed into a microprocessor within the flowmeter. The microprocessor uses the meter's calibration data and internal algorithms to convert the frequency data into a flow rate value in litres per minute (LPM).
4. Digital Output: The calculated flow rate in LPM is available as the digital output of the flowmeter. This can be displayed on the meter itself, transmitted through serial communication protocols, or used for digital control systems.

In both cases, the impeller rotation serves as the basis for flow measurement. However, the processing and interpretation of the signal differ, resulting in either an analogue voltage or a digital flow rate value as the output.

Nov 2023

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.

Nov 2023

10. (a) Describe, with the aid of a control block diagram, how a governor maintains the speed of a diesel engine driving a generator. (6)

(b) Describe the reasons for Integrating the error signal and the effect it has on the governor fuel rack. (4)

(a) Control Block Diagram:

The following control block diagram illustrates the essential components of a governor maintaining engine speed:

```
+-----------------+  +-------------------+  +-----------------+  +-------------------+
|  Speed Sensor   |  |   Speed Droop     |  |   Integral      |  |  Fuel Actuator    |
|                 |  | (Proportional)    |  | (Reset)         |  |                   |
| (Measures RPM)  |  |-----------------+  |-----------------+  |                   |
+-----------------+  |                 |                     | +-----------------+
                     |                 |
                     |   Error         |
                     +-----------------+
                             |
                     +-----------------+
                     |                 |
                     |Governor Setpoint|
                     | (Desired RPM)   |
                     +-----------------+
```

```
Output: Fuel Rack Position
```

(b) Integrating the Error Signal and its Effect:

1. Purpose of Integration: The integral action in the governor accumulates the error between the measured engine speed (from the sensor) and the desired setpoint (governor setting) over time. This helps eliminate steady-state errors, even if the proportional action alone cannot fully correct them.
2. Effect on Fuel Rack: The integrator's output adds an additional adjustment to the fuel rack position based on the accumulated error history.
    - Positive Error (Engine Speed Lower than Setpoint): The positive accumulated error triggers an increase in fuel delivery (fuel rack moves towards open position). This increases engine speed, reducing the error over time.
    - Negative Error (Engine Speed Higher than Setpoint): The negative accumulated error leads to a decrease in fuel delivery (fuel rack moves towards closed position). This slows down the engine, bringing the speed closer to the setpoint.
3. Benefits of Integration:
    - Improved Steady-State Accuracy: Eliminates errors that might persist with only proportional control, ensuring the engine speed settles exactly at the desired setpoint.
    - Reduced Hunting: Helps dampen oscillations around the setpoint, promoting smoother speed regulation.
4. Challenges of Integration:
    - Slow Response: The integrator acts slowly, taking time to accumulate the error. This can be a drawback for quick load changes requiring faster adjustments.
    - Overcorrection: Excessive integral gain can lead to overshooting the setpoint and cause instability if not tuned properly.