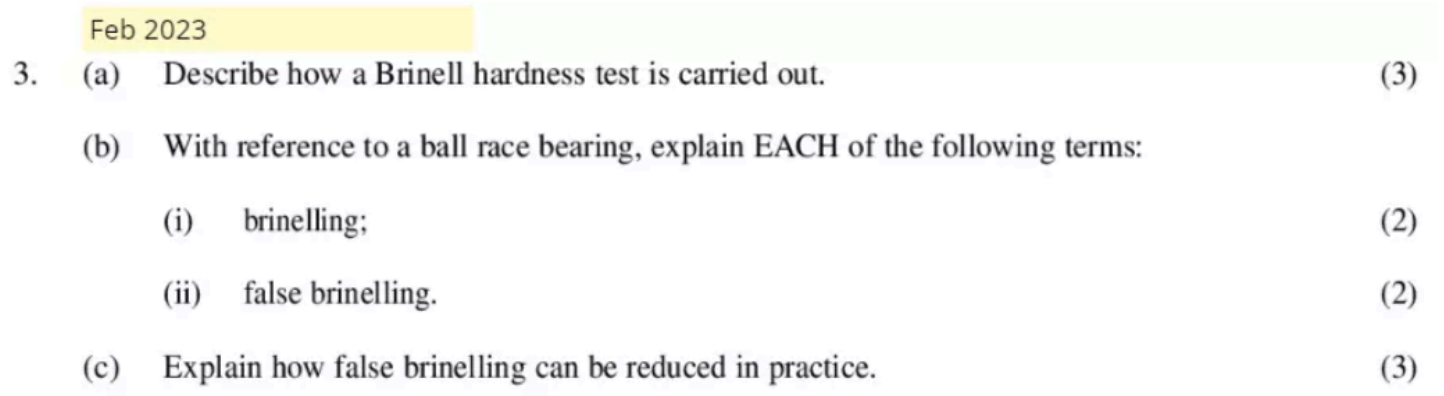
Fatigue and failure



Feb 2023

3. (a) Describe how a Brinell hardness test is carried out. (3)

(b) With reference to a ball race bearing, explain EACH of the following terms:

(i) brinelling; (2)

(ii) false brinelling. (2)

(c) Explain how false brinelling can be reduced in practice. (3)

(a) Brinell Hardness Test: https://www.youtube.com/watch?v=RJXJpeH78iU

The Brinell hardness test determines the indentation hardness of a material by measuring the permanent impression left by a hardened steel ball pressed into its surface. Here's how it's carried out:

1. Preparation: The test surface is prepared by polishing and cleaning to ensure accurate testing.
2. Test Equipment: A Brinell hardness tester consists of a press capable of applying a specific load, a hardened steel ball (typically 10mm diameter), and a measuring microscope.
3. Load Application: The chosen load (based on material and test standard) is applied to the ball in contact with the test surface for a specific dwell time (typically 10-30 seconds).
4. Indentation Measurement: The diameter of the indentation left on the surface is measured using a microscope.
5. Hardness Calculation: Using the measured diameter, load, and ball diameter, the Brinell Hardness Number (HB) is calculated using a specific formula. Higher HB values indicate higher hardness.

(b) Ball Race Bearing Terms:

(i) Brinelling:

Brinelling is a type of permanent indentation damage on the raceway (tracks) of a ball bearing caused by excessive static or shock loads. These indentations resemble the size and shape of the rolling elements (balls) and can lead to:

- Increased noise and vibration: Uneven rolling due to indentations creates noise and vibration during bearing operation.
- Reduced load capacity: Indentations weaken the raceway, lowering the bearing's ability to handle loads without failure.
- Premature bearing failure: Repeated stress on the indented areas can lead to cracks and eventual bearing failure.

(ii) False Brinelling:

False brinelling, also known as fretting fatigue, is another type of surface damage that resembles brinelling but arises from different causes. It occurs due to:

- Microscopic vibrations: Slight movement or vibration between stationary rolling elements and the raceway creates wear and micro-cracks.
- Loss of lubrication: Inadequate lubrication allows direct metal-to-metal contact, accelerating wear and fatigue.
- Corrosive environments: Corrosive elements can break down lubricants and promote surface damage.

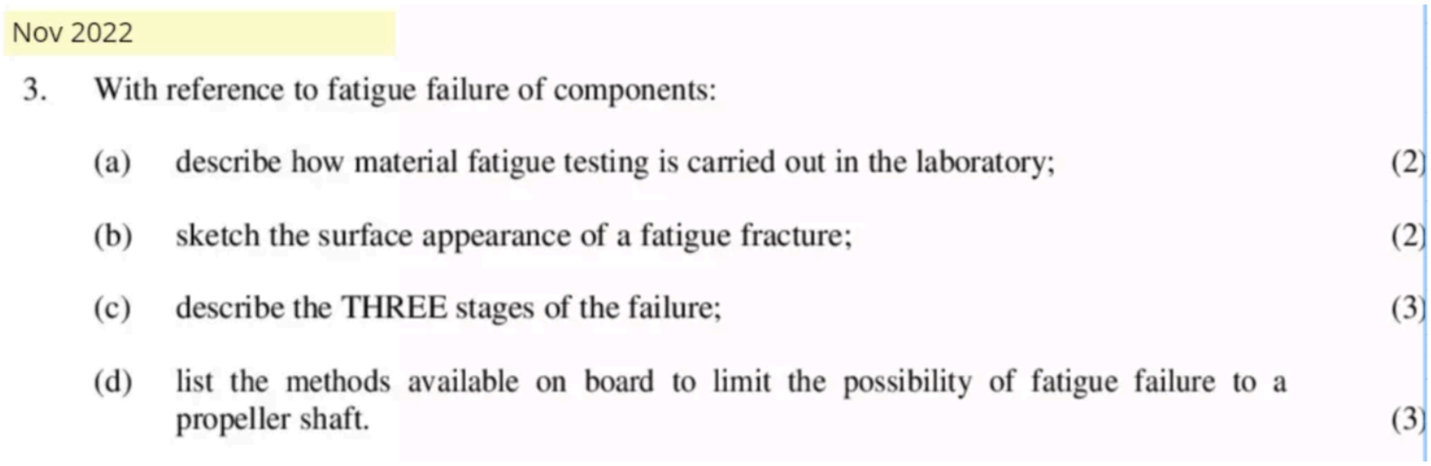
False brinelling appears as shallow, matte-textured lines or areas along the raceway and can also lead to noise, vibration, and reduced bearing lifespan.

(c) Reducing False Brinelling:

Several practices can reduce the risk of false brinelling in ball race bearings:

- Properly sized and selected bearings: Choosing bearings with adequate load capacity and appropriate materials for the expected loads and environment is crucial.
- Maintaining lubrication: Regular lubrication with the correct type and quantity of grease or oil minimizes metal-to-metal contact and protects against corrosion.
- Vibration control: Minimizing sources of vibration through proper component design, mounting, and alignment reduces stress on the bearing.
- Surface coating: Applying protective coatings to the raceway and rolling elements can enhance wear resistance and reduce micro-cracking.
- Monitoring and inspection: Regularly monitoring bearing noise, vibration, and temperature helps identify potential false brinelling before significant damage occurs, allowing for preventative maintenance.

By implementing these strategies, the risk of false brinelling can be effectively mitigated, ensuring optimal performance and lifespan for ball race bearings.



Nov 2022

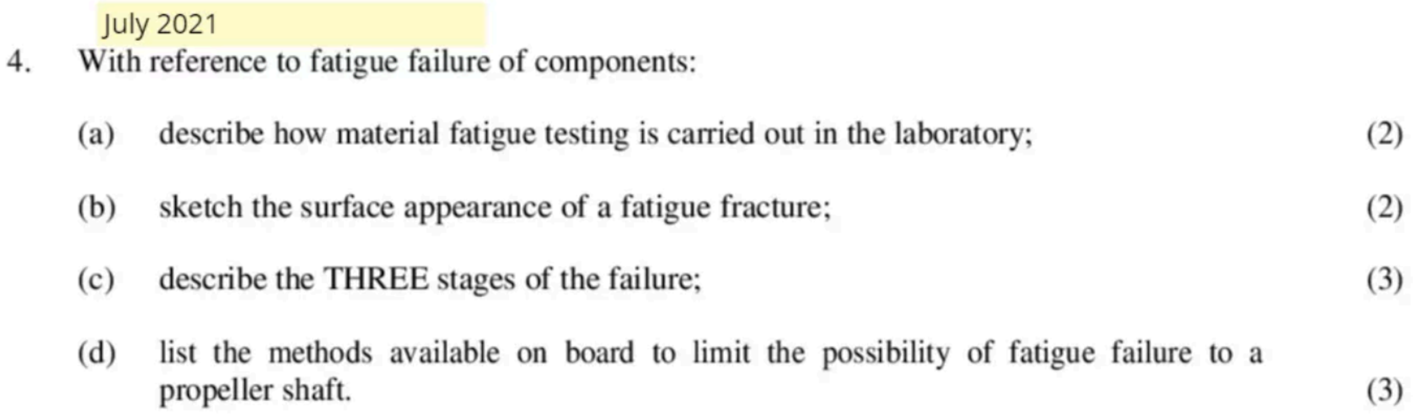
3. With reference to fatigue failure of components:

(a) describe how material fatigue testing is carried out in the laboratory; (2)

(b) sketch the surface appearance of a fatigue fracture; (2)

(c) describe the THREE stages of the failure; (3)

(d) list the methods available on board to limit the possibility of fatigue failure to a propeller shaft. (3)



July 2021

4. With reference to fatigue failure of components:

(a) describe how material fatigue testing is carried out in the laboratory; (2)

(b) sketch the surface appearance of a fatigue fracture; (2)

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(d) list the methods available on board to limit the possibility of fatigue failure to a propeller shaft. (3)

(a) Material Fatigue Testing in Lab:

https://www.youtube.com/watch?v=LhUclxBUV_E

Laboratory fatigue testing simulates real-world cyclic loading to assess a material's resistance to fatigue failure. Common methods include:

- Rotating Beam Test: A rotating cantilever beam experiences cyclic bending stresses as it spins. The number of cycles to failure at a specific stress level determines the fatigue strength.
- Axial Fatigue Test: A specimen is subjected to cyclic tension and compression loading to evaluate fatigue performance under these conditions.
- Push-Pull Test: A specimen is pulled in one direction and then pushed back in the opposite direction, mimicking cyclic axial stresses.
- Four-Point Bending Test: A specimen is supported at two points and loaded at two other points, creating a constant bending moment region to study fatigue behavior.

These tests measure fatigue life (number of cycles to failure) at various stress levels, generating S-N curves that map stress vs. number of cycles to failure. This data allows material selection, design optimization, and prediction of fatigue life in real applications.

(b) Sketch of Fatigue Fracture Surface:

https://www.youtube.com/watch?v=6y_PF0_Hr9k

A fatigue fracture exhibits distinct features:

- Initiation Site: Often a surface defect like a scratch, corrosion pit, or inclusion acts as the starting point for micro-cracks.
- Beach Marks: Concentric semicircular ridges around the initiation site represent progressive crack growth under each loading cycle.
- Final Fracture Zone: This area displays rougher fracture features due to rapid crack propagation leading to final failure.

Sketch: Imagine a circular area with concentric semi-circular ridges around a central point. The ridges become larger and closer as they move away from the center. The edge shows a rougher fractured area.

(c) Three Stages of Fatigue Failure:

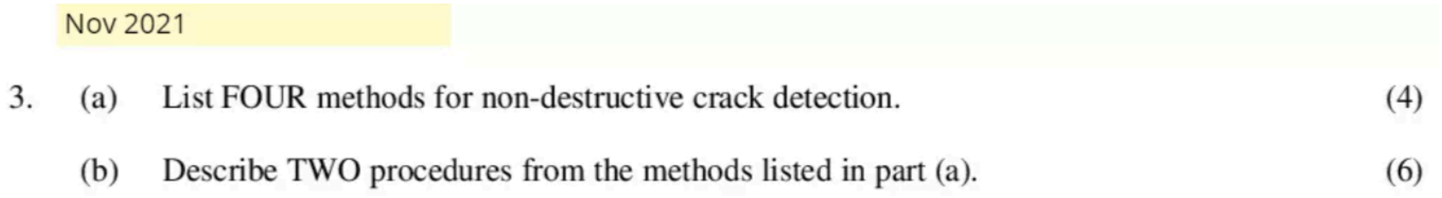
- Crack Initiation: Micro-cracks form and propagate at microscopic levels from stress concentrations at defects or inhomogeneities within the material.
- Crack Propagation: The micro-cracks gradually grow under repeated loading, creating beach marks on the fracture surface. The rate of crack growth depends on stress level, material properties, and environmental factors.
- Final Fracture: When the crack reaches a critical size, it can no longer withstand the applied stress and rapidly propagates across the remaining cross-section, leading to final failure.

(d) Mitigation Methods for Propeller Shaft Fatigue:

Onboard strategies to limit propeller shaft fatigue failure include:

- Preventative Maintenance: Regularly inspecting the shaft for surface defects, cracks, and corrosion allows for early detection and repairs, preventing further crack growth.
- Vibration Control: Minimizing vibrations through shaft balancing, alignment adjustments, and dampening devices reduces dynamic loading and stress concentrations.
- Propeller Maintenance: Ensuring proper propeller balance and blade pitch minimizes uneven loading on the shaft.
- Material Selection: Using fatigue-resistant materials can improve the shaft's overall fatigue life.
- Operational Monitoring: Monitoring stress levels, vibrations, and shaft RPM during operation allows for adjustments to operating conditions and early detection of potential fatigue concerns.

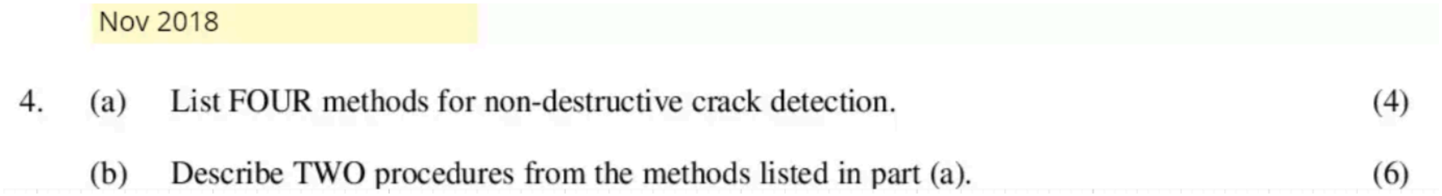
By implementing these mitigation strategies, the risk of fatigue failure in a propeller shaft can be significantly reduced, ensuring its continued reliable operation and preventing catastrophic consequences.



Nov 2021

3. (a) List FOUR methods for non-destructive crack detection. (4)

(b) Describe TWO procedures from the methods listed in part (a). (6)



Nov 2018

4. (a) List FOUR methods for non-destructive crack detection. (4)

(b) Describe TWO procedures from the methods listed in part (a). (6)

(a) Four Methods:

1. Visual Inspection: While seemingly simple, trained inspectors can often identify surface cracks and other defects under proper lighting and magnification. This method is quick and accessible but limited to surface flaws.
2. Dye Penetrant Testing (PT): A colored liquid is applied to the surface and allowed to seep into cracks. After wiping the surface, a developer draws the dye back out, highlighting crack locations. This is effective for surface and near-surface cracks but requires careful cleaning and interpretation.
3. Ultrasonic Testing (UT): High-frequency sound waves are transmitted through the material and reflected back. Cracks disrupt the wave path, generating signals detected by the receiver, indicating their presence and location. This works for internal and surface cracks but requires skilled operators and specialized equipment.
4. Eddy Current Testing (ET): Magnetic fields induced by a coil interact with the material, and cracks affect the resulting electrical currents. This method works best for surface and near-surface cracks in conductive materials like metals and can be automated for rapid inspection.

(b) Two Procedure Descriptions:

1. Ultrasonic Testing (UT):

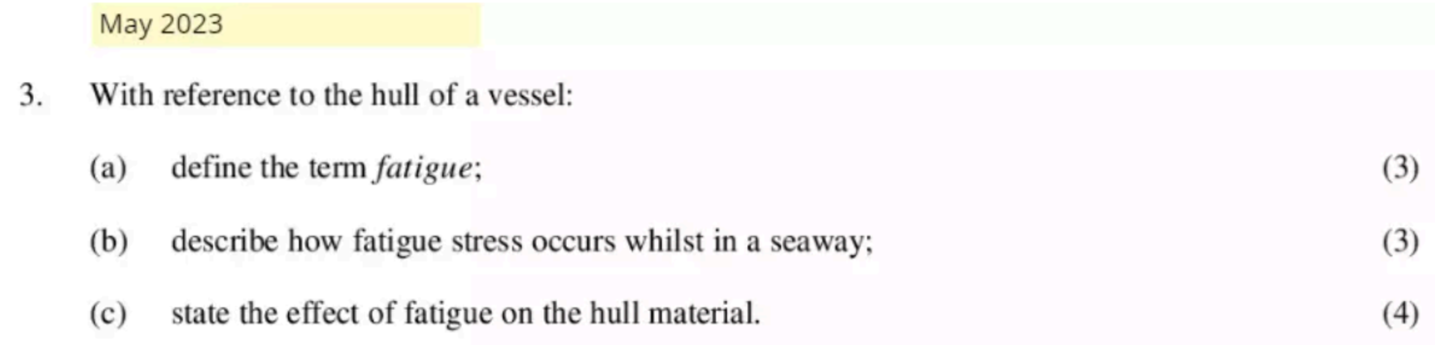
- Process: A transducer sends short bursts of ultrasound waves into the material at specific angles. These waves propagate and reflect back from interfaces within the material, including cracks. The received signals are analyzed to determine the time and intensity of reflections.
- Strengths: Can detect internal and surface cracks, pinpoint crack location and depth, and evaluate crack severity. Works on various materials, including metals, composites, and ceramics.
- Limitations: Requires skilled operators and specialized equipment, interpretation of signals can be complex, and access to both sides of the material may be needed.

2. Eddy Current Testing (ET):

- Process: A coil generates an alternating magnetic field that induces eddy currents in the material. Cracks disrupt the flow of these currents, causing changes in the electromagnetic field detected by the coil. These changes are analyzed to identify crack locations and characteristics.

- Strengths: Fast and automated, suitable for surface and near-surface crack detection in conductive materials, can be used for continuous monitoring during operation.
- Limitations: Only works on conductive materials, less effective for deep cracks, and requires careful calibration and interpretation of readings.

These are just two examples, and the choice of method depends on the specific material, crack type, application, and desired level of detail.



May 2023

3. With reference to the hull of a vessel:

(a) define the term *fatigue*; (3)

(b) describe how fatigue stress occurs whilst in a seaway; (3)

(c) state the effect of fatigue on the hull material. (4)

(a) Fatigue Definition:

In the context of a vessel hull, fatigue refers to a gradual weakening and eventual failure of the material due to repeated or cyclic stresses. These stresses are below the ultimate strength of the material but act over a prolonged period, causing damage to accumulate and micro-cracks to grow with each cycle. Eventually, the accumulated damage can lead to catastrophic failure even under relatively low loads.

(b) Fatigue Stress in Seaways:

Several factors contribute to fatigue stress in a vessel hull while navigating a seaway:

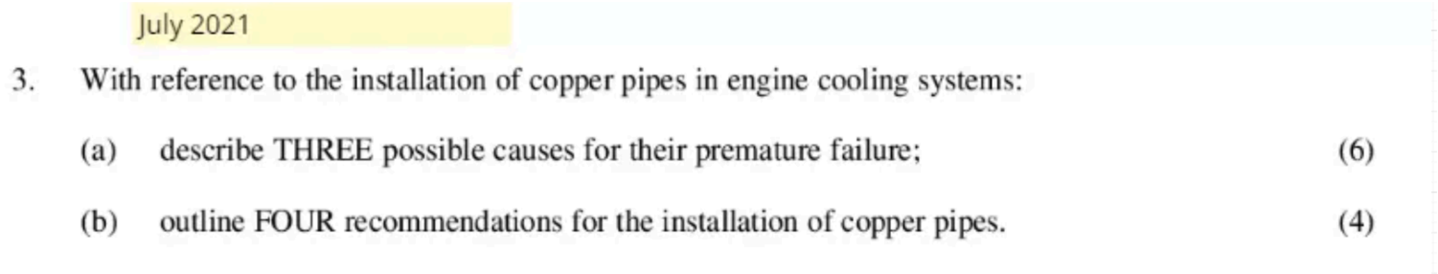
- Wave Loading: Waves create complex bending and twisting forces on the hull as it rises and falls with the water. These forces change direction and magnitude constantly, generating cyclic stresses.
- Vibrations: Engine vibrations, propeller forces, and other dynamic factors can induce additional cyclic stresses throughout the hull, further contributing to fatigue.
- Cargo Distribution: Uneven cargo distribution or shifting loads within the vessel can create localized stress concentrations and exacerbate fatigue in specific areas.
- Environmental Factors: Corrosion and erosion from seawater, as well as temperature and humidity fluctuations, can weaken the material and exacerbate the effects of fatigue stresses.

(c) Effects of Fatigue on Hull Material:

The accumulated damage from fatigue stress manifests in various ways on the hull material:

- Micro-crack Formation and Growth: Repeated stresses cause microscopic cracks to develop at weak points like weld seams, rivet holes, or areas with material imperfections. These cracks gradually grow with each cycle, reducing the overall strength and integrity of the hull.
- Loss of Material: As cracks propagate, small pieces of material can break off, leading to surface pitting, thinning of the hull plate, and eventual loss of structural integrity.
- Reduced Stiffness and Elasticity: The accumulation of micro-cracks and damage disrupts the material's ability to flex and absorb stress, making the hull less resilient and more susceptible to further damage or failure.
- Increased Stress Concentrations: Cracks and material loss create focal points where stress concentrates even more, accelerating further crack growth and potentially leading to sudden failure.

The effects of fatigue on the hull can be insidious, often progressing slowly until reaching a critical point. Regular inspections, monitoring for signs of damage, and employing strategies to mitigate fatigue stress are crucial for maintaining the structural integrity and safety of a vessel.

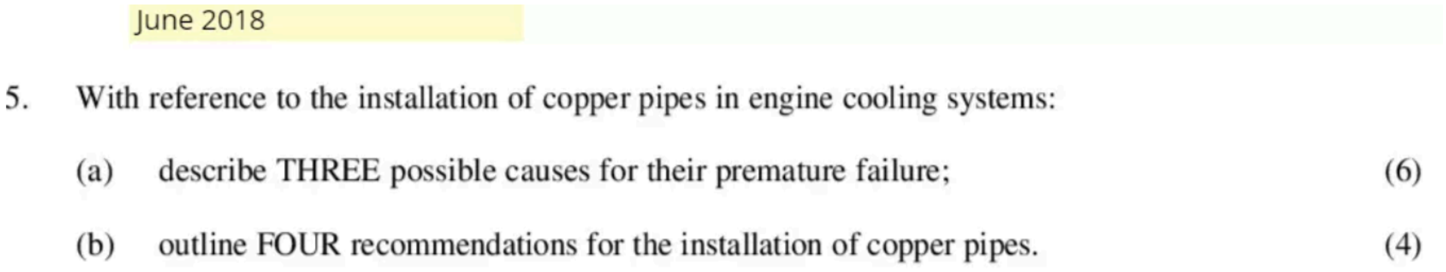


July 2021

3. With reference to the installation of copper pipes in engine cooling systems:

(a) describe THREE possible causes for their premature failure; (6)

(b) outline FOUR recommendations for the installation of copper pipes. (4)



June 2018

5. With reference to the installation of copper pipes in engine cooling systems:

(a) describe THREE possible causes for their premature failure; (6)

(b) outline FOUR recommendations for the installation of copper pipes. (4)

Premature Failure of Copper Pipes in Engine Cooling Systems:

(a) Three Possible Causes:

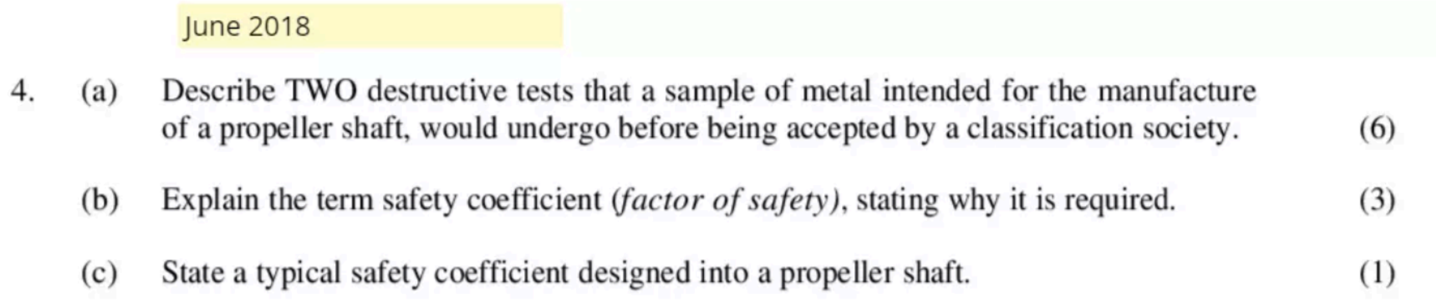
1. Fatigue Stress: Repeated bending, vibration, and thermal cycling due to engine operation can cause metal fatigue in copper pipes. This leads to micro-cracks that gradually grow, potentially leading to leaks or even pipe rupture.
2. Improper Brazing or Soldering: Faulty brazing or soldering joints can create weak points in the pipe system, compromising its integrity and potentially allowing leaks or even complete separation.
3. Corrosion: Exposure to aggressive chemicals like antifreeze or seawater can lead to corrosion of the copper pipes, thinning the walls and reducing their strength. This can eventually lead to leaks or burst pipes.

(b) Four Installation Recommendations:

1. Proper Pipe Support and Routing: Provide adequate support for the pipes throughout the system to minimize vibration and bending stress. Avoid sharp bends and ensure sufficient clearance from moving parts or potential sources of abrasion.
2. High-Quality Brazing or Soldering: Use proper brazing or soldering techniques with appropriate materials and temperatures to create strong, leak-proof joints. Ensure qualified personnel perform the work and follow best practices.
3. Corrosion Protection: Use corrosion-resistant materials for brazing/soldering and consider additional protective coatings on the pipes, especially if exposed to aggressive environments like seawater.
4. Regular Maintenance and Inspection: Regularly inspect the entire cooling system for signs of leaks, corrosion, or damage. Maintain proper antifreeze levels and monitor its condition to prevent excessive corrosion.

By following these recommendations, you can significantly reduce the risk of premature failure in copper pipes used in engine cooling systems, ensuring their long-term reliability and minimizing potential engine overheating or other consequences of leaks or failures.

Remember, proper installation and maintenance are crucial for the continued safe and efficient operation of your engine cooling system.



June 2018

4. (a) Describe TWO destructive tests that a sample of metal intended for the manufacture of a propeller shaft, would undergo before being accepted by a classification society. (6)

(b) Explain the term safety coefficient (*factor of safety)*, stating why it is required. (3)

(c) State a typical safety coefficient designed into a propeller shaft. (1)

(a) Destructive Tests for Propeller Shaft Metal:

Before being approved for propeller shaft fabrication by a classification society, the metal sample undergoes two rigorous destructive tests to ensure its suitability for the demanding application:

1. Tensile Test: This test measures the material's ultimate tensile strength and yield strength. A specimen is pulled until it breaks, recording the force required to break it (ultimate strength) and the force at which it begins to deform permanently (yield strength). High values are desired for propeller shafts to resist breaking under high tensile loads during operation.
2. Impact Test: This test assesses the material's toughness and resistance to brittle fracture. A notched specimen is struck with a heavy weight, measuring the energy absorbed before breaking. Good toughness is crucial for propeller shafts to withstand sudden shock loads from rough seas or collisions.

(b) Safety Coefficient and its Importance:

A safety coefficient (FS) is a factor applied to the design load of a component to ensure it has sufficient strength to handle actual operating conditions with a buffer against unexpected stresses or material imperfections. It acts as a safeguard against component failure and associated risks.

Requiring a safety coefficient is crucial for several reasons:

- Uncertainties in Loading: Actual operating conditions can involve loads exceeding the calculated design values due to waves, currents, or unforeseen circumstances. The safety coefficient provides a margin to ensure the component withstands these situations.
- Material Variances: Material properties can exhibit slight variations even within the same specification. The safety coefficient accounts for these potential variations and ensures the component performs reliably despite them.
- Manufacturing Imperfections: Even with best practices, minor imperfections or defects can occur during manufacturing. The safety factor provides a buffer against these imperfections and reduces the risk of failure due to them.

(c) Typical Safety Coefficient for Propeller Shafts:

The desired safety coefficient for propeller shafts depends on various factors like ship size, engine power, and classification society regulations. However, a typical value for steel and other common materials used in propeller shafts would be in the range of 5 to 8. This means the designed strength of the shaft is at least 5 to 8 times greater than the expected maximum operating load, providing a significant margin of safety.