Heat treatment Hardening Annealing Normalising

June 2018

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(b) describe the internal changes when it becomes work hardened; (2)

(c) state the effect work hardening has on its properties; (2)

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

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Nov 2022

2. 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) Work Hardening Explained:

Work hardening, also known as strain hardening, is a phenomenon where the strength and hardness of aluminium increase as it is plastically deformed (bent, stretched, hammered, etc.). This doesn't involve any change in its chemical composition, but rather a rearrangement of its internal structure.

Think of aluminium as a pile of spaghetti strands. In its soft state, the strands are loosely tangled. When deformed, the strands get tangled and interlocked, making it harder to further deform them. This increased resistance to deformation translates to higher strength and hardness.

(b) Internal Changes during Work Hardening:

During work hardening, several internal changes occur within the aluminium:

- Dislocation Formation: Plastic deformation creates defects called dislocations in the crystal lattice of aluminium. These dislocations act as obstacles to further movement of atoms, hindering deformation and thus increasing strength.
- Grain Refinement: In some cases, severe deformation can break down larger aluminium grains into smaller ones. This also contributes to work hardening because smaller grains have more grain boundaries, which again act as obstacles to deformation.

(c) Effects of Work Hardening on Properties:

Work hardening has both positive and negative effects on aluminium:

- Positive:
  - Increased Strength and Hardness: As explained above, work hardening makes aluminium stronger and harder, making it suitable for applications requiring higher load-bearing capacity.
  - Improved Wear Resistance: The increased hardness also enhances the material's resistance to wear and tear.
- Negative:
  - Reduced Ductility and Malleability: The tangled grain structure makes the metal less ductile (stretchable) and malleable (formable). This can limit its usability in applications requiring bending or shaping.
  - Increased Brittleness: Severe work hardening can also make aluminium brittle, making it more prone to cracking and failure under high stress.

(d) Annealing Aluminium on a Vessel:

Annealing is a process that reverses the effects of work hardening, restoring the aluminium to its original soft and workable state. On a vessel, this can be achieved through:

- Flame Annealing: A handheld torch is used to locally heat the work-hardened area above a specific temperature (around 350°C). This softens the crystal structure and relieves internal stresses, restoring ductility and malleability.
- Induction Annealing: A portable induction heating coil is used to generate heat within the metal. This method offers precise control over the heating process and is suitable for areas with limited access.

These methods are chosen based on the specific application and size of the work-hardened part. Regardless of the method, it's essential to control the annealing temperature and duration to achieve the desired result without melting or weakening the aluminium.

Nov 2018

3. (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)

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(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.

March 2018

2. 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:

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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.

March 2022

2. With reference to the case hardening of bearing journals:

(a) explain why this process may be carried out; (2)

(b) describe EACH of the following processes:

(i) induction hardening; (3)

(ii) nitriding; (3)

(c) explain why the processes described in part (b) are best suited to this application. (2)

a) Reasons for Case Hardening:

Case hardening is often applied to bearing journals for several key reasons:

- Improved Surface Hardness: The outer layer of the journal is significantly hardened, enhancing its resistance to wear and tear from rolling contact with other bearing components. This reduces friction and prolongs the lifespan of the bearing.
- Fatigue Resistance: Case hardening strengthens the surface against subsurface stresses and cracks caused by repeated loading and unloading. This improves the bearing's resistance to fatigue failure, a common cause of bearing degradation.
- Toughness Retention: While the surface is hardened, the core of the journal remains relatively soft and tough. This combination maintains the bearing's shock absorption capability and prevents brittle failure under high impact loads.
- Reduced Friction: The hardened surface offers smoother contact with other bearing components, leading to reduced friction and heat generation. This can improve energy efficiency and operational temperature control within the bearing system.

(b) Heat Treatment Processes:

(i) Induction Hardening:

- Process: An alternating current coil generates an electromagnetic field that induces localized heating in the journal surface. This allows for precise control of the hardened zone depth and temperature. Quenching can be done with water, oil, or even air depending on the desired properties.
- Advantages: Highly localized heating minimizes distortion and heat-affected zone, ideal for bearing journals. Fast heating and quenching offer excellent process control and repeatability. Can be easily automated for consistent results.

(ii) Nitriding:

- Process: The journal is exposed to a nitrogen-rich atmosphere at high temperatures (around 400-550°C). Nitrogen diffuses into the surface, forming a hard and wear-resistant iron nitride compound. No quenching is required.

- Advantages: Nitrided layer provides superior corrosion resistance and high-temperature performance compared to other case hardening methods. No quenching minimizes distortion and thermal stress. Suitable for applications with moderate impact loads.

(c) Suitability for Bearings:

Induction hardening and nitriding are particularly well-suited for case hardening of bearing journals due to their specific advantages:

- Precise Control: Both methods offer precise control over the hardened zone depth and temperature, ensuring optimal wear resistance and core toughness balance. This is crucial for maximizing bearing performance and lifespan.
- Minimal Distortion: Both processes minimize distortion due to localized heating or the absence of quenching, maintaining the critical dimensional accuracy of the journal for proper bearing operation.
- Fatigue Resistance: The hardened surface created by both methods enhances fatigue resistance against cyclic loading, a major concern for bearing components.
- Additional Benefits: Nitriding offers the bonus of corrosion resistance and high-temperature performance, while induction hardening allows for fast and automated processing.

Overall, induction hardening and nitriding provide effective and versatile solutions for case hardening bearing journals, contributing to their enhanced wear resistance, fatigue strength, and operational efficiency.

July 2021

2. Describe the heat treatment process EACH of the following components would undergo, stating the reasons for EACH of the processes:

(a) crankshaft; (4)

(b) valve spring; (3)

(c) used copper washer. (3)

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a) Crankshaft:

- Heat treatment: Nitriding or nitrocarburizing.
- Reasons:

- Improved surface hardness: Enhances resistance to wear and tear from bearing contact and fatigue from cyclic loading, increasing crankshaft lifespan.
- Reduced friction: Smoother surface minimizes friction and heat generation, improving engine efficiency and reducing operating temperature.
- Fatigue resistance: Hardened surface resists subsurface cracks from repeated stress, enhancing fatigue strength and preventing shaft failure.
- Corrosion resistance: Nitriding offers additional protection against corrosion, particularly beneficial for marine engines or harsh environments.

(b) Valve Spring:

- Heat treatment: Austempering or oil quenching and tempering.
- Reasons:
  - High strength and toughness: Enhanced tensile strength and fatigue resistance allow the spring to withstand high loads and repeated cycles without deformation or failure.
  - Heat resistance: The treatment maintains spring properties at elevated engine temperatures, ensuring consistent valve operation.
  - Dimensional stability: Minimizes spring relaxation and set loss over time, preventing valve clearance issues and maintaining engine performance.
  - Ductility: Austempering provides slightly better ductility for absorbing shock loads and preventing brittle fracture.

(c) Used Copper Washer:

- Heat treatment: None.
- Reasons:
  - Copper is malleable and soft: Its inherent properties allow it to conform to irregularities and create a tight seal even without heat treatment.
  - Heat exposure can weaken copper: Annealing or other heat treatments might reduce its strength and compromise its sealing function.
  - Used washers are typically discarded: Repetitive thermal cycling and mechanical stresses often render used washers unsuitable for reuse, regardless of heat treatment.

In summary, different engine components require specific heat treatment based on their function and desired properties. Crankshafts and valve springs benefit from hardening processes for strength, wear resistance, and fatigue resistance. Used copper washers, however, generally don't undergo any heat treatment due to their inherent properties and potential degradation from past use.