Alloy, Metals, Stainless Steel, Materials of Components

July 2021

1. (a) Define the meaning of the term *alloy*, stating why they are used. (3)

(b) Describe the changes in the mechanical properties of steel with increasing amounts of carbon. (4)

(c) List SIX common alloying elements used in the production of steel. (3)

(a) Define the meaning of the term alloy, stating why they are used.

An alloy is a mixture of two or more metals, or a metal combined with one or more non-metals. Alloys are used because they often have properties that are superior to those of the pure metals that make them up. For example, alloys can be stronger, harder, more corrosion-resistant, or more conductive than pure metals.

Here are some specific examples of why alloys are used:

- Steel is an alloy of iron and carbon. It is much stronger than pure iron, making it an ideal material for construction, bridges, and tools.
- Brass is an alloy of copper and zinc. It is more resistant to corrosion than pure copper, making it a good material for plumbing fixtures and musical instruments.
- Solder is an alloy of tin and lead. It has a low melting point, making it easy to use for joining metals together.

(b) Describe the changes in the mechanical properties of steel with increasing amounts of carbon.

As the amount of carbon in steel increases, its strength and hardness also increase. However, its ductility and toughness decrease. This means that high-carbon steel is strong and hard, but it is also brittle and more likely to crack. Low-carbon steel is less strong and hard, but it is more ductile and tough, making it more resistant to breaking.

The amount of carbon in steel is typically expressed as a percentage. For example, mild steel has a carbon content of about 0.2%, while high-carbon steel has a carbon content of about 1%.

(c) List six common alloying elements used in the production of steel.

Six common alloying elements used in the production of steel are:

1. Carbon: Increases strength and hardness, but decreases ductility and toughness.
2. Manganese: Increases strength, hardenability, and resistance to wear and tear.
3. Silicon: Increases strength, hardenability, and resistance to oxidation.
4. Chromium: Increases strength, hardenability, and resistance to corrosion.
5. Nickel: Increases strength, toughness, and ductility at low temperatures.

6. Molybdenum: Increases strength, hardenability, and resistance to creep (deformation under stress at high temperatures).

Nov 2022

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

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

(i) ferritic; (2)

(ii) austenitic; (2)

(iii) martensitic. (2)

1. (a) Define the term stainless steel, making reference to the percentage quantities of its two main constituents.

Stainless steel is a steel alloy with a minimum of 10.5% chromium by mass. Chromium is the key element that gives stainless steel its resistance to corrosion, staining, and pitting. Other elements, such as nickel, molybdenum, and carbon, are also often added to improve the mechanical properties and corrosion resistance of stainless steel.

Here is a table showing the percentage ranges of the two main constituents of stainless steel:

Element	Percentage Range
Chromium	10.5% - 30%
Carbon	0.015% - 1.0%

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

(i) Ferritic

- Unique property: Magnetic
- Common use: Cutlery

Ferritic stainless steels are the least expensive type of stainless steel. They are magnetic and have good corrosion resistance, but they are not as strong as other types of stainless steel. They are often used in cutlery, appliances, and automotive trim.

Ferritic stainless steel, while not as widely used as its Austenitic cousin on ships, still plays a key role in certain applications due to its unique properties and cost advantages. Here's how it finds its place in the maritime world:

Advantages of Ferritic Stainless Steel on Ships:

- Lower cost: Compared to Austenitic steels, Ferritic varieties are significantly cheaper, making them an attractive option for budget-conscious applications.
- Magnetic: Unlike Austenitic steel, Ferritic steel is magnetic, which can be an advantage for certain situations like attaching magnetic signs or equipment.
- Good mechanical properties: Although not as strong as Austenitic varieties, Ferritic steel still offers decent strength and ductility for specific applications.
- Good corrosion resistance: While not as stellar as Austenitic steel, Ferritic steel possesses reasonable corrosion resistance against mild freshwater and atmospheric conditions.

Specific Applications of Ferritic Stainless Steel on Ships:

- Interiors and decorative elements: Bulkheads, panelling, trim, and interior furnishings can benefit from Ferritic steel's cost-effectiveness and aesthetic appeal.
- Exhaust systems and flues: The heat resistance and decent corrosion resistance of Ferritic steel make it suitable for certain exhaust components.
- Freshwater tanks and piping: In freshwater systems with controlled environments, Ferritic steel can function effectively due to its corrosion resistance and affordability.
- Ballast water tanks: Some ship designs utilize Ferritic steel in ballast water tanks due to its lower cost, though careful considerations regarding corrosion protection are necessary.

Limitations of Ferritic Stainless Steel on Ships:

- Lower corrosion resistance: Compared to Austenitic steel, Ferritic steel is less resistant to seawater and aggressive environments, limiting its use in exposed areas.
- Brittle at low temperatures: Ferritic steel exhibits increased brittleness at low temperatures, requiring consideration in cold regions or cryogenic applications.
- Susceptibility to stress corrosion cracking: Similar to Austenitic steel, Ferritic steel can be susceptible to stress corrosion cracking under specific conditions, necessitating proper design and material selection.

(ii) Austenitic

- Unique property: Non-magnetic and ductile
- Common use: Food processing equipment

Austenitic stainless steels are the most common type of stainless steel. They are non-magnetic, ductile, and have excellent corrosion resistance. They are often used in food processing equipment, medical devices, and chemical tanks.

Austenitic stainless steel plays a significant role in various applications on ships due to its unique combination of properties:

Corrosion Resistance: Austenitic steel's high chromium content (typically 18-20%) makes it highly resistant to corrosion, which is crucial for a marine environment. It stands up to saltwater, chlorides, and harsh weather conditions, minimizing rust and wear.

Strength and Ductility: Despite its excellent corrosion resistance, Austenitic steel maintains good strength and ductility. This allows it to withstand the stresses and impacts encountered at sea, ensuring structural integrity and safety.

Ease of Fabrication and Maintenance: Austenitic steel is relatively easy to work with, being weldable and formable. This makes it adaptable to various ship components and simplifies repairs or modifications.

Non-magnetic: Unlike other steel types, Austenitic steel is non-magnetic. This is useful for applications where interference with compass readings or sensitive equipment needs to be avoided.

Specific Applications of Austenitic Stainless Steel on Ships:

- Deck fittings and railings: Handrails, ladders, stanchions, and other deck components benefit from Austenitic steel's corrosion resistance and durability for enhanced safety and aesthetics.
- Galley equipment: Austenitic steel's hygiene and non-toxicity make it ideal for food processing equipment, utensils, and tanks in kitchens and pantries.
- Piping and tanks: From freshwater systems to waste systems, Austenitic steel pipes and tanks offer longevity and resistance to aggressive fluids.
- Propeller shafts and rudders: The high strength and corrosion resistance of Austenitic steel are essential for these critical components, ensuring smooth operation and minimizing maintenance.
- Marine hardware: Fasteners, shackles, and other hardware benefit from Austenitic steel's strength and corrosion resistance, particularly in saltwater environments.

Further Considerations:

While Austenitic steel is a versatile material for ships, some limitations require consideration:

- Higher cost: Compared to other steel types, Austenitic steel can be more expensive, influencing material choices based on specific applications and budget constraints.
- Susceptibility to stress corrosion cracking: In certain environments and under high stress, Austenitic steel can be susceptible to cracking. Careful design and material selection are necessary to mitigate this risk.

(iii) Martensitic

- Unique property: Hard and strong
- Common use: Surgical instruments

Martensitic stainless steels are the strongest type of stainless steel. They are magnetic and have good corrosion resistance, but they are not as ductile as other types of stainless steel. They are often used in cutlery, surgical instruments, and tools.

Martensitic stainless steel, known for its exceptional strength and hardness, finds some niche applications on ships, where its unique properties offer valuable advantages despite certain limitations. Here's a closer look at how it plays its part in the maritime world:

Strengths of Martensitic Stainless Steel on Ships:

- High strength and hardness: Compared to other stainless steel types, Martensitic steel boasts superior strength and hardness, making it ideal for demanding applications.
- Good wear resistance: Its hardness translates to excellent wear resistance, ideal for components facing friction and abrasion.
- Magnetic: Similar to Ferritic steel, Martensitic steel's magnetic nature can be beneficial for specific situations like attaching magnetic tools or equipment.
- Affordable compared to other high-strength materials: While not as cheap as Ferritic steel, Martensitic steel can be more cost-effective than other high-strength materials like certain alloys or titanium.

Specific Applications of Martensitic Stainless Steel on Ships:

- Marine hardware: Shackles, pins, and other high-wear hardware pieces benefit from Martensitic steel's strength and wear resistance, especially for anchor chains and winches.
- Pumps and valves: Internal components of critical pumps and valves can utilize Martensitic steel for its strength and wear resistance, particularly in abrasive or high-pressure environments.
- Cutting tools and blades: Propeller blades and other cutting tools can benefit from Martensitic steel's hardness and strength for prolonged sharpness and durability.
- Springs and fasteners: In situations requiring high strength and fatigue resistance, Martensitic steel springs and fasteners can provide reliable performance.

Limitations of Martensitic Stainless Steel on Ships:

- Lower corrosion resistance: Compared to Austenitic and Ferritic varieties, Martensitic steel offers lower corrosion resistance, limiting its use in saltwater and harsh environments.
- Brittle at low temperatures: Similar to Ferritic steel, Martensitic steel becomes brittle at lower temperatures, requiring careful consideration in cold regions or cryogenic applications.
- Susceptible to stress corrosion cracking: Under specific conditions and high stress, Martensitic steel can be prone to stress corrosion cracking, necessitating proper design and material selection.
- Difficult to weld and fabricate: Compared to other stainless steel types, Martensitic steel presents challenges in welding and fabrication, requiring specialized techniques and expertise.

June 2022

1. With reference to EACH of the following materials, list their percentage composition and a different application for EACH material on board, stating, with reasons, why they are suitable for this application:

(a) cupro-nickel; (2)

(b) aluminium bronze; (2)

(c) admiralty brass; (2)

(d) duralumin; (2)

(e) solder. (2)

March 2018

1. With reference to EACH of the following materials, list their percentage composition and a different application for EACH material on board, stating, with reasons, why they are suitable for this application:

(a) cupro-nickel; (2)

(b) aluminium bronze; (2)

(c) admiralty brass; (2)

(d) duralumin; (2)

(e) solder. (2)

(a) Cupro-nickel

- Composition: 60-70% copper, 30-40% nickel, with small amounts of manganese and iron.

- Applications:
  - Piping systems, heat exchangers, and condensers in seawater systems, due to its excellent resistance to corrosion by saltwater.
  - Propellers, propeller shafts, and hulls of high-quality boats, for its strength and durability.

(b) Aluminum bronze

- Composition: 90-92% copper, 7-9% aluminum, with small amounts of iron, manganese, and other elements.
- Applications:
  - Marine hardware, such as propellers, shafts, and fittings, because of its resistance to corrosion and wear.
  - Bearings and gears, for its good strength and wear resistance.

(c) Admiralty brass

- Composition: 70% copper, 29% zinc, 1% tin.
- Applications:
  - Condenser tubes and plates in seawater systems, due to its good resistance to corrosion and erosion.
  - Heat exchanger tubes and marine hardware.

(d) Duralumin

- Composition: 90% aluminum, 4% copper, 1% magnesium, 0.5% manganese, with small amounts of silicon and iron.
- Applications:
  - Aircraft structures, because of its high strength-to-weight ratio and good fatigue resistance.
  - Marine applications, such as masts and booms, for its strength and corrosion resistance.

(e) Solder

- Composition: Varies depending on the type of solder, but typically a mixture of tin and lead, with or without other metals such as silver or copper.
- Applications:
  - Joining electrical components and stained glass panels.
  - Sealing metal cans and food containers.

Nov 2021

1. State, with reasons, a different material suitable for EACH of the following applications:

(a) a large motor vessel propeller; (2)

(b) a centrifugal pump impeller; (2)

(c) a sea water cooled heat exchanger tube; (2)

(d) a 300mm diameter sea water cooling pipe; (2)

(e) a cylinder head of a small auxiliary engine. (2)

June 2018

1. State, with reasons, a different material suitable for EACH of the following applications:

(a) a large motor vessel propeller; (2)

(b) a centrifugal pump impeller; (2)

(c) a sea water cooled heat exchanger tube; (2)

(d) a 300mm diameter sea water cooling pipe; (2)

(e) a cylinder head of a small auxiliary engine. (2)

Nov 2018

1. State, with reasons, a different material suitable for EACH of the following applications:

(a) a large motor vessel propeller; (2)

(b) a centrifugal pump impeller; (2)

(c) a sea water cooled heat exchanger tube; (2)

(d) a 300mm diameter sea water cooling pipe; (2)

(e) a cylinder head of a small auxiliary engine. (2)

(a) A large motor vessel propeller

- Material: Typically made of a bronze alloy, such as Ni-Al bronze or aluminum bronze. These alloys are chosen for their strength, toughness, and resistance to corrosion in seawater.

(b) A centrifugal pump impeller

- Material: Often made of stainless steel for its strength, corrosion resistance, and ability to handle abrasive fluids. In some cases, cast iron or nickel-aluminum bronze may be used depending on the specific application and cost considerations.

(c) A sea water cooled heat exchanger tube

- Material: Typically made of titanium or cupronickel. Titanium offers excellent corrosion resistance and strength, but is more expensive. Cupronickel is a more cost-effective option with good corrosion resistance and heat transfer properties.

(d) A 300mm diameter sea water cooling pipe

- Material: Often made of fiberglass reinforced plastic (FRP), which is lightweight, corrosion-resistant, and relatively inexpensive. In some cases, steel or high-density polyethylene (HDPE) may be used depending on the specific requirements and pressure rating.

(e) A cylinder head of a small auxiliary engine

- Material: Typically made of cast iron due to its good machinability, heat transfer properties, and affordability. In some high-performance engines, aluminum or aluminum alloys may be used for their weight saving benefits.

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.

(a) Aft deck bollard

- Material: Typically made of cast steel for its high strength and durability. Cast steel can withstand the high pulling forces exerted on the bollard when ships are being moored or towed.

(b) Anchor windlass

- Material: Often made of cast iron or cast steel for their strength and affordability. In some high-performance windlasses, duplex stainless steel may be used for its superior strength-to-weight ratio and corrosion resistance.

(c) Deck handrails

- Material: Typically made of stainless steel due to its strength, corrosion resistance, and ease of maintenance. In some cases, aluminum or fiberglass reinforced plastic (FRP) may be used depending on the desired weight and cost considerations.

(d) Mooring lines

- Material: Traditionally made from natural fibers such as manila or sisal for their high strength and shock absorption properties. However, synthetic fibers such as nylon or polyester are increasingly being used due to their superior strength, durability, and resistance to rot and mildew.

(e) Davit fairlead rollers

- Material: Often made from a polymer alloy with high wear resistance and low friction, such as acetal or UHMWPE (ultra-high-molecular-weight polyethylene). These materials help to protect the mooring lines from chafing and wear as they pass through the fairlead.

Nov 2020

1. With reference to austenitic stainless steels:

   (a) list the THREE main constituents with approximate percentage composition; (3)

   (b) state the main difference between grades 304 & 316 and how this is achieved; (3)

   (c) list TWO typical applications for EACH grade stated in part (b) that would be found on a modern vessel. (4)

June 2018

2. With reference to austenitic stainless steels:

   (a) list the THREE main constituents with approximate percentage composition; (3)

   (b) state the main difference between grades 304 & 316 and how this is achieved; (3)

   (c) list TWO typical applications for EACH grade stated in part (b) that would be found on a modern vessel. (4)

June 2019

1. With reference to austenitic stainless steels:

(a) list the THREE main constituents with approximate percentage composition; (3)

(b) state the main difference between grades 304 & 316 and how this is achieved; (3)

(c) list TWO typical applications for EACH grade stated in part (b) that would be found on a modern vessel. (4)

Feb 2023

1. With reference to austenitic stainless steels:

(a) list the THREE main constituents with approximate percentage composition; (3)

(b) state the main difference between grades 304 & 316 and how this is achieved; (3)

(c) list TWO typical applications for EACH grade stated in part (b) that would be found on a modern vessel. (4)

a) The three main constituents of austenitic stainless steel are:

1. Iron: As the base metal, iron makes up the majority of the composition, typically ranging from 60% to 70%.
2. Chromium: This is the key element that gives austenitic stainless steel its corrosion resistance. It usually constitutes between 18% and 20% of the composition.
3. Nickel: This element contributes to the austenitic structure and enhances properties like ductility, toughness, and strength at low temperatures. The nickel content in austenitic stainless steel typically ranges from 8% to 10%.

While these three elements form the core of austenitic stainless steel, other elements can be added in smaller amounts to further enhance specific properties. These include:

- Carbon: Increases strength and hardness but decreases ductility and toughness.
- Manganese: Improves strength, workability, and hardenability.
- Nitrogen: Provides additional strength and enhances corrosion resistance.
- Molybdenum: Increases high-temperature strength and resistance to certain types of corrosion.

b) Both 304 and 316 are popular grades of austenitic stainless steel, but they do have some key differences:

Molybdenum content:

- 304: Does not contain molybdenum.
- 316: Contains 2-3% molybdenum, which significantly improves its corrosion resistance, especially in chloride-rich environments like saltwater.

Corrosion resistance:

- 304: Offers good corrosion resistance to mild environments, food acids, and freshwater.
- 316: Offers superior corrosion resistance to chlorides, acids, and saltwater, making it ideal for marine applications, chemical processing, and food processing equipment exposed to harsh cleaning solutions.

Applications:

- 304: Widely used in kitchen equipment, architectural trim, automotive parts, and other general applications where good corrosion resistance is needed but saltwater exposure is minimal.
- 316: Widely used in marine hardware, chemical processing equipment, medical implants, high-temperature applications, and food processing equipment requiring extra corrosion resistance.

Cost:

- 304: Less expensive due to the absence of molybdenum.
- 316: More expensive due to the addition of molybdenum.

Other differences:

- Formability: Both are highly formable and weldable, but 304 may be slightly easier to work with.
- Strength: 316 may have slightly higher strength due to the molybdenum content.

Here's a table summarizing the key differences:

Feature	304	316
Molybdenum content	No	2-3%

Corrosion resistance	Good	Superior, especially to chlorides and salt
Applications	Kitchen equipment, architecture, automotive	Marine, chemical processing, medical, food processing with harsh cleaning
Cost	Less expensive	More expensive
Formability	Highly formable	Highly formable
Strength	Good	Slightly higher

Application 1: Food processing equipment (tanks, pipes, utensils)

- Possible grades: Austenitic stainless steels like AISI 304 (18/8) or 316 (18/10 Mo).
- Key features:
  - Corrosion resistance: Resists corrosion from food acids, cleaning chemicals, and saltwater.
  - Formability and weldability: Easy to shape and weld for complex equipment designs.
  - Hygiene: Smooth, non-porous surface prevents bacteria growth and is easy to clean.
  - Austenitic: Non-magnetic and has good low-temperature toughness.

Application 2: Chemical piping and tanks

- Possible grades: Depending on the specific chemicals, AISI 316L (16/10 Mo low carbon), 904L, or super austenitic grades like 254SMO.
- Key features:
  - High corrosion resistance: Resists strong acids, alkalis, and oxidizing environments.
  - Pitting resistance: Resists localized corrosion from chlorides and other aggressive ions.
  - Crevice corrosion resistance: Resists corrosion in tight spaces like under gaskets.

  - High strength and durability: Handles pressure and temperature extremes.

Application 3: Marine hardware (fasteners, fittings, shafts)

- Possible grades: AISI 316L (16/10 Mo low carbon), 17-4 PH, or duplex stainless steels like 2205.
- Key features:
  - Excellent saltwater corrosion resistance: Resists pitting and crevice corrosion from seawater.
  - High strength and toughness: Withstands mechanical loads and stresses.
  - Good machinability and weldability: Easy to fabricate and join for complex hardware.
  - 17-4 PH and duplex grades: Offer higher strength and hardness for demanding applications.

Application 4: Medical implants (surgical instruments, prosthetics)

- Possible grades: AISI 316LVM (16/10 Mo very low carbon) or 316L with electropolishing.
- Key features:
  - Biocompatibility: Non-toxic and does not reject human tissue.
  - High corrosion resistance: Resists body fluids and sterilization chemicals.
  - High strength and fatigue resistance: Withstands repeated stresses without breaking.
  - Smooth surface finish: Minimizes risk of infection and tissue irritation.

Application 5: Cryogenic tanks and vessels (storing extremely cold liquids)

- Possible grades: AISI 304L (18/8 low carbon) or 904L.
- Key features:
  - Excellent low-temperature toughness: Maintains strength and ductility at very cold temperatures.
  - Good weldability: Can be welded reliably for strong and leak-proof tanks.
  - Corrosion resistance: Resists contamination from cryogenic liquids and cleaning chemicals.
  - 304L: Offers a good balance of properties and affordability.