CHEMISTRY

Research Assignment on Metal

Part 1

Describe how the metal hull of a ship can be protected from corrosion by each of the 3 methods below and evaluate the effectiveness of each method:

- **Corrosion-resistant metals**
- **Surface alloys**
- **New paints**

Ships hulls are in an environment in which they are very susceptible to corrosion. The presence of salt water, oxygen, mechanical stressed and alloyed metals in the steel producing irregularities in the crystal structure of the metal all increase the likelihood of corrosion. Electrochemical cells form which hastens corrosion.

a) Corrosion-resistant metals

Corrosion-resistant metals can be pure metals which are extremely unreactive (such as gold) or can be alloys of certain metals which chemically have a higher level of chemical corrosion resistant than other unalloyed metals. In the case of ships, metals are alloyed with steel to change its chemical properties. The metals used in alloying the steel are either corrosion-resistant themselves or are passivating metals.

Examples of alloyed metals include: Molybdenum, chromium, nickel, tin, zinc and manganese.

The most common metal used in ships is chromium alloy steel which forms a protective layer of chromium (III) oxide; this layer is known as a passivating layer. Other metals such as molybdenum are corrosion-resistant and when alloyed with steel it will bestow this property in the metal formed. In ship building it is quite common for various combinations of the exampled (above) metals to be used to maximise the effectiveness, for example, as chromium is not extremely effective in protection against chloride ions in sea water, the nickel content of the alloy may be increased to combat this inefficiency. However a problem with using chromium and nickel alloys of steel is that as the chloride ions break down the passivating oxide layer, crevice corrosion can occur in the metal, especially in environments where oxygen levels are quite low. Therefore these particular metals will TEND to be used in the sections of the hull above water level rather than below water level.

The financial effectiveness of these metals places another problem on the production of ship hulls made out of corrosion-resistant metals. The manufacturing of such metals is so expensive that it is financially impractical for most shipyards to build ships from them. Therefore these expensive metals are used in the parts of the ship where it is absolutely essential that no corrosion occurs.

The environmental aspect of these metals is positive; during the lifetime of the ships they will cause infinitesimal levels of damage to the environment due to breaking down of the metals and the passivating oxide layer into the ocean or water body. However whilst the smelting and production of these metals may let of toxic and damaging substances such as sulfur which can form acidic oxides, the metals tend to last the entire lifetime of the ship and do not need to be replaced, therefore causing minimal overall environmental damage.

Thus, the overall effectiveness of corrosion-resistant metals is quite good but only on a small and manageable scale, not big enough to build entire ships out of, however if used in combination with other methods of corrosion protection, the financial and practical suitability of these metals is quite high.

b) Surface alloys

Surface alloys are essentially metals with a protective film of various metals/metal combinations which protects the base metal or alloy from corrosion. Producing an entire ship hull from stainless steel (an extremely effective corrosion-resistant metal) would be phenomenally expensive, and therefore through the process of surface alloying it is possible to 'mimic' the physical properties of stainless steel on an outer layer of the metal whilst maintaining cost efficiency.

Examples of common metals/alloys used in surface alloying: Copper/nickel alloys, chromium, chromium/nickel, molybdenum and chromium/manganese. (Note that these metals are almost the same as the metals most commonly used in corrosion-resistant metals – they have corrosion-resisting and/or passivating chemical properties)

There are two methods of producing surface alloys; electrodeposition and ion-spraying. Electrodeposition is the process of using electrical currents to reduce cations of a particular material from a solution and subsequently coating a conductive object with the product. This forms a protective film over the coated metal (which will only be corrosion-resistant if the metals above or a combination of the metals above are depositioned). The process of ion-spraying is completely different and when making surface alloys for ship hulls it tends to be the more employed method of manufacture. It involves using lasers or focused cathode beams from an electron gun to melt the surface of the steel alloy being coated, the material/s being used to coat the metal are then ionised (the ions are formed in a high temperature gaseous discharge – plasma), heated to high temperatures and subsequently bombarded onto the steel. The ions form bonds with the steel which creates the surface alloy which has different physical and chemical properties to the original steel alloy. (In the manufacture of ship hulls the corrosion-resistant metals/metal combinations above will be used as the material bombarded onto the steel). This new layer is passivating and acts much like stainless steel, whilst most of the metal below the surface will remain completely unaltered.

The most common corrosion-resisting metal combination used in the building of ship hulls is a chromium/nickel combination as these elements are so strongly bound to the surface the hull is not affected by the chloride ions in the sea water.

Environmentally this option of protecting ships from corrosion is the safest, the extent to which the surface alloys are bonded to the surface of the original metal is such that they do not react with ocean water. The production of these metals is only damaging in the actual toxins released during the refining, smelting and production of the steel and the refining of the various metals used in the surface alloying.

Surface alloying is a much cheaper process than creating corrosion-resistant metals to the extent where most shipyards can financially manufacture ship hulls which are made from surface alloyed steel; however the surface alloys themselves are not as long lasting or durable. Overall, whilst the lifetime is shorter, this process is financially sustainable and has the same minimal environmental impact as corrosion-resistant metals therefore being a perfect option for protecting ship hulls from corrosion.

Surface alloys can be produced using laser techniques. Chromium and nickel can be strongly bound to the surface layers of the steel by bombarding the surface with their ions at high temperatures. The steel surface can then form a passivating layer as the chromium atoms react with oxygen. Aluminium does not form a strong passivating layer in the presence of salts. If the aluminium hull is surface alloyed with a passivating metal such as chromium, then the aluminium hull is protected from corrosion.

c) **New Paints**

New paints used for example in protecting ship hulls from corrosion have been developed and improved to an extent to which they are extremely effective in protecting against rust. These paints are polymer-based and were specifically developed to prevent steel surfaces from coming in contact with air and water. A brand new development in corrosion-resistance by chemists is the product 'Rustmaster Pro'. This polymer paint cures in air forming an inert passivating film that is extremely impervious to oxygen and water. It is designed in such a way that additives in the paint itself react with the steel, similar to the process in surface alloying, forming a layer of an extremely insoluble ionic substance called pyroaurite, however unlike surface alloys the ionic layer itself extends well into the polymer layer. The layer itself prevents any migration of ions from one area on the steel surface to another, this in turn prevents rusting. Pyroaurite is a mineral which consists of divalent and trivalent hydroxyl metal complex cations of metals such as ion, nickel, cobalt and various anions. This means it contains cations of the general forms $MZ(OH)_2^+$ and $M_2Z(OH)_3^+$ where M is a 2+ ion such as Mg^{2+}, Fe^{2+}, Zn^{2+}, Co^{2+} or Ni^{2+} and Z is a 3+ ion such as Al^{3+}, Fe^{3+}, Mn^{3+}, Ni^{3+} or Co^{3+}, and the various anions, as mentioned above, will tend to be carbonates, chlorides and sulfates.

The Rustmaster Pro product was coated onto a steel surface and subjected to testing, showing no signs of rusting after over 10000 hours exposure to salt spray at 38^{o}C.

Environmentally, Rustmaster Pro is extremely effective as it only releases approximately 1% of the volatile solvents into the environment compared to other conventional rust-resisting paints. Also, Rustmaster Pro is a financially viable option for the production of ships hulls on an industrial scale for shipyards.

Therefore, considering all the factors including the financial practicality, environmental impact and the effectiveness and suitability of the product itself, it is an extremely effective and efficient means of protecting ship hulls from the detrimental effects of corrosion.

Part 2

Identify 3 different types of steel. For each type of steel, in the form of a table, give (a) the % composition of its components (b) at least 2 uses (c) at least 2 properties (d) how the different % composition gives it different properties from the other forms of steel.

There are two methods of cooling molten steel:

- **Quenching** – Quenching is the quick cooling of molten steel, which gives a harder but more brittle steel.

- **Annealing** – Annealing is the slow cooling of molten steel, the carbon in the steel alloy will remain as graphite which consequently produces extremely ductile steel; this in turn is not as hard as quenched steel.

(These processes are mentioned in the table below.)

Steel	Composition	Properties	Uses	Differentiation
Structural steel	0.3-0.6% Carbon, the rest is iron	• Hard • Malleable • High tensile strength • Corrodes rapidly	• Beams and girders • Railways, • Reinforcing for buildings	Structural steel's lack of metal alloying gives it poor corrosion resistance. However the low carbon and high iron composition gives it hard and malleable properties, if it had slightly higher carbon percentage composition it would be too brittle and slightly lower carbon percentage composition it would be too soft for construction and building reinforcement.
Stainless steel	There are over 1500 different types of stainless steel depending on the composition and manufacture, however the general composition is about 10-20% chromium, 5-20% nickel, and the rest is iron (and carbon <0.2%). Some stainless steel types can contain between 1-10% manganese, however this is more uncommon.	• Hard • Reduced brittleness • Extremely corrosion-resistant • High tensile strength (compared to mild steel)	• Food processing machinery, • Kitchen sinks and appliances • Cutlery • Surgical and dental instruments • Razor blades	The stainless steel has an increased corrosion-resistance factor due to the passivating chromium (III) oxide layer which forms on the surface of the steel. The low levels of carbon in the steel reduce the brittleness of the steel.

Tool steel	14-20% tungsten, 0-9% molybdenum, 5-12% cobalt, 0.5-4% chromium, 0.5% manganese and the rest is iron with little carbon (0.7-1.5%).	• Hard • Abrasion resistant • Extremely high tensile strength, especially at high temperatures • Extreme heat resistance	• High-speeding cutting and drilling tools • Jet engines	The hardness comes from the combination of the low levels of carbon and the addition of manganese (however if the manganese content is too high the steel will crack when quenched). The cobalt gives tool steel its abrasion resistance, it also contributes to the hardness of the alloy. The tungsten and molybdenum also contribute to the hardness of the steel but they give the steel the ability to maintain high tensile strength at high temperatures and resist extremely high temperatures.

Part 3

a) I) Explain how hydrothermal vents in mid-ocean ridges produce minerals in the oceans.

II) Include a labelled diagram.

b) Justify the reliability of your explanation.

a) Mid-ocean ridges are essentially underwater mountain ranges; they often have a rift running along them, formed by the plate tectonics. As these exist near the boundaries of tectonic plates they will tend to be the sites of geothermal activity, including sites at which magmatic fluids are present. As the ridges themselves spread apart, the magmatic fluids and molten material from the mantle cools, this cooling can cause fissures and cracks in the rock itself, and consequently sea water can sink into these cracks and is heated to approximately 350^{o}C and experiences great pressures. The pressure forces the water back into the ocean and as it passes through the cracks once more it dissolves ionic substances. The sites at which this hot water being released back into the ocean are called hydrothermal vents. As the water is cooled back into the cold ocean water the salts crystallise out of the solution and form mineral insoluble mineral deposits on the ocean floor. This only happens to the heavier minerals including sulfides of iron, copper, zinc and silver. Sulfates and chlorides of other elements including magnesium, calcium, sodium and potassium will remain in solution; these have chemically been proven to contribute significantly to the salt burden of ocean water.

Diagram is on final page

b) The explanation was a formulation of 5 different sources, including 2 different types of sources. Three textbooks all published for the HSC chemistry course ensures that the information is in fact relevant and specific to the question asked, but also the information they each present align and reinforce and reaffirm each other. The two internet websites weren't used in formulating the response, however they were read afterwards to check the accuracy of the explanation and offer possible refinements where necessary (no refinements were necessary in the end). Therefore considering the number of sources and the different types of sources, noting that none contradicted each other assures a high level of reliability in the response.

Part 4

Include a bibliography (with at least 3 sources).

Textbooks

Author	Year of Publication	Title	Publisher	Place of Publication
Peter Gribben and Marta Cassidy	2003	Cambridge HSC Study Guide – Chemistry	Cambridge University Press	Cambridge
Jim Stamell	2009	HSC Chemistry – Excel	Pascal Press	Sydney
Roland Smith	2000	Conquering Chemistry	McGraw-Hill Book Company	Sydney

Websites

Author	Year page created	Title of page	Name of site	URL	Date accessed
Linden Tregarthen	(2010)	HSC Chemistry	Google Books	http://books.google.com.au/	1st of June 2010
Charles Sturt University	2009	Shipwrecks, Corrosion and Conservation	HSC Online	http://www.hsc.csu.edu.au/chemistry/options/shipwrecks/	2nd of June 2010