Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Level 3 Technology 2024

91613 Demonstrate understanding of material development

EXEMPLAR

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Introduction

From the first aircraft being flown in 1903 with the Wright Flyer (though disputed with the New Zealander, Richard Pearce), aluminium has been used in some form in the design of aircraft. With it being used for the engine of the Wright Flyer, to it being used for the wings and fuselage of modern planes, the aluminium used has had to develop to suit the changing needs of these newer aircraft with their increased altitude and airspeed, which increases the stress put on the metal.

Overview of Aluminium

Aluminium is the 13th element of the periodic table and has a mass number of 26.98. It is a metal and was first discovered in 1825. The properties of pure aluminium are that it has high formability and high corrosion resistance, though it is very soft and weak. Because of its high formability, which means the material can undergo plastic deformation without being fractured, pure aluminium is very good at coating other metals as it can easily form to the shape required and will only very slowly oxidise.

An alloy is a combination of two or more elements to form a new metallic substance with different properties than its constituents. The elements used in the alloy are usually metals themselves, but can also be non-metals such as steel which is an iron and carbon alloy. Aluminium alloys are named with at least 4 numerical digits, the first of which denotes the main alloying element used. The latter 3 refer further to the composition features, and further digits may be added denoting further properties such as heat treatment conditions.

Table of Aluminium Naming Conventions

Alloy Group Series	Major Alloying Element
1xxx	None
2xxx	Copper
…	…
7xxx	Zinc

Depending on the type of alloy, the properties can greatly differ. 2000 series aluminium is an alloy with copper. It has higher strength and can withstand higher temperatures, making it ideal for aircraft usage. 7000 series is an alloy primarily with zinc but can also contain smaller amounts of copper and magnesium. It has high strength and toughness; it can also withstand good fatigue, which also makes it good for aircraft usage. Further alloys can be made with elements such as silicon, magnesium, and zinc. These alloys all have different properties with both benefits and drawbacks.

Research

Bauxite

Alumina

Bauxite is the raw material from which aluminium is extracted. There are two processes involved in the extraction of aluminium. Firstly the Bayer process refines the bauxite into alumina by removing the impurities of the ore, then the Hall-Heroult is a reduction-oxidation reaction that extracts the pure aluminium from the alumina.

Bauxite is mainly comprised of alumina (Al_2O_3), iron (III) oxide (Fe_2O_3), and silica (SiO_2). Alumina is an amphoteric oxide, which means it can react with both acids and bases, whereas iron (III) oxide is a basic oxide which means it can only react with acids.

Bayer Process

The first step of the Bayer process is crushing the bauxite ore. This is usually done in a jaw crusher where the raw ore is put in a V-shape cavity, called a crushing chamber, between a fixed jaw die and a movable jaw die. The force due to gravity acts on the ore pushing it downwards through the cavity, and a flywheel moves the movable jaw inwards and outwards of the crushing cavity. This inwards force compresses the ore allowing the ore inside to be crushed. The ore can leave the chamber when the movable jaw retracts and if the ore has reached the desired size, which is determined by the gap left at the bottom of the crushing chamber the ore will fall through the bottom of the crushing chamber.

The alumina, from the crushed bauxite, is digested through the usage of a base. This is because the alumina is amphoteric, so it is able to react with a base forming a new product, but since the iron (III) oxide is a base oxide, it cannot react with a base. The alumina from the bauxite is reacted with heated aqueous caustic soda (conc. NaOH), which is a base. This reaction continues for 2-8 hours at 110°C-270°C under pressure. The silica is insoluble in NaOH solution, so it is not digested. The iron (III) oxide is also not digested in the reaction as it is a basic oxide, so does not react with a base. The alumina is digested by the caustic soda and forms aqueous sodium aluminate (III) ($NaAlO_2$). The residues of silica and iron(III) oxide can then be filtered out and disposed of, if the factory has no further use for it.

The whole slurry is then pumped into a settling tank so that impurities that have not dissolved with the caustic soda (Fe_2O_3, SiO_2, and other trace metals) will settle into the bottom of the settling tank. The residue that settles to the bottom is called red mud, primarily due to the red colour from the iron; it contains the iron (III) oxide, silica, along with fine sand, and oxides of trace elements like titanium, thallium, and zirconium.

$$Al_2O_3(s) + 2NaOH(aq) \rightarrow 2NaAlO_2(aq) + H_2O(l)$$

The reaction of the alumina, from the bauxite with the caustic soda, leaves sodium aluminate when the desired product is only alumina. So now that the impurities have been removed, the sodium aluminate needs to be reacted back to alumina. First, the hot slurry is put through a series of flash tanks, where it is diluted with H_2O and pressure is reduced and the temperature is cooled down to 50°C. It is then pumped through a series of cloth filters where the final impurities can be removed. The filtered liquid is then pumped through a precipitation tank, and seed crystals of alumina hydrate are added to the top of the tank to start the precipitation process. These seed crystals grow in size from the sodium aluminate. These large crystals then settle to the bottoms of the tank, and they are then removed from the tank.

$$2NaAl(OH)_4(aq) \rightarrow NaOH(aq) + Al(OH)_3(s)$$

The $Al(OH)_3$ is then filtered, washed, and dried, then transferred to a kiln for calcinating. Calcination is heating to remove the water molecules which are chemically bonded to the alumina molecules. The kiln is heated to 1,100° C to drive out the water molecules, leaving anhydrous alumina crystals.

$$3Al(OH)_3(s) \xrightarrow{heat} Al_2O_3(s) + 3H_2O(l)$$

After passing through the kiln the crystals are cooled, and alumina remains.

Hall-Heroult Process
The Hall-Heroult process takes the alumina and separates it into molten aluminium, this is done through electrolysis. The anode electrode used is carbon blocks and the cathode electrode used is a carbon lining of the vessel used in the redox reaction. The electrolyte is molten alumina (Al_2O_3) mixed with cryolite (Na_3AlF_6). The alumina is the final product of the Bayer process, and this is mixed with cryolite to decrease the melting point of the alumina from ~2000°C to ~900°C. This helps decrease the cost of the production of aluminium because less chemical energy or electrical potential energy needs to be converted into thermal energy, which is very costly because of large amounts of heat lost in the system, this helps make the process more economically viable. When the alumina is heated, the ionic bonds between the lattice of the aluminium cation and oxide anion are broken, so they dissociate into free-flowing ions in the molten mixture.

$$Al_2O_3(s) \rightarrow 2Al^{3+}(l) + 3O^{2-}(l)$$

At the carbon block anode, the carbon rods react with the $3O^{2-}$ anion, and the $3O^{2-}$ is oxidised to form O_2 gas and loses 4 electrons. At high temperatures, the O_2 gas which is liberated at the anode reacts with the carbon from the anode to form CO_2, which causes bubbles to be released from the mixture. Therefore, the reaction with the carbon from the anode slowly burns away the anode.

$$2O^{2-}(l) \rightarrow O_2(g) + 4e^-$$

$$O_2(g) + C(s) \rightarrow CO_2(g)$$

At the cathode, the carbon lining reacts with the Al^{3+} cation, and the Al^{3+} is reduced to form molten Al, which is the desired product of this process! This reaction gains 3 electrons. Since molten aluminium is denser than the molten electrolyte, the molten Al settles at the bottom of the cell, and it is then tapped out and can be used as pure aluminium.

$$Al^{3+}(l) + 3e^{-} \rightarrow Al(s)$$

Combining the redox half-equations provides a full equation:

$$4Al^{3+}(l) + 6O^{2-} \rightarrow 4Al(s) + 3O_2$$

A few drawbacks with this process is the high temperatures required to melt the alumina, which even with the cryolite still requires high amounts of electrical and chemical energy to be converted into thermal energy. Furthermore, the reaction of the O_2 with the carbon anodes depletes the anodes, which means the carbon blocks will have to be replaced which further drives up the cost. Finally, the incidental reaction of the O_2 with the carbon anode produces carbon dioxide, which is released into the atmosphere which increases the carbon in the atmosphere which can increase the rate of global warming.

The molten pure aluminium is usually collected in a crucible which then transfers it to a holding furnace. The molten aluminium is then cast into various forms of ingots, which can then be cast into moulds to create desired shapes ready for use in manufacturing. The aluminium can be infinitely remelted and remoulded, assuming no impurities have been incorporated into the metal, to form new shapes for manufacturing.

Common Uses

Aluminium is the most abundant element in the Earth's crust at 8.1%. The first discovered usage of aluminium dates to before 5000 BC with people from Mesopotamia using clay, which consisted largely of an aluminium compound to make fine pottery. From 2000 BC the Egyptians and Babylonians are recorded to have used aluminium compounds in various medicines. These historic usages are only various compounds containing aluminium, instead of isolated aluminium. It took until 1825 to be isolated by Danish physicist Hans Christian Ørsted. The usage of pure aluminium, 99.996%, is very rare as it is soft and weak, though commercial aluminium, 99%-99.6% has small amounts of silicon and iron added which make it harder and stronger. This strengthened aluminium is still very malleable and ductile so it can be drawn into wire or rolled into foil. It is commonly used where high strength is required, but weight is an issue, for example in aircraft and automotive vehicles. It is also used in construction and building materials, along with consumer durables, such as refrigerators, air conditioners, and cooking equipment.

Properties and performance qualities

Aluminium is lighter than steel, but weaker than steel. Though the factor increase of its lightweightedness is greater in magnitude than the factor decrease of strength, this means it has a greater strength-to-weight ratio, which is a common appeal of the metal. Aluminium is light, strong, and abundant, which makes it an ideal choice when selecting a metal for a variety of applications.

Aluminium is also an excellent conductor of heat and electricity. Combined with its high ductility and malleability it is ideal for drawing into wires, as it can conduct electricity very well. It is also very highly corrosion resistant, which means it takes time for the surface to oxidise and lose the properties, for example, strength, of regular pure aluminium. Pure aluminium does not have much significant use commercially, though its alloys have a variety of uses.

The yield strength of pure aluminium is 30MPa this does not make it very suitable for usage in an airframe as the airframe undergoes bending during the flight and holding large amounts of load, which means it must be capable of high amounts of tensile strength and compressive strength. There is also no necking region of the stress-strain curve for pure aluminium, but rather the material deforms until failure in the strain-hardening region. This is typical of ductile metals because it means that the stress put on the metal can only continue positively in proportion to the decrease in radius, that is the stress applied cannot overcome the ultimate strength and cause necking, instead the metal immediately fractures. It has a density of 2.6989g/cc; it is very lightweight given its yield strength. Iron has a density of 7.85g/cc, which is 2.9 times greater than aluminium, and a yield strength of 50MPa, which is only 1.667 times greater than aluminium, so aluminium has a greater strength-to-weight ratio. The strength-to-weight ratio is how many units of load the metal can withstand (in this case measured by yield strength) per unit density of the metal. The strength-to-weight ratio of aluminium would be 11.11MPa/g/cc, and of iron would be 6.37MPa/g/cc.

The quality of strength is important for use in aircraft because aircraft work under high amounts of stress, during take-off and landing the change in acceleration requires high levels of strength to ensure the structural integrity of the aircraft. Furthermore, working close to the engines which generates lots of power, thus heat, up to 370°C. The metal must be able to withstand this heat, and not lose significant amounts of strength. Furthermore, at high altitudes and rough weather conditions, the temperature can also decrease down to -30°C. The corrosion resistance is also important because the metal can be exposed to lots of moisture in very humid environments, but also very dry desert environments. Since planes fly in the stratosphere, they are closer to the sun, so the Earth's atmosphere can absorb less ultraviolet light, so metal has greater exposure to UV light radiation, which can increase the rate of corrosion for metals, which increases the need for corrosion-resistant metals.

Product that is to be Manufactured

An alloy of aluminium has to be manufactured that can withstand high stress, temperature, and pressures, whilst also maintaining the lightweight properties of aluminium.

The product of concern is aircraft. There are several requirements for a successful material. Aircraft have a lot of mass, including the passengers and luggage, along with all the mechanical equipment, such as the engines and landing gear. This requires a material with high strength. The metal is constantly weathered, as it works outside, and can work through thunderstorms, which means it should be corrosion-resistant. The amount of energy required to move the materials should be minimised so that the cost of flying is decreased, so the material should be as light as possible, without decreasing strength. The engine also generates lots of heat, which the materials must be able to withstand, but also not significantly lose their strength.

The materials also undergo lots of stress, as during cruising the airframe has to withstand turbulence, and during takeoff/landing has to be able to withstand sharp changes in velocity (acceleration). Force is equal to the product of mass and acceleration, so the material will undergo lots of force due to the acceleration it will experience.

History of Material Use for this Product Type

The first all-metal aircraft, the Junkers F13 was first flown in 1919, and it used the aluminium alloy 2017-T4 for the body material. The major component in this alloy is copper at 3.5%-4.5%, followed by magnesium at 0.4%-0.8. The T4 suffix means the alloy has undergone solution heat treatment and it has been naturally aged to a substantially stable condition.

Development in the use of the aluminium alloy was based on the 2017 alloy first used. Magnesium was added to the 2017 alloy to form 2024, and a further development was made by adding zinc and adjusting the magnesium and copper content to create 7075. No major significant developments have been made to the alloy used since then. The 7075 alloy first appeared in the 1960s, and remains the prominent alloy used, though others have been developed such as 7150, 7050, and 7055, though these all present minor changes in the alloying agents, when the primary alloying agents remain for the 7000 series of zinc. The 2024 alloy has remained relatively unchanged since its first usage, with very minor changes being made for the specific situation of the aircraft, though the naming of the alloy remains the same, as 2024.

Chosen Material

The most common alloys used in aircrafts today are 2024 and 7075.

The properties of 2024 alloy are 90.7%-94.7% aluminium, 3.8%-4.9% copper, and >0.25% zinc. It has a tensile yield strength of 324MPa, which is 10.8 times greater than pure aluminium.

Aluminium 7075 is comprised of 87.1%-91.4% aluminium, 5.1%-6.1% zinc, and 1.2%-2.0% copper. It has a tensile yield strength of 503MPa, which is 16.7667 greater than pure aluminium, and 1.55 times stronger than than 2024 alloy.

The difference between 7075 and 2024 is that 7075 is part of the 7000 series alloys, which means it uses zinc as its main alloying element, whereas 2000, which 2024 is part of, uses copper as the main alloying element. This is shown by the relative proportions of copper and zinc as alloying agents between the two alloys. Copper has a molar mass of 65.38 g/mol, whereas zinc has a molar mass of 24.31 g/mol, so when zinc is used as the primary alloying agent of 7000 series alloys, it is expected that the alloy will be denser. The density of 7075 is 2.81 g/cc and the density of 2024 is 2.78 g/cc, this very minor difference is attributed to the small percentages of alloying agents used in the first place.

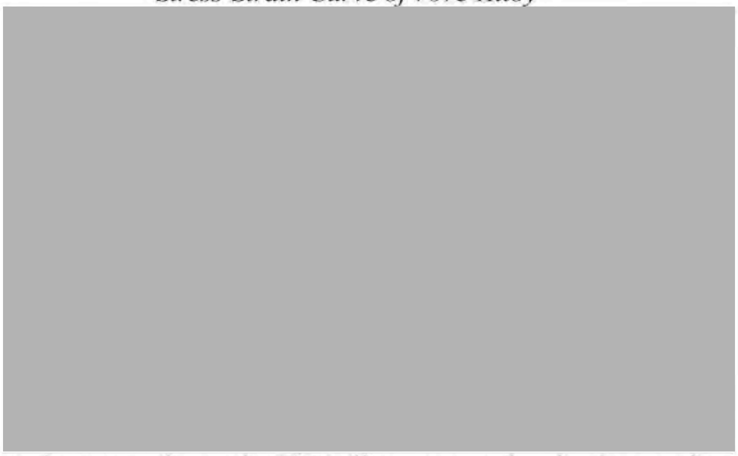
Desired Material Qualities that are Specific to the Product

The qualities that are required for the product are high strength, which both these alloys present in comparison to pure aluminium. This means the design of aircraft can be improved. During the 1960s with the development of the 7075 alloys, a major design improvement of aircraft was increasing the physical altitude barrier of flight. Whilst 7075 has decreased machinability than 2024, which makes 7075 somewhat more difficult to cut to its required shapes, it has increased strength. This means the aircraft could travel at very high altitudes where getting to such a high altitude would result in stress on the airframe. However, once at that altitude, the decreased air pressure means lower fuel consumption, so the aircraft could travel at higher speeds.

Product Enhancement

Stress-Strain Curve of 2024 Alloy

Stress-Strain Curve of 7075 Alloy



As seen from the stress-strain curves above, the 7075 alloy seems to be clearly superior, as both alloys have a yield strength with a strain of 0.01 mm/mm. The 2024 alloy reaches the yield strength at 340MPa, but it takes the 7075 alloy 570MPa to reach its yield strength, which is 1.68 times larger. This means that 7075 alloy can undergo more pressure and still return to its original shape, as the yield strength measures the maximum pressure that the material can withstand in the elastic deformation region. This is particularly useful for aircraft because their airframe will tend to bend a lot during flights due to the load it must bear, and weather conditions.

Beyond the yield strength is the ultimate strength, which is also higher in the 7075 alloy. The 2024 alloy reaches its maximum strength at 540MPa, but the 7075 alloy reaches it at 740MPa, which is 1.37 times larger. It can also be seen that if both alloys are put under the same pressure, the 2024 alloy will fracture before the 7075 even reaches its yield strength, this provides a strong case for the usage of the 7075 alloy.

The 2024 alloy has no necking region, that is, the metal will fracture before excess force is applied causing the cross-sectional area to decrease, causing a positive feedback loop and causing the metal to fracture. This is typical for ductile metals, and whilst 7075 alloy is also ductile, its increased stress tolerance allows it to withstand some plastic necking deformation.

The 2024 alloy is superior to the 7075 alloy when machineability is important. This can be seen in the stress-strain curve where the ultimate strength of 7075 is at a strain of 0.1mm/mm, but the strain at the ultimate strength of 2024 is at 0.18mm/mm. This means that the 2024 alloy can undergo more pressure in the plastic deformation region before fracture compared to the 7075 alloy. This allows the 2024 alloy to have greater machinability and formability, which is why it is still commonly used in aircraft despite its lower stress tolerance.

Compared to pure aluminium, both of these alloys are much stronger, which allows the aircraft to carry an increased load, which could be in the form of a larger and stronger engine, allowing the aircraft to travel faster and more fuel efficiently. The increased yield strength from 30MPa means the aircraft has greater impact protection and durability because it can return to its original shape after pressure has been applied.

Material Development

The process of alloying is very simple. The base metal is melted down into a liquid form, and then alloying agents are added, which are also in their liquid form, in this case, copper or zinc. This is then thoroughly mixed to incorporate the alloying agents into all of the base metal, and the alloy is formed. The liquid is then treated as required, either cooled into ingots, then remelted into moulds, or directly poured into moulds.

Techniques to be Used/Applied for Chosen Material Manufacture

Alloys are usually made when the metals are in their liquid form because it is very difficult to mix them together in any other state. The melting points of the various metals must be known, so that the furnace, or heating device used, can be heated to the appropriate temperature to ensure all metals are melted. The ratio of the alloying agents must also be known so that the correct alloy is formed.

How the Material Improves the Product's Usability (Implementation)

The various alloys of aluminium have different properties, all helping them be more usable for different purposes. 2000 series alloys can be precipitation hardened which can allow for strengths further on par with steel.

During the initiation conception of the aircraft, multiple materials were proposed for the aircraft body, this included light and strong woods, such as timber, and close-weaved fabrics such as linen. As the speeds these aircrafts travelled increased, the structural demands of the airframe also increased. Initially, the solution was to manipulate the current materials by laminating the wood and creating a monocoque airframe, which meant the structure was supported by the external skin, as opposed to individual struts. This meant greater strength, which allowed heavier loads to be carried, and better streamlining, which meant better aerodynamics, so less fuel consumption. However, the wood and fabric eventually reached a chemical limitation which was its susceptibility to deterioration when weathered. The quality of the aircraft lowered when left out in rain and wind. This led to the further incorporation of metal in aircraft by using the metal for the fuselage, as metal has low corrosion which means it can withstand weathering better than wood. This gradually led to the Junkers company making all-metal aircraft. The metal was also stronger than the wood, which meant essentially every benefit of wood was outdone by metal. With the development of the Bayer and Hall-Heroult processes, the extraction of aluminium became commercialised, so this lower cost of aluminium during this period helped increase the usage of aluminium in aircraft.

A research area for future materials used in aircraft design is bio-matter. This can include natural fibres, as currently being researched by Airbus, as these are lightweight and high-strength, so could be used in secondary, non-critical aircraft structures. This shows that the main priority still remains to be safety, though there is exploration into what else can be used, that still does the job but harms the environment less.

Another area of exploration is thermoplastics. Thermoplastics are plastic polymers that become moldable at certain temperatures, and this mould maintains its structure after cooling. Research is still being done in this field, as although the formability is excellent, strength cannot be compromised. For this reason, thermoplastics which are carbon fibre-reinforced are being developed, which are composite materials, similar in nature to alloys, which can add agents to a base material to increase the properties of the base material. The current carbon fibre-reinforced thermoplastics are 10% lighter than the aluminium alloy otherwise used. The commercialisation of these newer materials is a long way away because their development is still in progress, and then convincing the public that travelling in the stratosphere in a plastic shell or a bio-matter shell is safe may be difficult.

The stronger aluminium means that aircraft can be made that can withstand higher levels of stress and temperatures. At higher speeds, the materials will undergo greater amounts of fatigue, and the improved aluminium alloys can withstand high levels of fatigue, which makes travelling at these speeds safer. The better the alloy developed also removes the mechanical safety speed limitations on aircraft, this can be especially useful for military aircraft where speed is essential. With these aluminium alloys, the engineers can work on increasing the thrust these aircraft can generate without having to worry about the stress it will put on the body of the aircraft. Based on the possible alternatives, aluminium remains the preferred choice for aircraft because of its low cost, and mechanical properties which make it ideal for flying. People have also been used to metal used in places for over 100 years, so convincing the public that any other metal is safe, especially with the fear around flying currently, will be very difficult. The established process of aluminium production makes it cheaper than investing in developing products that may or may not work.

Another alloy of aluminium commonly mentioned is 5000 series, which is the alloy with magnesium as the alloying agent. This alloy is commonly used in the military because of its very high corrosion resistance and ease of weldability. This makes it good for marine applications and in tanks, where there is constant abrasion of the metal surface, and where servicing must be easy, as it might need to happen in dangerous environments. However, even with the benefits, the 5000 series cannot be age-hardened, and this is very important for aircraft as it means the strength increases. For aircraft, every part of the aircraft must be undamaged, otherwise the aircraft cannot fly, so the certainty of durability is important. So, even when other alloys are commonly used in similar areas, the 2000 series and 7000 series come on top for aircraft because they do exactly what is required for an aircraft to function.

Care and Maintenance

An issue with both 2024 and 7075 alloys is that they are very difficult to weld because of the large mixture of metals in the alloy. They are considered unweldable by the arc welding process. They are considered unweldable because they are susceptible to stress corrosion cracking after welding. Stress corrosion cracking is the growth of a crack formation on the metal, and this cannot always be detected immediately after welding and can take later in the service of the product to develop and thus cause failure of the metal. This means it is difficult to perform repairs on the metal while it is in service, rather the metal would have to be replaced altogether, which can be costly to get the exact alloy required for the repair.

The recent innovation of laser beam welding could see an end to this problem because the laser can weld at very specific points at very high temperatures. These temperatures are higher than the crack-sensitive peaks of the alloying agents in the 2000 and 7000 series alloys. This means that the probability of the stress corrosion cracks forming significantly decreases. The specific point of the laser welding also helps in not creating an environment when stress corrosion cracking is more likely. This could be a game changer in industries such as ventilation because currently galvanized steel is commonly used because of its high weldability, but it faces the obvious drawbacks of steel of being heavy and its susceptibility to corrosion (which is the purpose of the galvanisation). If strong and non-corrosive aluminium can be used, 2000 series and 7000 series, because we are finally able to weld them, this could prove very useful in ventilation applications, because the aluminium is also lighter, and infinitely recyclable, which makes the process cheaper and safer.

Since the metal is highly resistant to corrosion, not much has to be done to the metal, but it still must be cleaned. Usually, the exterior of the aircraft is wet-washed in the hangar using mild soap and water, then dry-washed with non-abrasive chemicals. Commercial airlines are washed every 2-6 months as required, and overall not much has to be done for the care and maintenance of the aluminium.

Disposal and Lifecycle

Aluminium is usually not disposed of but rather it can be infinitely recycled. This means that aluminium used in manufacturing can be infinitely reused as aluminium after the recycling process has taken place. The energy required to recycle aluminium is only 5% of the energy required to make new aluminium from aluminium ore. Because of the wide usage of the metal and the relative ease of recycling, ~75% of all aluminium manufactured is still in use today. The process of recycling aluminium is relatively simple, but the volume of aluminium recycled only began to grow when the volume of the primary production of aluminium increased. In the 1880s the Bayer and Hall-Heroult processes for aluminium were invented, which made it cheaper and more efficient to produce pure aluminium. This meant an increase in the overall quantity of used aluminium, which means people were able to find more uses for the metal, which meant a greater desire to recycle it, instead of disposing it.

Conclusion

The material development of aluminium alloys has improved the usage of aluminium in aircraft because it allows the weight of the aircraft to remain approximately the same, if not lighter, but the strength can significantly increase -- the strength-to-weight ratio of the material increases. The metal is also able to withstand greater weathering so it is durable. This increases the safety of aircraft as they are stronger, but also the aircraft can fly in more conditions, such as faster, during harsh weather events, and at higher altitudes.

The Bayer process and the Hall-Heroult process significantly helped in allowing the usage of aluminium to be more commonplace. This is because the production of aluminium became commercialised, so the cost of aluminium decreased. This allowed many manufacturers to use aluminium such as Junkers, and set the groundwork for using aluminium for all aircraft.

Aluminium came on top because of the ease of its production, therefore its low cost, combined with its superior properties to wood and fabric. Its usage in aircraft has remained for over 100 years, which makes it difficult to think of a world without aluminium for aircraft. This can mean resistance to better materials in aircraft, such as the bio-materials and thermoplastics being developed, but over time consumer confidence should allow these to take their place if they are better than the status quo. Though with the development of new materials, new processes are also being developed, with laser welding, which could eventually allow the welding of 2000 and 7000 series aluminium, which means their drawback of being difficult to repair could soon be a non-issue.

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Excellence

Subject: Technology

Standard: 91613

Total score: 08

Q	Grade score	Marker commentary
One	E8	The candidate refers to a product and how the material enhances its performance. This is done comprehensively, through analysis of techniques, manufacturing, material qualities and considers disposal and its lifecycle.