7075 Aluminum

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Abstract

7075 Aluminum is an alloy with zinc as the main alloying component. Its main composition includes, typically, 5.1-6.1% Zinc, 2.1-2.9% magnesium, 1.2-2.0% copper, and a small amount of a few other elements. The most common tempers of the alloy are 7075-O, 7075-T6, and 7075-T651. Its main advantage is its high strength while being lightweight. Aluminum alloys are typically corrosion resistant, but 7075 is less resistant in this regard. However, it is still less corrosion resistant than most other metal alloys. Often used in structural parts of aircraft, the earliest usage of 7075 aluminum was in the 1940s during World War II. It got to the United States and most other countries in 1945, making an immediate impact on the aerospace industry. Presently, it is used in transportation, large structures, the automotive industry, and most commonly in aircraft. This paper will discuss the history, production, applications, material properties, benefits, and disadvantages of 7075 Aluminum.

Introduction

The most common, and arguably most important, metal alloys are Ferric, consisting largely of iron, like steels. However, some non-ferrous metals have advantages and are useful in other applications, like aluminum (Al), copper (Cu), zinc (Zn), lead (Pb), and tin (Sn). Specifically, aluminum is best suited for applications in aerospace, high-rise construction, and automotive design because of its high strength to weight ratio. Aluminum is the third most abundant element on Earth, and the most abundant metal in Earth's crust, with a relative natural abundance of 8.3 weight percent (1). Due to its high reactivity, aluminum cannot be found naturally in its free form. It most commonly occurs naturally with an oxide layer, in the form of Alumina (Al_2O_3) (2). The oxide layer protects it from corrosion. In 2014, the world produced 53 million metric tons of aluminum, with the leading producers being Alcoa, Rio Tinto Alcan, Rusal, Norsk Hydro, and Chalcoa (1).

Discovered in 1727, the aluminum was only produced in small amounts until, in 1885, it was reduced electrolytically. Its alloys have two main categories: wrought alloys and cast alloys. Wrought aluminum is mechanically worked into its desired form through rolling, drawing, and extruding. Aluminum 7075 and its 7XXX alloy counterparts fall in the wrought category. The 7XXX series are alloys of either aluminum, zinc, and magnesium; or aluminum, zinc, magnesium, and copper (1). The alloys are designated by a 4-digit number (XXXX), with a letter coming after the four digits to designate the temper. The first digit indicates the principal alloying element, and the second digit identifies modifications made to the original alloy. Meant for identification purposes, the last two digits help with a timeline of the development of the alloy. The temper, also known as the hardness value or condition of the alloy, has five options: F (as-fabricated condition), O (annealed), H (strain-hardened), W (solution heat-treated and unstable; ages naturally at room temperature), and T (heat-treated to a stable condition). Some of the tempers also have their own sub-categories, with 'T' being the most notable. T6 is the most common for Aluminum 7075, with the second most common being O. There are a total of 17 variations of the 7075 alloy (3). Figure 1 shows a table of properties of three of the most common alloys: 7075-O, 7075-T6, and 7075-T73. This figure will be further discussed in the properties section of the paper.

Physical Properties

Property	7075-O	7075-T6, -T651	7075-T73, -T7351
Density	2.81 g/cc | 0.102 lb/in³	2.81 g/cc | 0.102 lb/in³	2.81 g/cc | 0.102 lb/in³

Mechanical Properties

Property	7075-O	7075-T6, -T651	7075-T73, -T7351
Tensile Strength	228 MPa | 33000 psi	572 MPa | 83000 psi	505 MPa| 73200 psi
Yield Strength	103 MPa | 15000 psi	503 MPa | 73000 psi	435 MPa | 63100 psi
Modulus of Elasticity	71.7 GPa | 10400 ksi	71.7 GPa | 10400 ksi	72.0 GPa | 10400 ksi

Thermal Properties

Property	7075-O	7075-T6, -T651	7075-T73, -T7351
Coefficient of Thermal Expansion @ 20.0 - 100 °C Temp	23.4 µm/m-°C | 13.0 µin/in-°F	23.4 µm/m-°C | 13.0 µin/in-°F	23.4 µm/m-°C | 13.0 µin/in-°F
Thermal Conductivity	173 W/m-K | 1200 BTU-in/hr-ft²-°F	0.960 J/g-°C | 0.229 BTU/lb-°F	155 W/m-K | 1080 BTU-in/hr-ft²-°F

Figure 1: List of physical, mechanical, and thermal properties of three common aluminum 7075 tempers (4)

Discussion

History

In 1935, a Japanese company named "Sumitomo Metal" attempted to create a lightweight, high strength-to-density ratio aluminum alloy, with the purpose of developing a faster and stronger aircraft for the Imperial Japanese Navy. With the secret development, they ended up creating what is now known as Aluminum 7075. Not put to use in the Navy until 1940, it constructed the Mitsubishi A6M Zero Fighter, as seen in figure 2, which was considered the best carrier-based fighter of its time. Its lightweight frame made it easier for the pilot to handle and control and extended its flight range. Consequentially, the Japanese developed more of these fighters than any other plane in its fleet in World War II. The alloy eventually came to the United States and other countries in 1943, from Alcoa. By 1945, aerospace and aircraft industries standardized its use (5).

Figure 2: The Mitsubishi A6M Zero Fighter (6)

Extraction

Aluminum occurs in many minerals: corundum (Al2O3), Spinel (MgAl2O4), Gibbsite (Al(OH)3), boehmite (AlO(OH)), diaspore (AlO(OH)), Alunite(KAl3(SO4)2(OH)6), kyanite (Al2SiO5), sillimanite (Al2SiO5), and some other clay minerals (1). The majority consist of aluminosilicates, but taking out aluminum from silicate minerals is expensive, hard, and takes a lot of energy. Thus, aluminum is typically extracted from ore. As the world's main source of aluminum, bauxite occurs from plate tectonics and climate conditions. It is a residual sedimentary rock with high content of alumina. Its appearance is a soft, red clay. Originally discovered in 1821 by Pierre Berthier, the name stems from the French *Les Baux de Provence*, a small village in southeastern France (1). The limited number of places that source the ore include

Australia (35%), South America (25%), and Africa (15%) (1). 95% of bauxite found is sufficient for production of aluminum metal. Figure 3 reflects the composition of bauxite.

Oxide	Chemical composition (wt%)	Mineral constituents
Alumina (Al_2O_3)	35–65	Gibbsite, boehmite, diaspore
Silica (SiO_2)	0.5–10	Quartz, chalcedony, kaolinite
Iron oxide (Fe_2O_3)	2–30	Goethite, hematite, siderite
Titania (TiO_2)	0.5–8	Rutile, anatase
Calcia (CaO)	0–5.5	Calcite, magnesite, dolomite

Figure 3: Mineral constituents and chemical composition of bauxite (1)

The production of aluminum contains two main processes, the Bayer process and the Hall–Héroult process, followed by alloying and refining.

The Bayer Process

After being invented in 1887, the Bayer process first got implemented in 1893 in Gardanne, France. Today, over 95% of aluminum in the world is extracted from the Bayer process (1). The conditions of the process depend on the bauxite used, but they all follow similar steps. Below, in figure 4, is a flow chart of the Bayer process, with further explanation after the diagram.

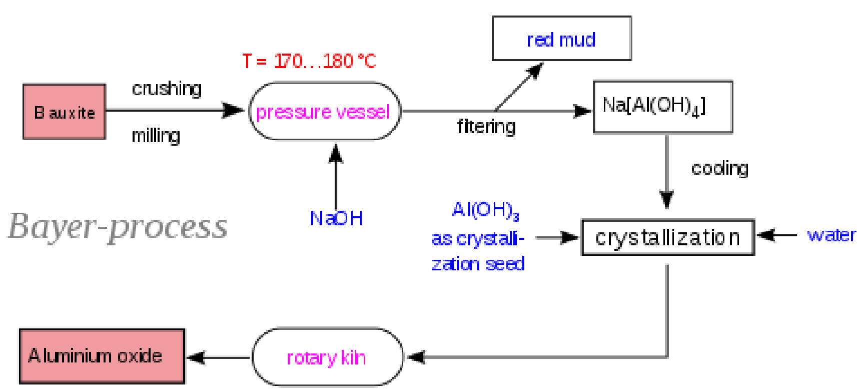

Figure 4: Flow chart of the Bayer Process (7)

The first part, comminution, starts with the ore being crushed by an industrial machine, creating particles no larger than 30 millimeters in diameter. Next comes desliming, where the contents are washed with water, removing silica and clay minerals. After, the ore is mixed with recycled caustic liquor and then ground smaller, creating a slurry of bauxite where 90% of the particles are less than 300 micrometers in diameter. The second step, digestion, depends on the composition of the ore. The conditions and exact chemical formulas for each digestion reaction are shown in figure 5. The aluminum oxide in the ore is converted into soluble sodium aluminate (1).

Bauxitic ore	Digestion reaction	Conditions
Gibbsitic	$2AlO(OH) \cdot H_2O + 2NaOH \rightarrow 2NaAlO_2 + 4H_2O$	Atmospheric pressure, 135 °C < T < 150 °C
Boehmitic	$2AlO(OH) + 2NaOH \rightarrow 2NaAlO_2 + 2H_2O$	Atmospheric pressure, 205 °C < T < 245 °C
Diasporic	$2AlO(OH) + 2NaOH \rightarrow 2NaAlO_2 + 2H_2O$	High pressure (3.5–4 MPa), T > 250 °C

Figure 5: Digestion conditions for various bauxitic ores (1)

The contents are heated, which dissolves the alumina. The sodium hydroxide reacts with both alumina and silica. The slurry is then diluted, which helps with settling of the matter. After, the solution is heated slowly, causing the silica to precipitate out. Finally, more filtering occurs and alumina trihydrate ($Al(OH)_3$) is obtained. This can now be used in its form or be calcined into other types of aluminum. If one chooses to calcinate the alumina trihydrate, it will happen in a rotary kiln or a fluidized bed calciner at 1100-1300 degrees Celsius (1). The aluminum trihydrate may then decompose into alumina and water, according to the formula:

$$2\ Al(OH)_3 \rightarrow Al_2O_3 + 3\ H_2O$$

The Hall– Héroult Process

Invented in 1886, one year before the Bayer process, The Hall– Héroult process is used for electrowinning aluminum and comes after the Bayer process in the steps of extraction. As a very energy intensive process, the electricity used to produce aluminum makes up 25% of its cost (1). In basic terms, the pure and anhydrous aluminum previously produced is reduced to regular aluminum, with the scrap getting remelted. The reaction looks as so (1):

2 Al_2O_3 (dissolved in Na_3AlF_6) + 3 C(s) → 4 Al (I) + 3 CO_2 (g)

In the final refining stages, the molten aluminum can be purified more or mixed with other elements to create the desired alloy. An average aluminum smelter has about 250-300 pots, making 125,000 metric tons of aluminum yearly, typically of 99.7% purity (1).

Figure 6 is an aluminum oxide electrolysis cell, used as part of the Hall– Héroult process. The cathodes and anodes are made of graphite. During electrolysis, the positive Aluminum ions take electrons from the cathode and form molten aluminum. Coincidingly, the oxide ions lose electrons at the anode and form oxygen molecules (8).

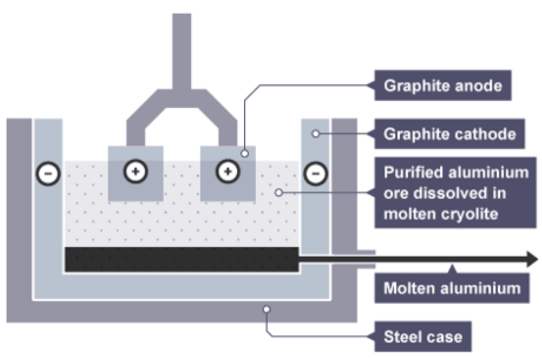

Figure 6: The cross section of an electrolysis cell (8)

Production of Alloys

Wrought alloys are produced with thermomechanical processing, and cast into ingot products like billets, bars, plates, sheet extrusions, or wires. There are two types of wrought alloys: heat-treatable alloys, which are strengthened by solution heat-treatment, or non-heat-treatable alloys, which are strengthened by cold work. The 7075 alloy is heat-treatable, and figure 7 shows the conditions for heat treatment of two tempers: W and T73 (9).

Alloy	Product	Solution heat treatment		Precipitation heat treatment		
		Temp, °F	Temper designation	Temp, °F	Time of aging	Temper designation
7075	Forgings	860-880	W	215 – 235 } * 340 – 360 }	6-8 h 8-10 h	T73

Figure 7: Heat treatment conditions for Aluminum 7075-W and 7075-T73 (9)

Structure

As seen in figure 8, the alloying of aluminum 7075 consists largely of Zinc (5.1-6.1% weight), magnesium (2.1-2.9% weight), copper (1.2-2.0% weight), and a small amount of a few other elements: silicon (0.50% weight), iron (0.70% weight), manganese (0.30% weight), titanium (0.20% weight), chromium (0.18-0.40% weight), and 0.05% weight of three other elements (9).

AA Alloy Number	Si	Fe	Cu	Mn	Mg	Zn	Ni	Ti	Cr	Other Elements (Each)	Other Elements (Total)
7075	0.50	0.70	1.2–2.0	0.30	2.1–2.9	5.1–6.1		0.20	0.18–0.4	0.05	0.15

Figure 8: Elemental composition of Aluminum 7075 (9)

At room temperature, pure aluminum has a face-centered cubic (FCC) crystal structure, as seen in figure 9, with an atomic radius of 0.143 nanometers. The most common tempers of Aluminum 7075 also have a face-centered cubic crystal structure.

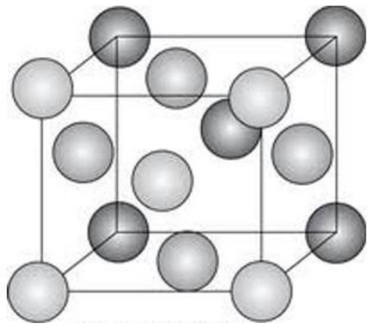

Figure 9: Pure aluminum crystal structure (10)

Figure 10 is the graph of an X-Ray diffraction pattern of an annealed sample of 7075 aluminum, showing the alloys reflecting patterns at various miller indices. Notice that the intensity is greatest at (111), with it also reflecting at (200) and (220) (11).

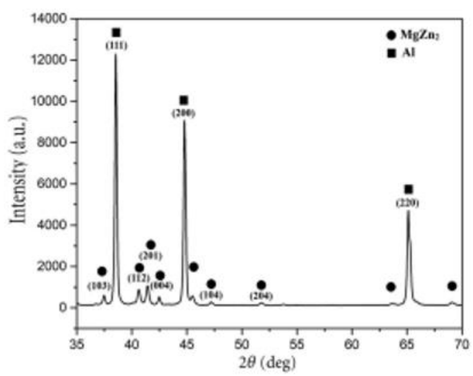

Figure 10: X-Ray diffraction pattern of an annealed sample of aluminum 7075 (11)

The most common compound of aluminum, aluminum oxide (Al_2O_3), bonds metallically, along with most other aluminum compounds. Figure 12 shows the molecular structure of the compound, while figure 11 shows the way it is bonded, with two aluminum atoms and three oxygen atoms (12).

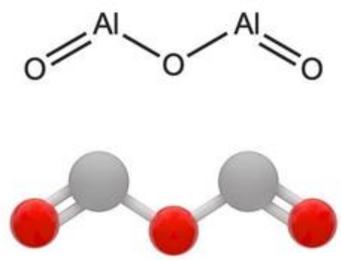

Figure 11: Molecular structure of aluminum oxide (Al_2O_3) (12)

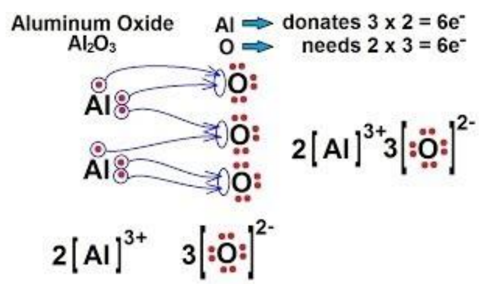

Figure 12: Bonding of aluminum oxide (Al_2O_3) (13)

Properties, Advantages, and Disadvantages

Pure Aluminum

On the periodic table, aluminum lies in the third group and third period, with atomic number 13. Its basic properties are listed in figure 13, including an atomic weight of 26.97 grams per mole and an electron configuration of $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^1$ (2). Compared to other metals, it has a low density. In solid form, it is of silvery-white color. Due to its high electrical conductivity, aluminum and its alloys are commonly used as conductors (2). They also reflect radiant energy throughout the whole spectrum. It has better heat transfer capabilities than other metals because of its high thermal conductivity. It is nonmagnetic and does not easily ignite. Due to it containing both metallic and nonmetallic properties, like being amphoteric, some consider it a metalloid, but it is more commonly referred to as a metal (2). Further, it is not soluble in water at room temperature (2). Pure aluminum is soft and ductile in the annealed condition, so it is easily cold worked to good strength (3). Another advantage comes with corrosion resistance. Aluminum corrodes less than iron and steels because it reacts to oxygen better. Lastly, the greatest advantage to aluminum is its high strength to weight ratio. Some of these properties can be improved from strain hardening, thermal treatment, or combustions (1). One key drawback from aluminum is its high specific energy consumption, which causes it to take more energy to produce, bringing up the cost.

	Atomic no.	Atomic weight	Density, lb/in^3	Melting point, °F	Boiling point, °F	Specific heat*	Latent heat of fusion, Btu/lb	Linear coef of thermal exp. per °F × 10^{-6}	Thermal conductivity (near 68°F), Btu/(ft^2 · h · °F/in)	Electrical resistivity, μΩ · cm	Modulus of elasticity (tension), lb/in^2 × 10^6	Crystal structure†	Transition temp., °F	Symbol
Aluminum	13	26.97	0.09751	1,220.4	4,520	0.215	170	13.3	1,540	2.655	10	FCC		Al

Figure 13: Properties of pure aluminum (9)

Aluminum 7075

Aluminum and its alloys come in many forms commercially. Zinc is the main alloying element in the 7XXX series, usually combined with magnesium through heat treatment in order to strengthen the alloy. Most of the alloys in this series contain 4.5-7.6% zinc, 1.4-2.7% magnesium, and sometimes have copper, manganese, silicon, titanium, or zirconium (14). Figure 14 is the phase diagram of zinc in aluminum, portraying phases of the compound depending on atomic percent of each element and temperature. Notice that the diagram is much more intricate than typical phase diagrams. The pure alpha phase is significantly larger than the beta phase, proving that increasing the atomic weight of zinc greatly changes the compound.

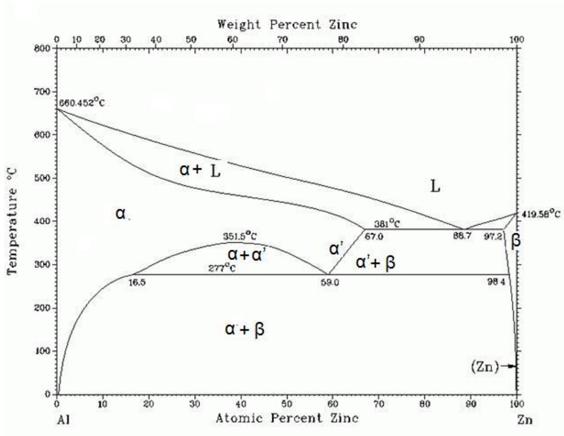

Figure 14: Phase diagram of zinc in aluminum (15)

The high zinc concentration reduces corrosion and stress corrosion cracking resistance. Also, when zinc combines with small amounts of magnesium or copper, it sometimes turns heat-treatable with very high strength, making it ideal for aircraft. On the other hand, the small copper component makes it not easily welded. Also, adding copper makes the alloy more susceptible to corrosion. One of aluminum's main advantages is its corrosion resistance, so adding copper causes issues for 7075 (9).

Looking back at figure 1, the differences in physical properties, mechanical properties, and thermal properties are shown for three common tempers of aluminum 7075: 7075-O, 7075-T6, and 7075-T73. Notice that the range in tensile strength is between 228 and 572 MPa, while the range in yield strength is slightly larger, lying between 103 and 503 MPa. Further, the density, modulus of elasticity, and coefficient of thermal expansion are the same for each temper (4). The temper only affects certain properties, and it does not affect common constants, like the modulus of elasticity.

Below, in figure 15, is a longer list of physical properties of the most common aluminum 7075 temper: T6. This temper is used most widely in industry applications.

Alloy and Temper	Density, g/cm3 (lb/in.3)	Specific gravity	Melting point, °C (°F)	Specific heat capacity, J/kg·K (Btu/lb ·°F)	Coefficient of thermal expansion, 10-6/K (µin./in. ·°F)	Thermal diffusivity, mm2/s	Thermal conductivity, W/m·°C (Btu·in/h·ft2·°F)	Electrical conductivity, Equal volume (Equal weight), % IACS	Electrical conductivity, Equal volume (Equal weight), MS/m	Electrical resistivity, Ω·mm2/m (Ω·circ mil/ft)
7075-T6	2.81 (0.101)	2.81	477-638 (890-1175)	960 (0.23) at 20 °C (68 °F)	23.6 (13.1) at 20-100 °C (68-212 °F)	48.36	130 (900) at 25 °C (77 °F)	33 (105) at 20 °C (68 °F)	19 (61) at 20 °C (68 °F)	0.0515 (31) at 20 °C (68 °F)

Figure 15: Physical properties of aluminum 7075-T6 (14)

In correlation with the physical properties, figure 16 displays the stress-strain curve for aluminum 7075-T6 (16). The graph looks like a typical stress-strain curve for metals. If the graph continued past the 0.12 engineering strain, it would dip slightly, and a fracture point would be reached.

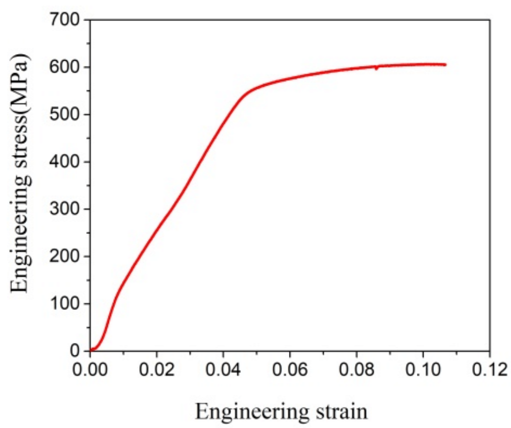

Figure 16: Stress strain curve for aluminum 7075-T6 (16)

Like all metals, Aluminum 7075 is affected by the phenomenon of creep at high temperatures. Its creep rate is not an advantage nor a disadvantage, as it is average in comparison to other metals. The final figure of the properties section, figure 17, shows the creep rate of the alloy with three different stresses (17). Notices that the creep strain increases as the stress increases, expectedly.

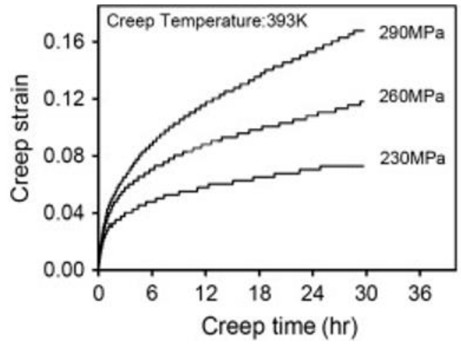

Figure 17: Creep graph of aluminum 7075 at a temperature of 393 K (17)

Applications

Like most metals, aluminum is ductile, so it can be formed or machined into various shapes easily. Typically, aluminum alloys are easily joined by welding, brazing, soldering, and riveting. Its nontoxicity makes it useful for certain applications. This, combined with its low cost, make it desirable for use in construction and similar applications (9).

The most common application of the 7075 alloy is in the aircraft industry. For some planes, it is the principal structural metal. More specifically, it is used for components like aircraft fittings, missile parts, or gears. As one of aluminum's highest strength alloys, it is picked to be used when a material is needed that is stronger than Aluminum 2024. A downside to its high strength is its difficulty to work, and it must be formed while in an annealed state or under high temperatures (18). As seen in figure 18, large commercial airplanes often use Aluminum 7075 for their upper wing surfaces.

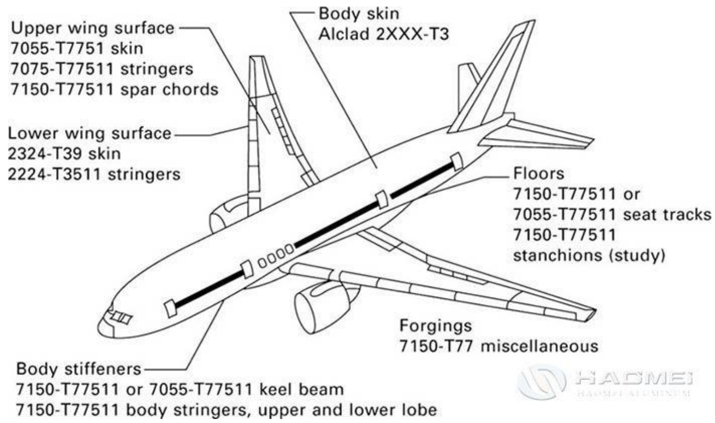

Figure 18: Types of aluminum for each part of a commercial airplane (19)

Four common forms of pure aluminum include flake (figure 19), otherwise known as powder, paste, shot (figure 20), and foam (figure 21); they each have different advantages and uses. Aluminum flake enhances the reflectance and durability of paints and can be used in catalysts, soaps, explosives, fuels, and thermite welding. Aluminum paste is used in the same applications as flake, while shot is used for deoxidizing steel. Lastly, foam is made with zirconium hydride or other hydrides, and is a good core material for lightweight structures (3).

Figure 19: Aluminum flake (20)

Figure 20: Pure aluminum shot (21)

Figure 21: Aluminum foam (22)

Oftentimes during processing, heavy deformation creates exfoliation corrosion, which causes the alloy to be non-suitable in operations with water systems. 7075 is commonly used for plastic molding. Figure 22 shows an example of this, with a two-liter bottle mold experiencing this exfoliation corrosion. Looking closely at the picture, the corrosion occurs at the bottom of the mold, near where the ruler is placed. It is hard to notice from sight because most of the corrosion occurs under the surface (9).

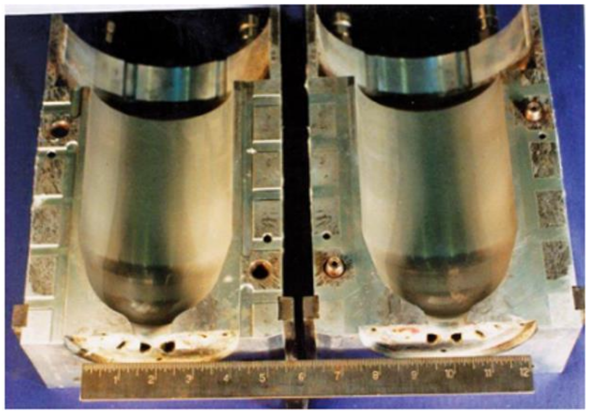

Figure 22: Aluminum alloy mold used to produce two-liter plastic bottles (9)

Figures 23 and 24 portray the effects of aluminum oxide corrosion on aluminum 7075 in a water system. Gaps formed between the grains, and the grains were forced apart because the products were more voluminous than pure aluminum (9). This led to bulging. The chemical formula of the occurrence portrays the reaction between water and pure aluminum:

$$2\ Al + 3\ H_2O \rightarrow 3\ H_2 + Al_2O_3$$

Figure 23 shows this from a normal eyesight perspective, while figure 24 is the microstructure of the piece. In figure 23, towards the bottom of the hole and in the center of the picture, the material looks layered where the corrosion occurs. Further, in figure 23's microscopic view, the corrosion forms where the black lines are being separated in the right-bottom quarter of the image (9).

Figure 23: Aluminum grains forced apart from aluminum oxide corrosion (9)

Figure 24: Microstructure of intergranular corrosion of aluminum grains (9)

Occasionally, aluminum alloys are anodized, which is when an aluminum oxide layer is formed around the alloy, which is thicker than produced naturally. The purpose of anodizing is to make the part more corrosion resistant, and it also adds a better look to the part. Since aluminum 7075 contains copper, it has worse corrosion resistance than most aluminums, and thus, adding an anodization layer diminishes those effects of copper (9). The method of anodizing is called an electrolytic oxidation process, where the part is put in a chemical solution, usually containing sulfuric, chromic, or organic acids. A direct current is then applied, as the part serves as an anode to make the thicker layer. The part typically becomes shinier than previously, and that is one way to tell that a piece has been anodized. Figure 25 depicts an anodized component.

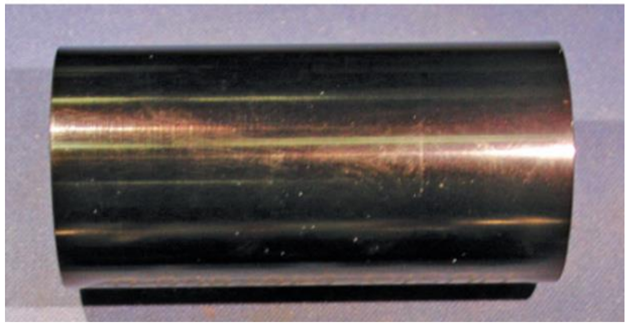

Figure 25: Aluminum part with a shiny, black anodization layer (9)

Other industries with usage of Aluminum 7075 include defense, marine, and automotive. Listed next are other random applications of Aluminum 7075: shafts, regulating valve parts, worm gears, silicon wafers, rock climbing equipment, bicycle components, inline skating frames, hang glider airframes, M-16 rifles, AR-15 rifles, lacrosse stick shafts, camping fork and knife sets, and competition yo-yos (23).

Conclusion

Aluminum is one of the most important metals on the planet. Its high strength to weight ratio and great resistance to corrosion makes it ideal for certain industry applications. Aluminum 7075 is an even stronger alloy, making it common in the aerospace industry. However, due to its copper content, it is less corrosion resistant than other aluminum alloys. It is also less ductile than other aluminums and takes more energy to form. Despite these drawbacks, aluminum 7075 is still one of the most common aluminum alloys because of its incredible strength. As the automotive, transportation, and aeronautics industries continue to develop, stronger and more lightweight materials will be needed, and aluminum 7075 will continue to be used with these progressions.

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