Aluminum Alloys and Their Applications

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One of the most versatile materials available to Engineers for their products, structures and vehicles is Aluminum in one its many alloys and conditions. Aluminum is the most abundant available metal on Earth comprising 8.2% of the Earth's crust by mass it is however found only as one of its many compounds.

Below: The innovative application of a new Al – Cu alloy helped make possible the Wright brothers' first powered flight roughly ten years after Aluminum became commercially available.

In contrast to Aluminums abundance, practicality and usefulness to modern society is the fact that it was one of the last common metals that are applied today in large quantities to be discovered and isolated. Sir Humphry Davy, who is credited with the isolation of Magnesium, Strontium, Barium, Potassium, Sodium, Calcium and Boron during the years 1807 and 1808, discovered the metal contained in the common substance Alum also in 1808 and named it Aluminum in 1812 however Davy was not able to isolate the metal he had discovered. Despite the name Aluminum that Davy had given the 13th element the official name of Aluminium was adopted to conform with the names of most other elements. The 1828 Webster's dictionary applied the Aluminum spelling and maintained this in later editions. In 1925 the American Chemical Society decided to go from Aluminium back to Davy's original name of Aluminum for the element and for this reason the metal is referred to as Aluminum in North America and as Aluminium in most other parts of the world. The IUPAC periodic table currently lists both spellings and states that both are entirely acceptable.

By whichever name it is referred, the metal was first produced (in impure form) by the Danish chemist Hans Christian Oersted in 1825 and two years later by the German chemist Friedrich Wöhler who had developed a different way to obtain Aluminum by mixing anhydrous Aluminum Chloride with Potassium and was the first to produce a pure form of the metal. By 1845 Wöhler was able to produce samples large enough to determine some of the metals basic properties. Wöhler's method was improved in 1854 by Henri Etienne Saint-Claire Deville, a French chemist. Deville's process allowed for the commercial production of Aluminum and as a result, the price of Aluminum (at rates of the time) dropped from approximately $1,200 per kilogram in 1852 to $40 per kilogram by 1859, this was of course still much too expensive to be widely used. The scarcity of pure Aluminum through the mid-1850's had made it more valuable than Gold and Aluminum was selected for the 2.8-kilogram capstone of the Washington Monument. This capstone was set in place in an elaborate ceremony on December 6, 1884 and was the largest single piece of Aluminum ever cast at the time.

Two important developments in the 1880's greatly increased the availability of Aluminum. The first was the invention of a new process for obtaining Aluminum from Aluminum Oxide. The American chemist Charles Martin Hall and French chemist Paul L.T. Heroult had each invented this process independently in 1886 and Hall received U.S. patent #400,666 for it in 1889. The second was the invention of a new process that could inexpensively obtain Aluminum Oxide from bauxite, an ore that contains a large amount of Aluminum Hydroxide along with other compounds, this process was developed by the Austrian chemist Karl Joseph Bayer. The Hall-Heroult and Bayer processes are still used today to produce nearly all the worlds Aluminum. With an easy way to extract Aluminum from Aluminum Oxide and an efficient way to extract large amounts of Aluminum Oxide from bauxite, the era of affordable Aluminum had begun. In 1888, with the financial backing of Alfred E. Hunt, Hall formed the Pittsburgh Reduction Company, which is now known as the Aluminum Company of America or ALCOA. When it opened his company could produce about 25 kilograms of Aluminum per day, by 1909 his company was producing over 41,000 kilograms of Aluminum per day and because of this huge increase in supply the price of Aluminum fell rapidly to about 60 cents per kilogram.

It is entirely possible that the affect this new metal would have on our future culture was best demonstrated in 1903 with the Wright brothers flight of the first heavier than air, steerable aircraft. Once they had decided to attempt powered flight, the Wrights calculated that they needed an engine that produced at least 8 horsepower and weighed no more than 200 pounds. The need for an 8-horsepower internal combustion engine directed them to the fledgling horse-less carriage industry and a quick survey revealed that no such engine with that power was available within their 200-pound weight limit and that they would have to develop their own. An acquaintance at the nearby Buckeye Iron and Brass Works in Dayton, OH advised them that they could save weight if they cast their engines block from Aluminum. Although this was a soft metal, alloys had recently been developed that were much stronger and both Benz and Daimler in Germany had been experimenting with these alloys in making Aluminum alloy engine blocks. The Wrights decided to cast their engine block from an alloy of 92% Aluminum and 8% Copper. The four-cylinder engine they produced developed 12 horsepower at 1,075 RPM and weighed only 180 pounds giving it a very high specific power for its time.

Figure 1: Engine castings for a replica of the Wright Brothers 1903 flyers engine showing engine block cast from Aluminum alloy and combustion chamber and ignition system components cast from Bronze.

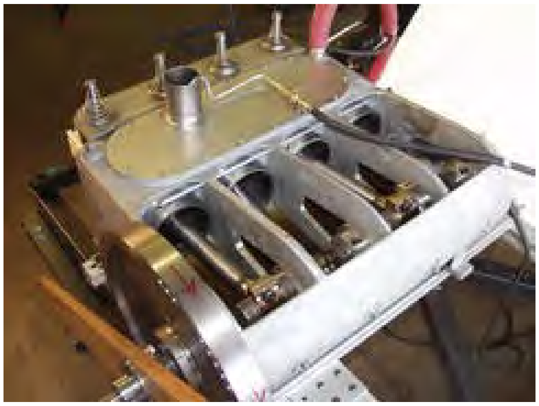

Figure 2: Assembled replica engine of Wright Brothers first plane with sheet metal side cover of crankcase removed to show novel Aluminum engine block/crankcase construction with iron cylinder liners. Major components of the original engine were donated to various museums and never returned.

The Hall-Heroult process produces Aluminum with a purity of above 99% and further purification can be done by the Hoopes process. This process involves the electrolysis of molten Aluminum with a Sodium - Barium and Aluminum Fluoride electrolyte, the resulting Aluminum has a purity of 99.99%.

The ability to produce Aluminum with a known and predictable purity of greater than 99% became very significant early in the 20th century for use in electrical power transmission and the production of Aluminum foil which was first introduced in 1910. When the first U.S. electrical transmission and distribution system was built in 1882 it was already known that nearly pure Aluminum was a much better conductor of electricity than Copper by weight (204% greater conductivity) however Aluminum was too expensive, and the system was built using Copper wire. By 1909 Alcoa was able to produce and draw what we know today as alloy 1050 Aluminum wire in large quantities and at a relatively low cost and this and its successor, 1350 became the conductor of choice for long distance power transmission. Wrought Aluminum alloys are assigned a 4-digit designation and in the case of alloy 1050, it meant that the material was at least 99.50% pure Aluminum and possessed the electrical conductivity, ductility and malleability desired for this wire.

Aluminum alloys are divided into two general categories and each has a distinct system for identification of the alloys principle alloying metals, properties and applications. The two general categories under which nearly all the Aluminum used will fall are: **Wrought alloys** and **Casting alloys.** Our discussion will begin with wrought alloys which comprise over 80% of all Aluminum alloys used today.

Wrought Aluminum Alloys

Wrought alloys are most often in the form of sheets, bars and plate as initially produced. Wrought Aluminum alloys are further sub-divided as either strain hardening or heat treatable alloys and this as well as their general composition will be covered.

As briefly mentioned earlier, all wrought Aluminum alloys are identified by a four-digit numerical system which is administered by the Aluminum Association. This system for alloy identification was first adopted in the U.S. in 1954 and three years later was approved as the American National Standard H35.1. This designation system was officially adopted by the International Signatories of the Declaration of Accord in 1970 and became the accepted international designation system. In the same year, Standards Committee H35 was authorized by the American National Standards Institute (ANSI) and the system became the universal designation system for wrought Aluminum products. The alloys are conveniently divided into seven common groups based on their principal alloying element. The first digit identifies the alloy group as follows,

Table 1

ALLOY GROUP	**PRINCIPAL ALLOYING ELEMENT**	**PROPERTIES ENHANCEMENT**
1xxx	Unalloyed Aluminum	Strain harden-able
2xxx	Copper	Heat treatable
3xxx	Manganese	Strain harden-able
4xxx	Silicon	Heat treat-able*
5xxx	Magnesium	Strain harden-able
6xxx	Magnesium and Silicon	Heat treat-able
7xxx	Zinc	Heat treat-able
*with controlled additions of Copper and Magnesium		

The last two digits in the 1xxx group correspond with the two digits after the decimal which indicate the minimum Aluminum content. For example, the Aluminum content of 1060 is 99.60% minimum, 1100 is 99.00% minimum, 1350 is 99.50% minimum and so on. The last two digits of the other groups are sequential numbers issued by the Aluminum Association to ensure that each alloy is uniquely identified. The second digit in all the groups indicates a minor modification of the basic alloy, for instance 5252 is the second modification of 5052 alloy.

In addition to the four-digit identifier applied to wrought Aluminum alloys are alpha-numeric temper designations that appear after the four-digit code separated by a hyphen. As can be seen in the above table 1, alloy groups 1, 3 and 5 are strain hardening alloys meaning that improved or otherwise altered mechanical properties of these is obtained by varying degrees of cold forming the material (stamping, rolling, etc.) The following general conditions of these alloys are described by the letter immediately following the hyphen.

Table 2

xxxx- F	**As fabricated:** Applies to products of rolling or forming where there is no special control over the thermal or work-hardening conditions. Since mechanical properties may vary widely, no limits have been assigned and this temper usually applies to sheet products which are at intermediate stages of production.

xxxx- H	**Strain-Hardened:** Applies to wrought products which are strengthened by cold-rolling or cold-working.
xxxx- O	**Annealed:** Applies to wrought products which have been heated above the re-crystallization temperature to produce the lowest tensile strength condition of the alloy.
	The following descriptors are applied af esignation to define its temper and ther achieve the final temper condit
-H1	**Strain** ain hardened to obtain the des rmal treatment.
-H2	**Strain H** cts that are strain hardene by a partial anneal which re
-H3	**Strain Ha** s to Magnesium containing age-soften at room temperatu eal is then applied which stab
	A final desc the conditions mentioned above to indicate the amount of strain hardening applied and hence the strength level of the product.
-Hx2	Quarter Hard
-Hx4	Half Hard
-Hx6	Three Quarter Hard
-Hx8	Full Hard
-Hx9	Extra Hard (the minimum tensile strength exceeds that of the Hx8 temper by 2 thousand pounds per square inch or more)