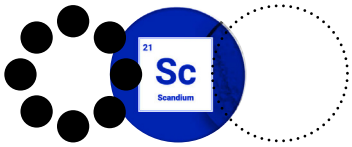
WHITE PAPER



ALUMINUM-SCANDIUM ALLOY

Executive Summary

Scandium (Sc) is one of the highest-valued elements in the periodic table and a critical raw material essential for several emerging applications. The technological applications for Sc are unique, as it is a key component in producing solid-oxide fuel cells and high-strength aluminum alloys used in aerospace and 3D printing. Historically, the supply of Sc has been limited, due to its scarcity and high cost of production. Coherent has significantly advanced the availability of Sc through a series of patented processes for the economical recovery of the element.

COHERENT

Scandium Production Technology

Most Sc is produced today as a by-product of other mineral refining processes, such as bauxite residues from alumina production and acid wastes from titanium dioxide pigment production. These sources have Sc concentrations that are at the levels of milligrams per kilogram and are considered exploitable but technologically complicated to recover. Coherent has developed its patented Selective-Ion Recovery (SIR) technology to cost-effectively extract Sc from solution containing such low concentrations. Coherent also uses its advanced technologies to further purify the intermediate Sc concentrate to produce greater than 99.9% scandium oxide.

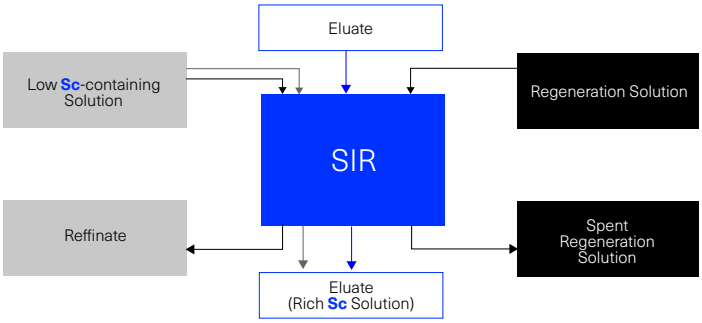


Figure 1. Scandium recovery process using Coherent SIR techonology

Using Scandium as a Strengthener

Sc is the most effective microalloying strengthener for aluminum and aluminum alloys. Sc imparts substantial improvement in strength, even with small additions of between 0.1% to 1%, or 50 MPa per 0.1%. Sc promotes fine-grained equiaxial structure during solidification and evenly distributed nano-sized precipitates during specific heat-treatment processes that are coherently bound to the aluminum matrix.

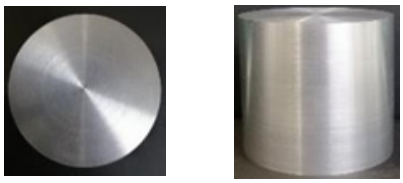


Figure 2. Aluminum-scandium alloy billet

Benefits of Aluminum-Scandium Alloys

Aside from improved strength, other beneficial impacts of Sc on the properties of a wide range of aluminum alloys are improved resistance to hot cracking, resistance to crystallization, and reduced grain size. These exceptional properties, coupled with the inherent lightweight property of Sc-containing aluminum alloys, make them particularly suitable for advanced engineering applications by allowing design and construction of strong, lightweight structural parts.

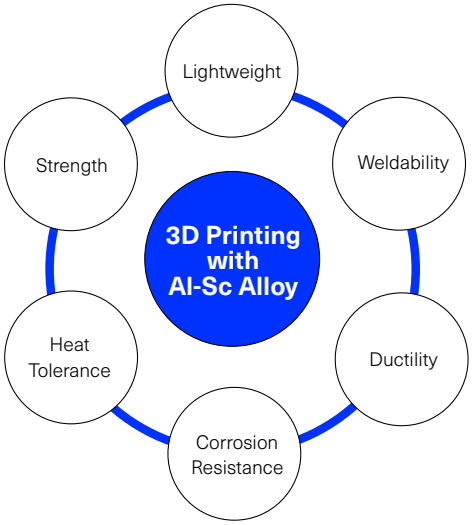


Figure 3. Properties of aluminum-scandium alloy

Scandium Benefits Compared with Other Microalloying Elements

While strength is the most important property for consideration in aluminum alloys, other measurable properties are to be considered as well. Typically, as strength improves, the alloy becomes brittle and other desirable properties tend to degrade. Copper and zinc, for example, impart strength when alloyed with aluminum, but they make the alloy brittle, less weldable, and more susceptible to corrosion. Sc is unique in comparison with other microalloying elements in that it minimizes loss of the various desirable properties while maintaining strength.

Aluminum-Scandium Effect on 5000 Series Alloys

Among the aluminum alloy families, Sc has the most pronounced strengthening effect on the 5000 series (Al-Mg). The Al-Mg combination is a soft alloy and has relatively

low strength, often below usable limits in demanding applications. Sc improves the strength of 5000 series alloys while preserving or even enhancing the best properties. Specifically, Sc additions of 0.25% can increase yield strength on a 5000 series alloy by 150% while maintaining ductility. The other benefits of Sc to 5000 series alloys are a significant enhancement in formability, improved thermal stability, improved resistance to recrystallization, and enhanced resistance against fatigue-crack growth.

Additions of Other Microalloying Elements

The presence of other microalloying elements such as manganese, titanium, and zirconium, single or in combination, influence the properties of the alloy. Additions of manganese improve hardness and strength, even at elevated temperatures, and improve machinability without impairing corrosion resistance but decrease ductility. Titanium depresses the electrical conductivity and has a grain-refining effect, which when present in weld-filler wire, refines the structure and prevents weld cracking. Small additions of zirconium allow the formation of a fine precipitate of intermetallic particles that inhibits recovery and recrystallization.

Aluminum-Scandium Alloy Applications

Sc-containing aluminum alloys are particularly suitable for automotive and air transportation applications, due to their ability to reduce the weight of critical moving parts. They are a promising material for aerospace applications, including bulkheads, heat shields, running gears, and fuel and exhaust systems. Other applications are in high-strength extrusions for body-frame and crash-management systems and in solid-oxide fuel cells. Due to their enhanced corrosion resistance, aluminum-scandium alloys are suitable for use in marine transportation applications and heat-exchanger tubes in desalination plants. Aluminum-scandium welding wire imparts high part strength and high fatigue resistance aside from other benefits such as improved processing, reliability, and high weld quality, applicable for additively manufactured parts.

Defense Sysems	Automotive	Aviation
Additive Manufacturing Center	Laser Welding	

Figure 4. Example of applications of aluminum- scandium alloy

Coherent's Alloying Plant

Coherent introduces yet another addition to its diverse capability that aims at contributing to the growing market for aluminum-scandium alloys. Coherent has successfully commissioned its alloying plant. Coherent has produced Al-Mg-Mn-Sc-Ti and Al-Mg-Mn-Sc-Ti-Zr alloys that conform to the specifications of its customers.

Figure 5. Alloying plant at Coherent

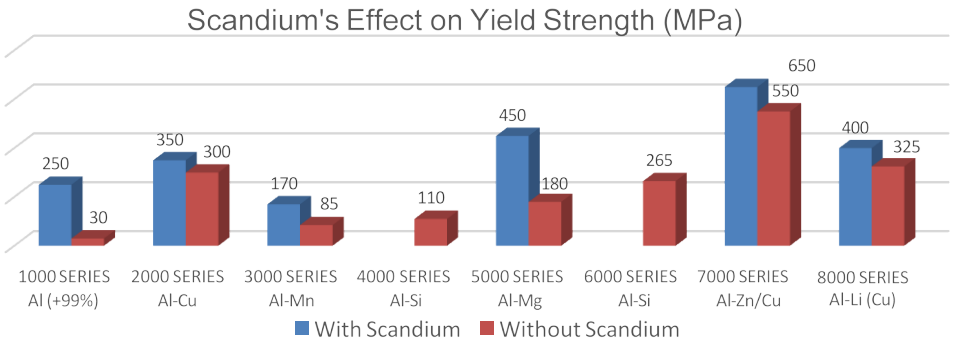


Figure 6. Effect of scandium on the yield strength of aluminum alloys

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