THE COMPREHENSIVE GUIDE TO

ADVANCED AEROSPACE THERMAL PROCESSING

It takes a lot of science and a ton of organization to turn drawings and documents into commercial, civilian and military aircraft. The firms who do it well make it seem more like an art form.

It's hard work—and it's getting harder. Prices are rising. Supply chains are unpredictable. Maintaining safety is paramount.

At a time when OEMs are under great pressure to meet their obligations while preserving part quality and safety, strong supplier partnerships—including those with thermal processors—can change the game.

PART 1

PRECISE HEAT TREATMENT IS VITAL FOR AEROSPACE ALLOYS

The stakes are high in aerospace research & development and manufacturing. In military, commercial and private aviation sectors, the industry has focused on developing better-engineered parts that withstand abusive service over long periods of time.

The pursuit of faster, lighter, more efficient aircraft has spurred the development of countless complex alloys. And for those alloys to perform as designed, equally complex heat treatments have emerged.

The development of these parts and the advanced heat treatments necessary for them to achieve superior mechanical properties will be forever linked.

COMMON AEROSPACE ALLOY TYPES

Complex thermal processes have emerged to match the complexity of alloys developed in the pursuit of faster, lighter and more efficient aircraft.

Aircraft feature a wide variety of complex materials. Manufacturers must balance important design and material selection concerns with pressure placed on them by aerospace OEMs to produce long-lasting parts at reasonable costs.

In a game of tradeoffs, the options are almost endless. Heat treaters can play an important part in sorting through the choices to achieve the right balance of a diverse array of alloys.

ALUMINUM ALLOYS

Aluminum alloys have been crucial to aerospace material and design advances for decades. As production techniques matured, aluminum alloys like 6061 helped make aircraft lighter and sturdier.

Today, modern aluminum alloys remain integral in some aerospace applications due to their high strength-to-weight ratio. Common types include:

- 5xxx alloys featuring silicon and manganese that are relatively workable and feature high hardness and high tensile strength despite low density.
- 2xxx alloys commonly used for structural service and as fasteners and rivets.
- 7xxx alloys that also perform well in structural applications and which boast high toughness and resistance to stress corrosion cracking.

Learn more about aluminum alloys here.

TITANIUM ALLOYS

Titanium and titanium alloys are commonly used in critical aircraft applications where resistance to constant stress is necessary.

Ti6Al4V, a titanium formula containing aluminum and vanadium as alloying elements, is the most popular. It's known for its performance under constant severe motion in the cold sections of jet engines. Ti6Al4V is often specified for discs, ducts, turbine blades and bearing housings. Slight tweaks to the formula result in excellent performance in cryogenic temperatures. It's also sometimes used to make fasteners.

Titanium performs well in many aerospace settings, but it's not as widely used as many in the industry would like. That's because the element is hard to mine and process. It may become more widely used as mining and processing techniques improve.

NICKEL ALLOYS

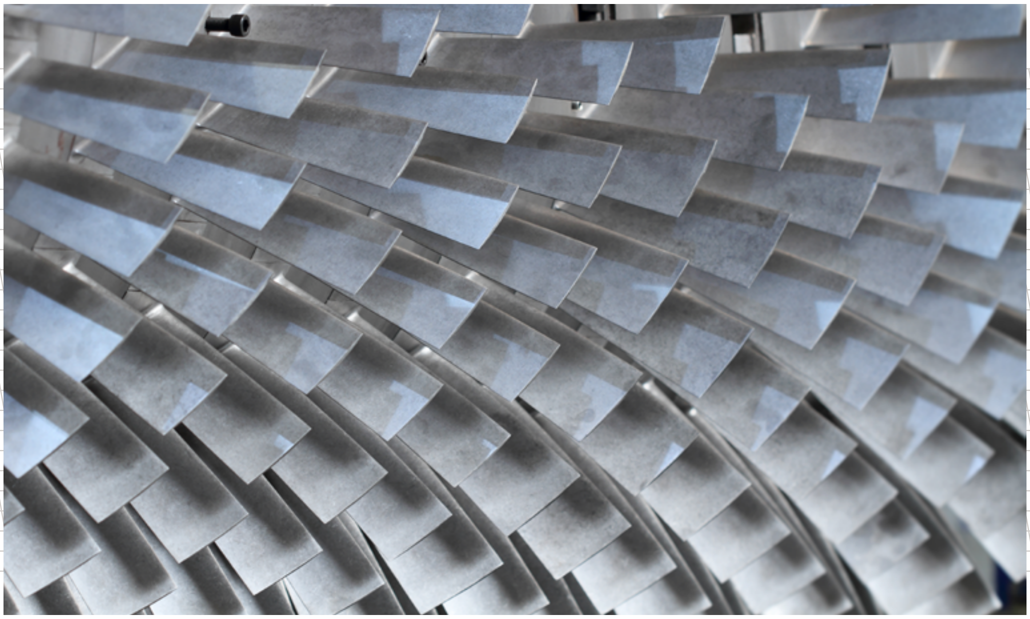
Nickel alloys are also lauded for their performance in high-stress service environments. They're also generally very resistant to corrosion, making them ideal for use in jet engine components in constant motion and subject to high heat and corrosive gases. Common aerospace nickel alloys include:

- WASPALOY and its variants, which are very strong at high temperatures.
- Inconel 718 and Inconel 625, each of which boast high strength in hot environments; 718 is stronger than 625 but 625 is more corrosion-resistant.
- Alloy 36, which retains dimensional properties in high temperatures and is often specified for complex aircraft instrumentation.
- Alloy 230, which resists corrosion under high stress and is suited for cold-section service.
- PWA 1484, a formula which is very resistant to high temperature creep. Alternatives include the René alloys N5 and N636 among others.

Nickel alloys are widely used in critical service environments due to their corrosion resistance and performance under high stress.

COBALT ALLOYS

Cobalt alloys such as L-605 exhibit good oxidation resistance and high strength at elevated temperatures. They're commonly used in turbine rotors, nozzle diaphragm valves, springs and other components.



STAINLESS STEEL ALLOYS

Stainless steel alloys are among the most versatile in modern industry. From automotive to power generation to pharmaceutical applications and beyond, stainless steel alloys are widely specified for their excellent corrosion resistance.

The following stainless steel formulas are widely used in a broad range of aerospace settings:

- 304, used in fuel tanks and some structural components not subject to very hot temperatures.
- 309, a heat-resistant formula containing extra chromium and nickel.
- 316, 316L, 321, S30415 and S30815, all of which are more heat-resistant and suitable for use in exhaust systems, engines and some high-temperature structural service.
- 17-4Ph, a formula containing copper and niobium alloys that is comparable to 304 stainless but chosen when extra corrosion resistance is desired.

VACUUM HEAT TREATMENT OF AEROSPACE ALLOYS

Many aerospace components sustain constant strain and motion and serve in extremely hot or cold environments. For parts like these, complex and precise heat treatments are necessary.

Vacuum furnaces are ideal for hardening and strengthening aerospace components for a couple reasons. First, parts treated in vacuum furnaces cannot oxidize or become otherwise contaminated when atmosphere is removed from the chamber. Second, these furnaces are built to include process controls that allow metallurgists to design the complicated treatment cycles that fulfill the industry's incredibly strict specs.

Process control is crucial. In aerospace, there's no room for error.

Some projects come with specs that dictate the exact treatment parameters we must follow. Other orders specify treatments based on the properties parts must exhibit, and it's up to us to develop the treatment that makes it happen. Either way, we rely on our experienced team of metallurgists and the industry's most advanced equipment.

Process control is crucial. In aerospace, there's no room for error.

Vacuum furnaces operating in Paulo's Cleveland Division routinely execute complex day-long treatments that top 2,400 degrees Fahrenheit. Consider these notable process control capabilities:

- We can create treatments that feature very slow ramp rates (down to around 1 degree per minute). This ensures that parts reach the required treatment temperature slowly and evenly, which promotes proper solutionizing.
- Fine-tuned thermocouples help our furnaces sustain temperatures to within +/- 2 degrees for an extended period.
- Using programmable logic controllers (PLCs), we can apply correction factors to treatments in progress.
- Dozens of sensors monitor around 1,000 different variables in real time and trigger alarms if out-of-spec conditions are observed.

Earning and maintaining key certifications is just as important for aerospace thermal processors as understanding materials and metallurgy.

There's more to thermal processing for the aerospace industry than an in-depth understanding of materials and metallurgy. Earning and maintaining key certifications is equally critical. Read on to learn about the industry's most rigorous certification—and the benefits of working with providers who've earned it.

PART 2

WHAT YOU CAN EXPECT FROM NADCAP-APPROVED HEAT TREATERS

At its core, heat treating is simple: Use heat to change the properties of metal components to improve their performance.

But when those parts are incredibly complex aerospace and defense components, it's not so simple. That's why heat treatment in the industry is governed by the Nadcap program.

Prior to the formation of Nadcap, individual aerospace and defense OEMs completed heat treatment and other manufacturing audits of suppliers on their own. The auditing process was exhaustive, expensive and redundant. OEMs and government officials wondered if they could enhance quality and efficiency in the industry if a single entity developed standards and performed audits.

The result was the Nadcap program, implemented in 1990 and administered by the Performance Review Institute. Given the serious and safety-critical nature of components that make up aerospace and defense assets, the Nadcap program is not a list of suggestions. If heat treaters haven't earned Nadcap certification, they're not doing business in the industry.

NADCAP-APPROVED HEAT TREATER REQUIREMENTS

Nadcap requirements are quite prescriptive. Other industry standards programs give suppliers varying amounts of leeway en route to achieving the benchmarks they set. Nadcap features no such liberty. It's their way or the highway.

Nadcap-approved heat treaters must meet requirements regarding all aspects of their operation, including:

- The types, sizes and capabilities of heat treating equipment used to treat aerospace and defense components.
- The details of how certain components must be treated (for instance, we need documentation showing our vacuum brazing or other solution treating operations meet muster according to the Nadcap program).
- The degree of precision in pyrometry (remote temperature measurement) that must exist in heat treatment furnaces.
- Ensuring furnace repairs are executed in accordance with the standards.
- The properties of appropriate quench oils and the quality tests the oils must pass before use.
- The training of personnel operating the equipment used in aerospace and defense heat treating.

Nadcap starts as a crucial requirement and ends as a mutually beneficial asset.

Becoming a Nadcap-approved heat treater requires proving you have the equipment and processes in place to treat safety-critical aerospace and defense components. Keeping the certification is all about maintaining the mountain of documents showing you're continually able to meet the strict requirements.

Benefits to customers come built into being Nadcap-certified. With all this information well-organized and easily accessible, heat treaters and their customers enjoy more seamless communication and can collaborate more efficiently during critical research and development phases. In short, Nadcap starts as a crucial requirement and ends as a mutually beneficial asset.

But earning the certification isn't the end of the story. Thermal processors—especially those involved in aerospace component research and development—must also comply with the rigorous documentation requirements under the AS9102 standard.

PART 3

FIRST ARTICLE INSPECTIONS AND AS9102 COMPLIANCE: HOW HEAT TREATERS FIT IN

One of the industry's most important quality assurance principles is first article inspection (FAI)—the systematic inspection of new parts to ensure they'll perform as designed.

The aerospace, automotive, medical and other industries all feature FAI requirements. In general, these inspections (and the exhaustive documentation supporting them) entail the thorough investigation of parts pulled from the first-ever batch to verify that:

- The exact material specified for a given part was used.
- Manufacturing or finishing methods detailed in the specs were followed.
- Part characteristics that result from manufacturing or processing are within tolerances stated in the specs.

In the aerospace industry, SAE AS9102 standardizes the documentation that industry suppliers must provide to meet OEMs' FAI requirements. According to SAE, the standard is meant to provide "objective evidence that all engineering design and specification requirements are properly understood, accounted for, verified and documented."

Heat treaters (and any other provider at any stage in the aerospace manufacturing process) must submit three forms:

- Form 1 covers part number accountability and notes the part and subassemblies being inspected.
- Form 2 covers product accountability and accounts for materials, special processes and functional testing.
- Form 3 covers characteristic accountability, verification and compatibility evaluation. Information about how inspected parts compare against drawings is recorded on this form.

FAI REPORTING FOR HEAT TREATERS

Because heat treatment of aerospace components is so critical to their end use, heat treatment documentation for FAI parts is quite exhaustive.

First article inspections help heat treaters and customers determine whether processing specifications will result in parts that perform as intended.

Every aspect of heat treatment is documented, including:

- The inspection of parts before they're even processed to verify they meet initial tolerances stated in specs.
- Heat treatment parameters including type of treatment, how long the treatment lasts, how hot the furnace gets (and even how quickly or slowly that temperature is reached) and the way the part is quenched.
- Verifying post-treatment variables like hardness, tensile strength, yield strength and critical dimension characteristics against tolerances stated in specs.

That last point is extremely important. Heat treatment almost always distorts parts—it's the price that comes with enhancing mechanical properties. First article inspections help heat treaters and customers determine whether specified processes will result in acceptable amounts of distortion or if design, material, manufacturing and processing specs need to change.

Completed FAI documents are forwarded to customers. They'll add it to the pile of similar reports provided by upstream providers. The result is a massive collection of documents tracing every process in a newly-developed part's production journey.

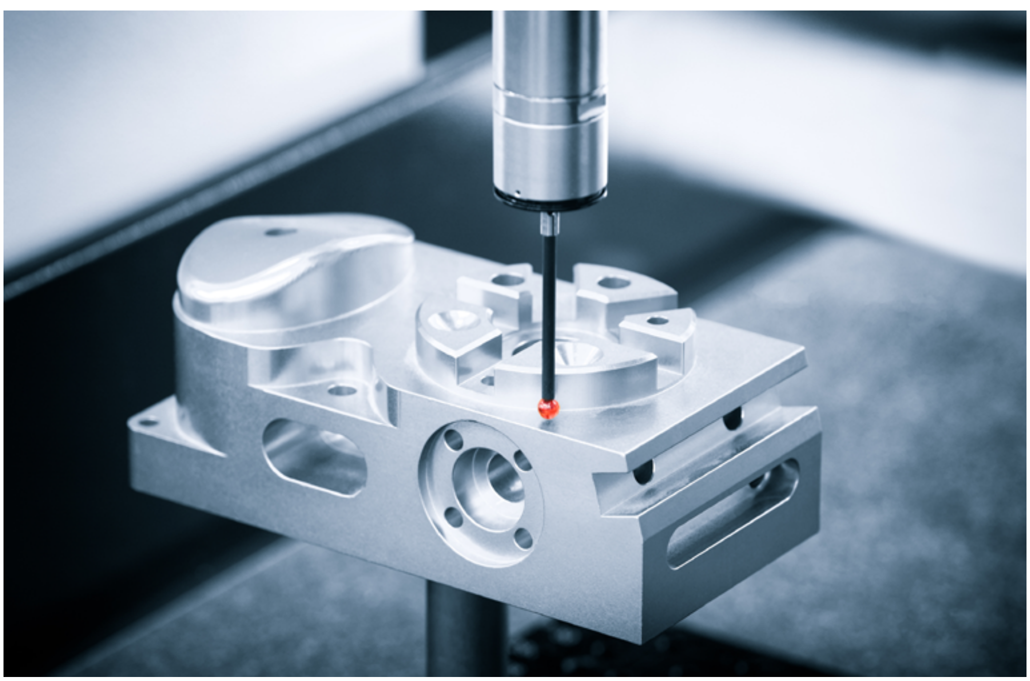
WHAT IT MEANS FOR YOU

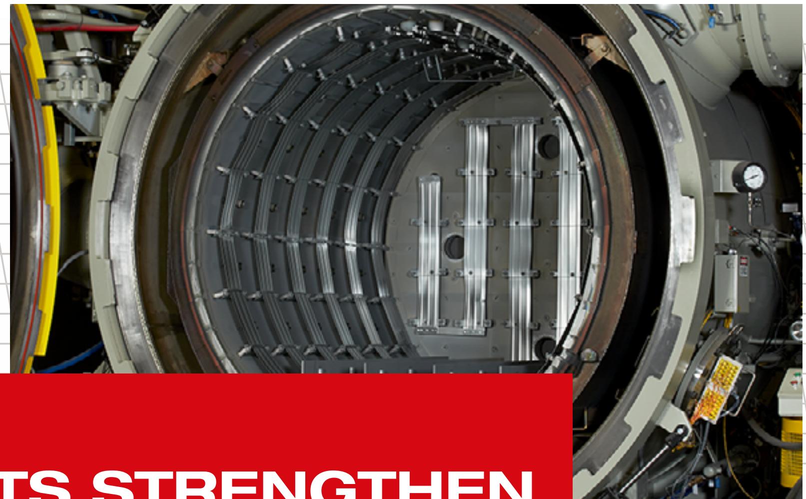
When it comes to managing quality for our customers, everything is scrutinized. Nothing is left unplanned. Our cross-functional team applies its heat treatment expertise to the information we gather about part design, material and manufacturing. This intensive review allows us to flag potential problems earlier in the process and, when possible, recommend upstream tweaks that will result in parts that pass inspection.

Then, we run heat treatments backed by our Product Information and Customer Service (PICS) software. This advanced system provides value to customers by recording process information in real time and alerting operators if furnace conditions such as pyrometry slip outside of the tolerances defined in treatment specs. This saves time and enhances our ability to troubleshoot potential problems.

Simply put, our job is to collect and act on information in ways that ensure that our heat treatments are successful and repeatable.

We apply that mindset more broadly, too. We're in the business of making our customers more successful, something we couldn't do if we didn't keep a watchful eye on how the industry is changing. Below, we discuss important actions Paulo has taken to ensure it helps catalyze that change instead of getting left behind by it.





PART 4

KEY INVESTMENTS STRENGTHEN TIES TO AEROSPACE

Now is a dynamic period for the aerospace industry. As OEMs grapple with a significant backlog of orders, their reflex has been to go vertical where it makes sense. And when it doesn't, they refine existing outsourcing relationships (as well as build new ones) to keep costs down, quality up and production steady.

The door is open for suppliers to step up by increasing production capacity to work through the backlog, continuously improving efficiencies in the face of growing price pressures and remaining committed to the research and development efforts that push the industry forward.

We know that our specialty—thermal processing and metal finishing—is but one piece of a huge puzzle. But we've been around long enough to know a chance to make a meaningful difference when we see it.

We try to see what the industry sees on the horizon and react accordingly. It's produced tangible results we know will deepen our ties to aerospace customers. The most notable is a multi-phase expansion at our Cleveland Division, a location specializing in aerospace thermal processing.

Phase one of an ambitious expansion at the site is underway: A 30,000-square-foot addition to the existing plant is under construction as we speak. A new vacuum furnace—the first of an order of five—was installed there in July. When the expansion is complete, we'll have added 50,000 square feet to the site.

Adding service offerings can be just as crucial as expanding current ones. As aerospace components become more and more complex, the thermal processes required for them to perform as designed must also evolve. We added hot isostatic pressing (HIP) capabilities to our menu of aerospace heat treating services to meet that need. As a result, we're in position to work directly with OEMs to develop the industry's next generation of advanced thermal processes.

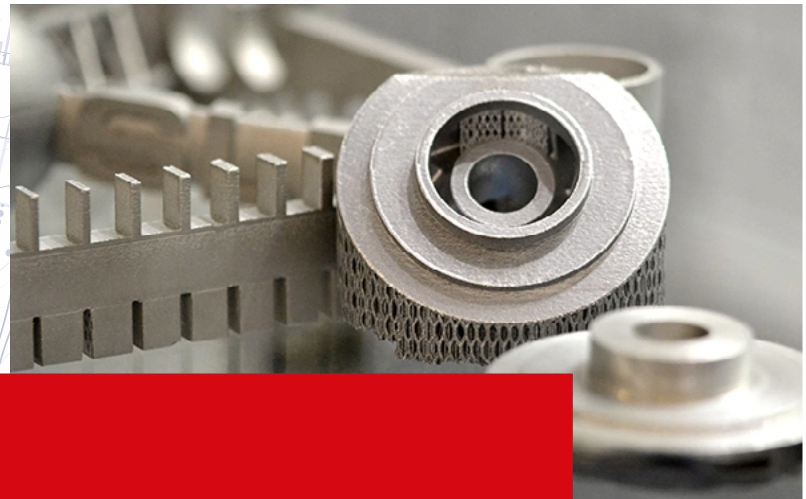
DEFINING THE LEADING EDGE

The elements we discuss in this guide amount to far more than just a message. They are our promise to customers: We'll continue to develop advanced processes that meet the industry's rigorous demands. And with our industry-leading quality systems, we'll guarantee consistency and quality for the duration of a relationship.

Building an extensive understanding of metallurgy is hard work. Earning and maintaining industry certifications requires care and diligence. Expanding our facilities and filling them with equipment is expensive. Adding new service offerings can be costly and sometimes risky.

But it's all well worth the investment: Existing relationships are strengthened. New partnerships are formed. Part quality increases and aircraft fly safely in our skies.

We're ready to get to work for you. Have any questions? Want to discuss a project? Contact us now or request a quote.



SERVICE HIGHLIGHT:

HOT ISOSTATIC PRESSING

Hot isostatic pressing (HIP) improves the mechanical properties of cast or additive manufactured parts by bringing them to very high temperatures in a sealed chamber capable of generating very high pressures. It's becoming a preferred thermal process for aerospace parts that are 3D printed using selective laser or electron beam sintering technology.

It's common for very small voids to form as parts are 3D printed. These voids can compromise the mechanical properties of high-performance parts, so HIP is used to reduce the size of the voids or eliminate them entirely.

Parts treated with HIP display:

- Better fatigue resistance and improved performance at extreme temperatures.
- Improved resistance to impact, wear and abrasion.
- Improved ductility.

Common examples of aerospace components treated with HIP include additive manufactured turbine blades and other parts with complex geometries.

The HIP vessel in use in Paulo's Cleveland Division is a Quintus model QIH 122. With a 26-inch diameter and a 68.9-inch height, the vessel can reach temperatures of over 2,550 degrees Fahrenheit and pressures up to 30,000psi. That's almost twice the pressure recorded at the bottom of the Mariana Trench in the Pacific Ocean, 36,000 feet below the sea surface.