

# Tight-Tolerance Aluminum Furnace Systems

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Lighter, stronger and faster aircraft and automobiles means today's heat-treat furnaces must be more uniform, flexible and energy-efficient than the heat-treat furnaces of the past.

**Fig. 1. Homogenizing furnace system capable of processing 450 tons total per batch**

**W**hether homogenizing aircraft aluminum after casting or solution heat treating wrought and cast automotive and aircraft components, end users demand the best in heat-treat furnace performance.

## What is aluminum homogenizing?

"When aluminum is cast, the alloying elements aren't uniformly distributed in the microstructure," said Gary Schmauch, retired metallurgist and heat-treat/finishing manager with Kaiser Aluminum. "Therefore, we use the homogenization process to reduce micro-segregation. Some alloys and end uses don't require very tight controls on homogenization, but the newest high-strength aerospace alloys will have much higher fracture toughness, fatigue life, etc. if we can eliminate as much of the micro-segregation as possible."

"It also improves corrosion resistance with equal or better strength. In aerospace alloys, as well as a few other applications, we want to homogenize the ingots (here I'm referring to both rounds and slabs) at as close to the incipient-melting point of the metal as possible. That's why we asked for such tight controls on the homogenization furnaces. In fact, we use two-step homogenization practices on many of the alloys, especially aerospace materials. We'll homogenize material at a slightly lower homogenization temperature and then increase the temperature after we have dissolved the lowest melting-point constituents first. The higher we can take the homogenization practice without starting to melt the ingot, the better the final properties will be for critical alloys," Schmauch added.

## Homogenizing Furnace

Today's homogenizing furnaces need to incorporate complex

control algorithms along with dynamic pressure and air-recirculation control systems to achieve tolerances as tight as  $\pm 0.7^{\circ}\text{C}$  in the homogenization temperature range of  $400\text{--}620^{\circ}\text{C}$  ( $752\text{--}1148^{\circ}\text{F}$ ). According to Schmauch, the tighter the tolerance, the safer it is to approach the eutectic melting temperature and thus reduce micro-segregation as much as possible. The closer the furnace and aluminum can get to this melting temperature, the better required parameters such as strength, corrosion resistance, fatigue life and fracture toughness will be.

Though AMS 2750E allows TUS testing to be performed either empty or with a load, confirming uniformity with a representative load is most critical.

"The important feature here is not the ability of the homogenization furnace to hold a very close tolerance when



**Fig. 2. Seven-foot-diameter drop-bottom aluminum solution heat-treat system with glycol quench**



**Fig. 3. Charge station of round-ingot homogenizing furnace line**



**Fig. 4. Car-bottom furnace for homogenizing and stress relieving**

surveyed with air thermocouples, but the temperature uniformity that can be achieved with production loads,” Schmauch said. “The requirements by the specification to meet excellent temperature control with an air-couple survey is not sufficient. The accuracy of the furnace must be established with the types of loads used in production, which requires building loads that represent production loads and then using that load configuration during homogenization of production metal. If the production group decides they need to change the load configurations, then the furnace needs to be recertified with the new load configuration as well.”

The impact of a poorly performing furnace can be severe. According to Schmauch, if the temperature uniformity of the furnace isn’t good enough, the aluminum alloy may exceed the eutectic temperatures and cause melting, along with porosity, which will cause the material to not achieve the required properties or may impact corrosion and fatigue life as well. At the other extreme, if a portion of the material doesn’t get hot enough because of a cold spot in the furnace, then the properties of the metal that is being processed won’t be uniform. The cold area will have lower strength, lower fatigue life, lower fracture toughness, and possibly lower corrosion resistance and low formability. All of these lead to either an inferior or even rejected final product.

Many of today’s homogenizing furnaces suffer from poor uniformity along with slow heat-up to uniform temperatures.

“For many aerospace applications the homogenization furnaces didn’t have the temperature control to allow us to achieve the homogenization temperatures we needed to have for the best metal performance,” Schmauch said. “A lot of work done over the last few years has shown how important controlling the homogenization practices at temperature close to the melting point of the metal can improve desired properties. The other big issue is not having enough capacity. In rolling terms, we called it being out of heat, which meant that we had to shut the hot line down for a period of time to catch up on homogenization and/or preheating ingots to get them ready for rolling.”

Rebuilding existing furnaces to today’s performance and

energy-efficiency standards is an excellent option to purchasing new homogenizing furnaces.

“If a company is making aerospace materials, then there would certainly be an advantage of increasing the uniformity of older homogenization furnaces,” said Schmauch, who added that there certainly are other applications for close homogenization control, especially if it is coupled with higher heating and cooling rates because that is what impacts productivity.

### **What is aluminum solution heat treatment?**

Aluminum solution heat treatment is the heating of an alloy to a suitable temperature, holding it at that temperature long enough to cause one or more constituents to enter into a solid solution and then cooling it rapidly enough to hold these constituents in solution. This is often followed by a precipitation-hardening process to increase the yield strength of the alloy.

### **Solution Furnace**

Just as described in the homogenizing-furnace section, the properties of the alloy can be greatly affected by the temperature uniformity of the solution furnace. There are many types of solution furnaces, including basket batch or indexing, drop-bottom and basketless. The system type chosen is typically based on a variety of factors, including production volume, quench requirements, heat-up rates, flexibility, budget and end-user preference. Besides all of these, a common factor for most solution furnaces is the need for tight temperature control and uniformity.

In the aerospace industry, drop-bottom furnaces are typically utilized because of the need for very tight temperature control, fast quench times and rapid heat-up. This design allows for quench rates as fast as five seconds and temperature uniformities as accurate as  $\pm 0.5^{\circ}\text{C}$ , which is achievable through advanced-engineered air-recirculation control systems. These tight uniformities have proven to be very effective in distortion control of critical aerospace components.

Temperature uniformity remains critical when a basket or basketless system is chosen, but these system types will most likely require different engineered air-recirculation systems





Fig. 5. 30-ton gas-fired homogenizing furnace



Fig. 6. Eight-furnace homogenizing line with cooler and charge car

to meet the requirements for uniformity. In addition, many times the most difficult problem to solve with these types of furnaces is the heat-treatment rate and consistency between parts. Without the proper air-recirculation system, parts on different levels or in different baskets can experience significant differences in their heat-treatment cycles, requiring extended processing times with varying metallurgical results. In many cases, even though all parts may meet the metallurgical requirements, end users are becoming extremely critical of time/temperature curves with large discrepancies between parts.

Immediately upon completion of the solution process, the material needs to be quenched to preserve the solid solution. The quench process is probably the most critical treatment, especially with today's new materials and end-user requirements. While many of the materials are quenched either in water or a water/glycol mixture, air-quench technology has become increasingly important in the solution heat-treatment process.

### Air Quench

Many end users are requiring greater material properties, more quench control and reduced residual stresses. By utilizing a custom-engineered air-quench air-distribution system, it is now possible to meet these new demands. Many new cast materials, including engine blocks and cylinder heads, require cooling rates with air up to 120°C/minute. It is also critical to have very consistent quenching from part-to-part but also have the option to run multiple parts simultaneously to offer more flexibility.


To assist in the design of these complex air-distribution systems, computational fluid dynamics (CFD) is incorporated into the design process.

"CFD is a branch of fluid mechanics that uses numerical analysis and algorithms to solve and analyze fluid-flow problems," said Dr. Joe Zhao, manager of the R&D facilities at International Thermal Systems (ITS). "Today's

powerful software programs can provide reliable and accurate simulation results. In the furnace industry, ITS is at the leading edge of technology by using CFD to simulate the air flow in the entire distribution system, including fan inlet, supply ductwork and nozzles, and return ductwork and its product influence. By utilizing this CFD simulation as part of the design process, an optimal air-distribution system can be achieved scientifically."

Advanced air-quench systems utilize variable air-pressure and velocity controls, high-volume and high-pressure air-distribution systems and advanced smart control systems to meet these ever-changing requirements. With the importance of volume and flexibility, the need for engineered air-quench systems capable of not just handling one part at a time but multiple parts simultaneously while closely maintaining precise control is more and more critical to meet the demands of today's materials. Air-quench systems capable of processing from one to 180 parts simultaneously will allow manufacturers the flexibility to meet industry demands.

### Conclusion

Whether homogenizing aircraft aluminum after casting or solution heat treating wrought and cast automotive and aircraft components, tight-temperature furnace uniformity and precise air-distribution control remain the critical factors in aluminum heat-treat furnace systems. All furnaces and air-control systems are not created equal. A greater understanding of the technologies that are available will lead to higher-quality end products with greater flexibility and process control. 

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