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Horizontal Quench Solution Treatment Systems – A User's Story

By Gary Schmid & Jason Schmid – Derrick Company; Cincinnati, Ohio
Daniel H. Herring – The Herring Group; Elmhurst, Ill.
Mike Grande – Wisconsin Oven; East Troy, Wis.

WISCONSIN OVEN

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Fig. 1. Large steel tank processed by Derrick Company

Prior to World War II, Cincinnati, Ohio-based Derrick Company was a local brick-maker that used large kilns in the manufacture of bricks from clay mined from the hillsides of Cincinnati and northern Kentucky.

During World War II, there was a need to heat treat large tank parts for use in the North African theater, which prompted Harry Derrick Sr. to devise a way to use his brick-making kilns as heat-treating ovens. The results were so good that the Department of Defense brought experts in from all over the country to learn the methods being employed at the Frank J. Derrick Brick Company. For their efforts, Derrick was awarded the prestigious Army/Navy "E" Award for outstanding effort and service.

As time passed, Cincinnati grew as the world capital of machine tools, and the need for more and larger heat-treating furnaces was evident. Derrick Company continued to grow the heat-treating side of the business and eventually phased out brick-making altogether. Meanwhile, Derrick built some of the largest heat-treating furnaces in the region and would routinely heat treat 120,000 pounds of steel fabrications in one batch (Fig. 1). By the 1990s, Derrick Company was a very well-respected heat treater of small and large steel weldments and castings.

In the early 2010s, Derrick began investigating the potential of performing more specialized heat-treating processes and soon came to focus on aluminum heat treating. It became evident from their research that there was a need for high-volume heat treatment of small aluminum parts. In particular, the market demanded heat treaters that could process aluminum efficiently while conforming to the high quality standards inherent in the automotive, aerospace and other fields. The capability to meet specifications such as AMS 2770 (Heat Treatment of Wrought Aluminum Alloys), AMS 2771 (Heat Treatment of Aluminum Alloy Castings) and AMS 2750 (Pyrometry) were critical.

Derrick knew they would need to handle high volumes of smaller parts, but the company also preferred to have the ability to process larger aluminum components. The traditional means of solution treating such a wide variety of aluminum parts would typically require a large drop-bottom furnace. Drop-bottom systems, however, are expensive and require a large floor-space commitment.

After consulting industry experts and other commercial heat treaters, Derrick instead decided on an advanced-technology solution manufactured by Wisconsin Oven Corp. This method employs a horizontal quench system, consisting of a batch furnace with an external quench tank positioned in front and special material-handling equipment to quickly transfer the load from the furnace into the quench.

Recent developments in the technology provide a seven- to 10-second quench time, which competes favorably with drop-bottom-style equipment. This faster quench time meets the strict requirements for most of the aluminum heat-treating work Derrick was seeking as a commercial heat treater. Consequently, the horizontal quench approach made sense as a logical entry point into the aluminum heat-treating market as Derrick began to integrate the more technical and precise requirements of specialized heat treating into their existing large-part heat treating.

Heat Treatment of Aluminum

In order to better understand Derrick Company's selection of equipment, it is useful to review the aluminum solution heat-

Table 1. Process matrix (courtesy of Dan Herring, The Herring Group)			
Process	**Solution heat treating**	**Quenching**	**Aging (age hardening)**
Goal	To take into solid solution the maximum practical amount of soluble hardening elements (e.g., Cu, Si, Mg) in the alloy.	To preserve as nearly intact as possible the solid solution formed at elevated (solution-treat) temperatures.	To cause precipitation to occur (the degree of stable equilibrium for a given grade is a function of time and temperature).
Purpose	To take advantage of the precipitation hardening reaction (aging), it is first necessary to produce a solid solution.	To cool rapidly enough to produce a supersaturated solution.	To create a change in which the structure recovers from an unstable or metastable condition (produced by quenching or cold working)

treatment process.

Heat-treatable aluminum contains alloying elements such as copper, silicon and magnesium dissolved into the aluminum matrix. In order to execute a proper solution treatment, a specific sequence of time-dependent and temperature-dependent changes are required (Table 1).

Solution Heat Treating

The purpose of solution heat treatment is to evenly dissolve the alloys contained in the aluminum (e.g., copper, silicon and magnesium) throughout the aluminum itself. The process consists of heating and holding the aluminum alloy at a temperature sufficiently high and for a long enough period of time to achieve a nearly homogenous solid solution in which all phases have dissolved. Typical solution-treatment temperature is in the range of 850-1050˚F (454-566˚C).

Care must be taken to prevent overheating or under-heating of the parts. In the case of overheating, eutectic melting can occur with a corresponding degradation of properties such as tensile strength, ductility and fracture toughness. If under-heated, solution is incomplete, and strength values lower than normal can be expected. Since at this point in the manufacturing process the parts have already been forged, extruded or cast, and sometimes machined, scrap caused by improper heat treatment is an expensive failure and must be avoided.

In general, a temperature variation of ±10˚F (±5.5˚C) from control setpoint is allowable, but certain alloys require even tighter tolerances. The time at temperature is a function of the thickness of the material and may vary from several minutes to many hours. The time required to heat a load to the solution-treatment temperature also increases with section thickness and loading arrangement. Therefore, the total cycle time must take this into consideration.

Quenching

Rapid and uninterrupted quenching in water or polymer is required. The solid solution formed by heating must be cooled rapidly enough to produce a supersaturated solution at room temperature. This provides the optimal condition for the subsequent age (precipitation) hardening.

Quenching is in many ways the most critical step in the sequence of heat-treating operations. The objective of quenching is to preserve as nearly intact as possible the solid solution formed at the solution heat-treating temperature by rapidly cooling to some lower temperature, usually near room temperature. In general, the principles and procedures for heat treating wrought and cast aluminum alloys are similar. For cast alloys, allowable quench times are longer, and quenching is typically done in water. For thinner sections and for certain alloys, the quench time must be shorter, and glycol or hot water is used to prevent distortion, especially in complex shapes. After quenching, the aluminum is soft and must be age hardened prior to use.

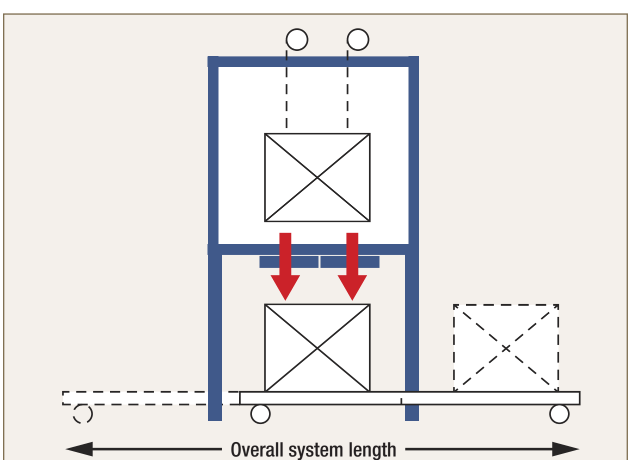

Fig. 2. Drop-bottom floor-space requirement

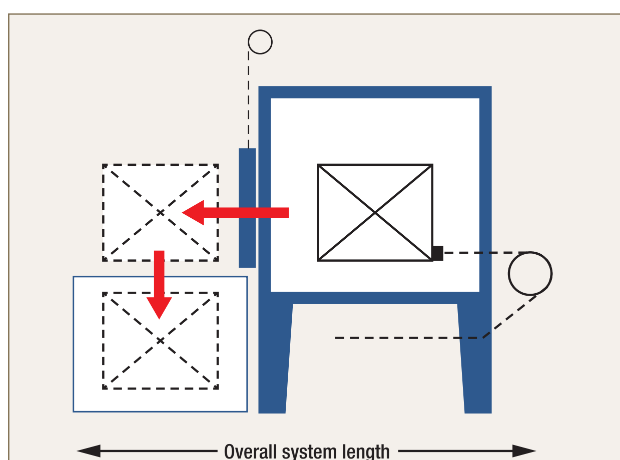

Fig. 3. Horizontal quench floor-space requirement

Aging (Age Hardening or Precipitation Hardening)

Age hardening is achieved through a precipitation heat-treatment cycle, which involves reheating the quenched material to approximately 212-424˚F (100-200˚C) and soaking it at temperature for a prescribed period of time, typically several hours. This improves both the tensile properties and the yield strength while improving the hardness. Also, ductility (as measured by percent elongation) decreases.

Solution-Treatment Equipment, Comparison of Technologies

The goal of the solution-treatment system is to accurately and reliably perform the aging solution-treatment process while providing repeatable results and efficiency of material handling and work flow. There are two types of equipment commonly employed: the drop-bottom system and the horizontal-quench-style system.

Traditional Design: Drop-Bottom-Type Equipment

This type of system involves an opening in the bottom of the furnace from which the load is quickly lowered into the quench tank below. The furnace has a door (or two opposing doors) that slides open to permit the load to exit the bottom (Fig. 2). The quench tank rides on a traveling powered car so that it can be moved into place beneath the furnace for quenching. The furnace is elevated on legs in order to provide room for the quench tank and the car it rides on. A hoist system located above the furnace lowers the load into the quench tank. The load is connected by hooks to the hoist cables, which run vertically through the roof of the furnace.

The primary advantage of drop-bottom-type furnaces is a fast quench speed, which is defined as the time from when the furnace door(s) starts to open until the load is fully submerged.

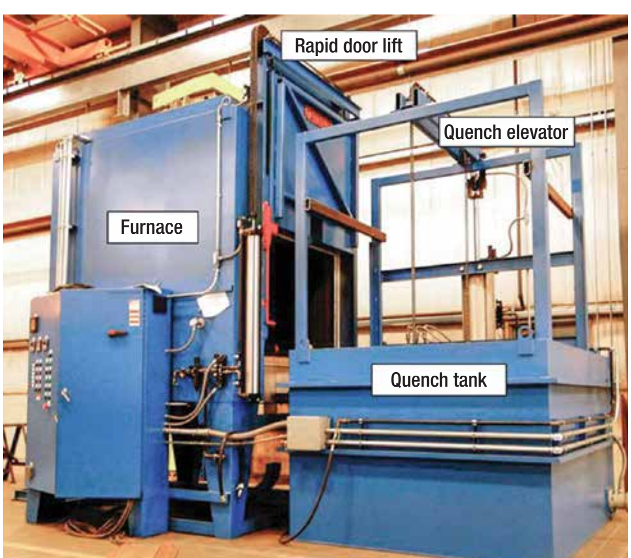

Fig. 4. Components of a horizontal quench system *(courtesy of Wisconsin Oven Corp.)*

Table 2. Maximum allowable quench delay times (source: AMS 2770N)

Minimum thickness (note 2)		Maximum time seconds (note 3)
Inch	Millimeters	
Up to 0.016, incl	Up to 0.41, inclusive	5
Over 0.016 to 0.031, inclusive	Over 0.41 to 0.79, inclusive	7
Over 0.031 to 0.090, inclusive	Over 0.79 to 2.29, inclusive	10
Over 0.090	Over 2.29	15

NOTES:
1. The delay time is measured from the time the furnace door of an air furnace starts to open, or the first portion of the load emerges from a fluidized bed or salt bath or the heating zone of a continuous furnace, to complete immersion of the load in the quenchant.
2. Minimum thickness is the minimum dimension of the thinnest section of any part in the load.
3. The maximum quench delays specified may be exceeded providing tests made within the past year have demonstrated that part temperatures do not fall below 775 ˚F (413 ˚C) before Immersion except, for 2219 alloy, part temperatures shall not fall below 900 ˚F (482 ˚C) before Immersion.

A quench time of seven to 10 seconds is typical, and five seconds is even possible for smaller loads. The disadvantages are the price of the equipment and the space requirements within the factory.

Advanced Technology Approach: Horizontal-Quench Equipment

In recent years, an alternative to the traditional drop-bottom system has gained popularity – the horizontal quench furnace. In this design the door is located on the front of the furnace instead of the bottom (Fig. 3). After the load is heated and held at temperature for the necessary soak time, the door rapidly opens and a specially designed extractor quickly transfers the load from the furnace chamber onto the quench elevator in front of the furnace. The quench elevator then immediately lowers the load into the quench tank.

In the past, the state of horizontal quench technology was such that it was only suitable for pieces with a thicker cross

Fig. 5. Quick load-transfer system *(courtesy of Wisconsin Oven Corp.)*

section – typically cast parts – where a longer quench time was acceptable. The first-generation equipment had a typical quench time of 15 seconds or longer and did not meet the stringent requirements of AMS 2770, which dictates the allowable quench times for parts of various thicknesses (Table 2).

Through advances in sensor and motion control technology, along with improvements in material-handling techniques, the quench time for horizontal systems has progressively improved over the years. Quench times can now be as low as 10 seconds or even seven seconds for smaller loads. This allows horizontal quench equipment to compete with drop-bottom equipment and meet the stringent requirements of automotive and aerospace users. Horizontal systems offer the advantages of lower capital cost and reduced footprint in comparison to drop-bottom equipment.

Horizontal Quench System Design Features

There are several important elements to the design of horizontal quench equipment that provide reliable, quick quench capability (Fig. 4).

Rapid Door Lift

In comparison to a traditional batch furnace, which typically has a door lift time of five seconds or more, the vertical-lift door on a horizontal quench furnace must fully open in two seconds or less. This requires a unique high-flow pneumatic system in the case of an air-operated door lift or a variable-frequency controlled motorized lift if the door lift is electric. In general, the electric lift system can provide faster, more-accurate motion than pneumatic, but both are used depending on the door size (dictated by the load size).

Fig. 6. Horizontal quench system located in a pit
(courtesy of Wisconsin Oven Corp.)

Quick Load Transfer

The material-handling system that extracts the load from the furnace is located at the rear and pushes the load from behind (Fig. 5). The load must be removed from the furnace and placed on the quench elevator within two to three seconds. This includes the time required for acceleration, transfer and deceleration. It is critical that the motion is smooth in order to prevent the load from being jarred during transfer, which can lead to jamming of the system or shortened equipment life.

Quench Elevator

The quench elevator is a platform that accepts the load from the furnace and lowers it quickly into the quench tank. It is important that the elevator has a multipoint pickup to prevent the load from tipping while being lowered. As with the door lift, the elevator utilizes a carefully designed pneumatic system to raise and lower the load quickly and smoothly. In order to reduce the overhead height requirements, the equipment can be located in a pit in the factory floor (Fig. 6).

Industry Trends

With the increasing demand for aluminum horizontal quench systems, the trend is toward shorter quench times and larger load capacities. Currently, the maximum load size is roughly 6 feet long, and efforts are under way to increase this. In addition, ever-faster quench times are being demanded to allow larger loads to meet the AMS 2770 MIL spec. The horizontal quench system is a promising technology of the present and for the future.

For more information: Contact Mike Grande, sales manager/senior application engineer, Wisconsin Oven Corporation, 2675 Main Street, East Troy, WI 53120; tel: 262-642-6003; e-mail: mgrande@wisoven.com; web: www.wisoven.com