# Case Studies Related to Hydrogen Embrittlement of Fasteners – Part Two

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Most if not all fasteners undergo some type of thermal processing during their manufacture and many undergo multiple heating and/or cooling processes. The primary purpose of these treatments is to achieve some defined level of hardness and strength. Finishing (i.e., curing of a coating) can also be classified as a thermal process.

During processing many things can go wrong, resulting in a myriad of quality related problems, one of the most insidious of which is delayed failure, often due to hydrogen induced cracking (i.e., hydrogen embrittlement). This article discusses more ways to mitigate these problems through proper equipment selection.

## Fastener Heat Treatments

The following heat treatments are commonly used in the fastener industry. It is important to note that the heat treatment of steel and alloy fasteners is different than that of aluminum fasteners. Also, the heating temperature, time, and quench process vary depending on the material and the desired material properties.

## Annealing (Steel)

Subcritical annealing of steel (i.e., stress-relief annealing) is performed on the raw material to reduce stress. This process is run below the lower critical temperature (Ac1) of the material, typically at 540 - 650°C (1000 - 1200°F).

## Normalizing (Steel)

Normalizing is a process step that is also typically performed on raw material (e.g., wire, rod, bar) and is done at approximately 19 - 38°C (50 - 100°F) above the upper critical temperature (Ac3 or Acm) of the steel.

## Tempering (Steel)

Tempering is the final step required to relieve the internal stresses that are built up during the hardening process. Tempering transforms the structure into tempered martensite, which is both hard and ductile. Some hardness is lost but relieving the internal residual stresses and improving its toughness achieve a significant gain in properties. This treatment also increases the steels shock resistance and lowers the tensile strength to more favorable levels.

## Hydrogen Embrittlement Relief (Steel)

Hydrogen embrittlement of fasteners is a result of electrochemical surface treatments whereby hydrogen in atomic form enters the lattice of the steel and causes microcracks in the structure, followed by mechanical failure. It is prevented by heating of the material at temperatures of 177 - 221°C (350 - 430° F) for a period of 8 to 24 hours.

## Solution Heat Treatment (Aluminum)

Solution treatment involves heating the aluminum to a temperature of 427 - 538°C (800 -1000°F) at which alloying constituents are taken into solution (i.e., brought near their melting point), prior to a rapid quench which retains the grain structure but leaves the material soft, requiring a subsequent aging operation. The heating time and temperature is dependent on the alloys contained in the aluminum and the cross sectional thickness of the material.

The time required to extract the material from the furnace and quench it (quench delay) must be kept within a specified limit, typically 5 to 15 seconds, and varies depending on the alloy being processed. Thinner, cold-worked aluminum alloys require a faster quench than cast alloys. The quench medium is most commonly heated or ambient water, although glycol and air are used in certain cases.

## Age Hardening (Aluminum)

After solution treatment and quenching, aluminum is age hardened (aged) either at room temperature (natural ageing) or at elevated temperature (artificial ageing), also referred to as precipitation heat treatment. The aging process increases the strength and hardness of the material. Artificial aging requires temperatures of 115 - 200°C (240 - 392°F) and heating times of 5 to 48 hours. The time-temperature parameters for aging are carefully selected based on the alloy used and the desired mechanical properties.

With some alloys natural aging can be suppressed or delayed until a controlled artificial age can be performed, typically for maintaining production flow and desired batch sizes. Conventional practice allows for refrigeration, for example, of 2014-T4 alloy rivets at -18°C (0°F) for several days.

## Curing of Coatings

After steel or aluminum fasteners are heat treated, they are often coated with a water based or solvent based coating. In order to provide a consistent finish and maintain desired production rates, the coated fasteners are typically cured at temperatures of 93 - 204°C (200 - 400°F) for a period of 15 to 45 minutes.

## Case Studies

### Case Study #5

An electrically heated mesh belt conveyor oven (Fig. 1) is commonly used to quickly dry coatings on titanium and stainless steel fasteners. The design features include a stainless steel wire mesh belt to carry the parts on trays, and processes the fasteners at a rate

**Figure 1**
Continuous mesh belt conveyor oven for quick curing of coatings on fasteners (Courtesy of Wisconsin Oven Corporation)

**Figure 2**
Five-drawer oven for hydrogen embrittlement relief of aerospace fasteners (Courtesy of Wisconsin Oven Corporation)

of 1,300 parts per hour, running two shifts per day for a total production of over 5 million fasteners per year. The oven uses a small footprint to optimize floor space.

The conveyor oven shown has a maximum temperature rating of 204°C (400°F) and a work chamber of 1372 mm wide x 2210 mm long x 152 mm high (4.5 ft. x 7.25 ft. x 0.5 ft.). The recirculation system utilizes a 10,200 cubic meter per hour (6,000 cubic feet per minute) direct driven blower and top-down airflow, with a 72 kW heating system to maximize heating rates and temperature uniformity of the product. The conveyor belt includes a variable speed drive to allow changing of the heating times. A digital paperless recorder using optional Ethernet communcation is often a useful feature to record and archive the oven operating temperature.

## Case Study #6

A manufacturer of helicopters required processing of steel fasteners for the purpose of hydrogen embrittlement relief. Due to the long baking times required and the restricted floor space available, three electric heated 5-drawer ovens (Fig. 2) were used. The ovens each have a capacity of 91 kg (200 pounds) per drawer, for a total capacity of 454 kg (1,000 pounds) per oven. With an operating range of 177 - 260°C (350 - 500°F), the oven uses closed-loop temperature control to provide tight temperature tolerances. It maintains a temperature uniformity of ±5.5°C (±10°F) throughout the heating chamber. The air is delivered from ductwork located on both sides and discharges horizontally to each drawer, before traveling vertically and returning to the heating/recirculation system at the top.

## Case Study #7

A job-shop manufacturer of fasteners wanted to use a new plating chemistry to give its parts greater corrosion resistance and better appearance. The new plating, however, caused hydrogen embrittlement of the fasteners. The solution was to bake the parts in an embrittlement relief oven (Fig. 3a). Due to the wide variety of fasteners, they were processed in baskets of varying sizes and capacities. Considering the long heating times (in the order of 24 hours) required for embrittlement relief, a dense loading in the oven was desired to maximize throughput. The oven included a heavy-duty steel plate floor (Fig. 3b) to allow fork truck loading of 1815 kg (4,000 lbs.) per cycle.

The system has a heat input of 72 kW, to heat the load to 191°C (375°F) in 90 minutes. A 7,650 cubic meter per hour (4,500 cubic feet per minute) recirculation system delivers the heated air from supply ducts located on both sides of the load, before being returned to the heating system on the roof. The oven achieved a temperature uniformity of ± 5.5°C (±10°F) at 191°C (375°F). A side-hinged door provided full width chamber access and a composite style door handle was utilized to minimize heat transfer and maximize operator comfort.

## Case Study #8

A high production fastener manufacturer required a continuous hydrogen embrittlement relief oven (Fig. 4) to process miniature screws for eyeglasses and other applications. In order to handle the throughput of 1815 kg (4,000 pounds) per hour, a double conveyor belt arrangement was utilized. It utilized a compound weave mesh belt riding on top of a conventional flat wire belt. The upper belt provided a very tight weave to carry the tiny screws without getting caught in the mesh. The lower belt served as the carrier, and was driven by the conveyor drive. The lower belt rides on a low-friction roller bed, which allows a loading of 366 kg per cubic meter (75 pounds per cubic foot) without overloading or excessive wear. The 18.3 meter (60 foot) long oven has 3 heating zones to provide a 1 hour heatup and a 7 hour soak time at temperature. A high volume recirculated airflow system delivered air to both the top and bottom of the conveyor belt to provide a temperature uniformity of ± 5.5°C (± 10°F) at 204°C (400°F).

**Figure 3 (a)**
Electric heated batch oven for embrittlement relief of fasteners (Courtesy of Wisconsin Oven Corporation)

**Figure 3 (b)**
Embrittlement relief oven with a plate steel floor (Wisconsin Oven Corporation)

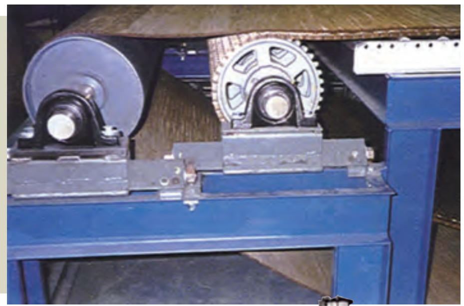

**Figure 4**
Embrittlement relief oven utilizing a double conveyor belt to process miniature fasteners (Courtesy of Wisconsin Oven Corp)

**Figure 5**
Solution treatment furnace and quench tank with chiller system for aluminum rivets (Courtesy of Wisconsin Oven Corporation)

## Case Study #9

A leading aircraft manufacturer required a high capacity solution treatment system for aluminum rivets. The process required heating a 450 kg (1,000 pound) load of rivets carried in twelve 254mm diameter x 152mm high (10" diameter x 6" high) baskets to 455°C (850° F), then water quenching them in 10 seconds.

A batch style electrically heated solution treatment furnace (Fig. 5) was utilized in this application. Baskets of rivets were placed in the preheated furnace and then, after a predetermined soak time, manually transferred from the furnace to the quench elevator, which was rapidly lowered into the quench tank.

The quenching is done in unheated water. Since the water temperature increased 14°C (25°F) after each quench, a chiller was provided to bring the water temperature back down prior to the next quench, which allowed more frequent processing of the loads and higher throughput.

The furnace was rated for a 650°C (1,200°F) maximum operating temperature and achieved a temperature uniformity of ± 5.5°C (± 10°F) at 427°C and 593°C (800°F and 1,100°F) per AMS 2750 (Class 2 furnace and Type C Instrumentation). The heating system features incoloy sheathed heating elements and is rated for 36 kW heat input, with SSR power control. The recirculation system utilizes a 4,760 cubic meter per hour (2,800 cubic feet per minute) fan powered by a 2.25 kW (3 HP) motor.

## Summary

The examples presented here underscore the importance of controlling both process and equipment related variability, not only to maximum production and produce the desired fastener properties, but to avoid problems related to loading, heating or cooling and to ensure that processes such as hydrogen embrittlement relief are properly performed. Remember, not all ovens perform the same and as such it is important to clearly communicate your process and expectations to your potential supplier partner. If you operate an existing oven, be sure to completely understand its capabilities and its limitations. ◘