Technology Evolution of the Integral-Quench Furnace

Over the years, the heat-treatment industry has seen a number of truly innovative technology advancements – the oxygen probe and the adaptation of process simulators for recipe development being perhaps the most impactful to date.

Figure 1. Super IQ Furnace in operation – charge end

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Now the heat-treat world is seeing another groundbreaking technological advancement, the introduction of the next generation of integral-quench furnaces (Figs. 1-2).

Figure 2. Super IQ furnace – heat chamber with rear maintenance door

Atmosphere Processing

Traditionally, integral-quench furnaces in either batch or straight-through configurations have been the workhorses of the industry for light- and medium-duty production. Pusher-style furnaces are in that same position for heavy-duty production. The reason for this is due to their many advantages, which include:

- Lowest initial capital-equipment cost
- Adequate process control – all process variables are understood, and reliable control devices are available to provide a measure of process repeatability
- High-volume output available in a wide variety of equipment styles, types and workload sizes – both in batch and continuous designs (e.g., box, pit, mechanized box aka

“integral-” or “sealed-quench” furnaces, pusher, conveyor (mesh-belt and cast link belt), shaker hearth, rotary hearth, rotary drum (rotary retort), gantry, car bottom

- Excellent up-time productivity
- Automation-capable with recipe or part-number control of heat-treat cycles possible
- Problems are understood, allowing troubleshooting based on an established empirical knowledge base.

However, this technology is not without its limitations, which include:

- Equipment needs to be run 24/7.
- The furnace atmosphere must be conditioned if the furnace is idled or shut down prior to processing work.
- Knowledge of these systems is operator-dependent, gained only through empirical experience by running them on the shop floor.
- A high level of expertise is required to achieve repeatable results (due to wide variability in the type of equipment, its operation, maintenance and constantly changing process conditions).
- Large material stock allowances are required to accommodate post-processing operations, primarily due to dimensional changes and finish requirements.
- Case depths are typically specified in wide ranges (e.g., 0.030-0.050 inch) to compensate for cycle-induced variability.
- Quality of case is often compromised; post-heat-treatment operations (e.g., grinding) remove the area of highest hardness.
- The presence of intergranular oxidation/intergranular attack (IGO/IGA) and surface oxidation (dealloying) to a depth of 0.0075-0.020 mm (0.0003-0.00075 inch).
- Environmental pollution issues require constant monitoring. These include air quality and potentially hazardous gases (CO and NOx); water quality; waste (chemical) disposal; safety issues related to the combustible atmosphere used and the danger of oil fires due to an unstable condition; fire (combustible gases, quench oils); hot contact surfaces; and pinch points to name a few.
- Downtime and maintenance costs increase exponentially with increased process temperature, with the equipment being limited to a practical process temperature of 950-980°C (1750-1800°F).

Make no mistake, atmosphere furnaces can be made better, and some of these limitations can be minimized or eliminated by such techniques as adding a preheat step to the cycle to help reduce case-depth variation (at the sacrifice of production throughput) and adding both multi-gas and shim-stock analysis in combination with oxygen probes to better control carbon potential. The main obstacle, however, is (quite frankly) a lack of desire to improve or innovate in a mature market.

At one time, the future of the atmosphere furnace was thought to be a hybrid design incorporating a high-gas-pressure quench chamber to replace the oil-quench tank. This did not materialize, principally due to cost and limited demand since gas quenching often required changes to steel grades (to develop equivalent oil-quench properties) and the inherent difficulties of integrating an endothermic gas atmosphere furnace with this type of quench arrangement.

Ultimately, the design failed to be commercially viable for the same reason as the motivation to make process improvements: a lack of market demand.

Vacuum Processing

The invention of the oil-quench vacuum furnace and later the option of eliminating oil in favor of high-pressure gas quenching was thought to be the answer to replacing atmosphere processing and meeting the needs of all types of industries. Equipment cost, up-time reliability (at the time) and the necessity, in some cases, to change steel grades limited full acceptance. However, the reasons for wanting to employ vacuum technology are impressive and include:

- Optimized metallurgical properties (e.g., microstructure, surface and core hardness, variation in case depth both within a given geometry and throughout the workload, avoidance or minimization of non-martensitic phases in critical areas), reduced retained-austenite values, carbide morphology (size, type and distribution) and grain-size control
- No surface or subsurface (intergranular) oxidation or intergranular attack (IGO/IGA)
- Improved depth of high (>58 HRC) hardness on carburized grades after post-heat-treatment machining operations (e.g., grinding)
- Tight case-depth control, typically ±0.038-0.051 mm (0.0015-0.002 inch)
- Tight temperature uniformity of ±5.5°C (±10°F) meeting Class 2 AMS 2750 (Pyrometry) requirements
- Process development via simulators with the ability to predict case profile, surface carbon content, hardness and metallurgical phases
- Maintenance costs, regardless of operating temperature, essentially the same

By contrast, the single biggest limitation of vacuum processing has always been initial investment cost, which has proven to be a major stumbling block in replacing atmosphere technology. This has heretofore restricted the use of vacuum to specific industries (e.g., aerospace, medical) where uncompromised quality is an absolute necessity; to custom or ultrahigh-temperature processes; or, more recently, to high-volume industries (e.g., automotive) that can justify the added expense by reducing post-heat-treatment operations.

The Future of the Integral-Quench Furnace

An innovative design (Fig. 3) combining the advantages of atmosphere and vacuum technology is now available to the industry; a unit that combines a traditional oil-quench tank with a low-pressure “vacuum” carburizing chamber. It offers the best of both the atmosphere- and vacuum-processing worlds in a highly cost-competitive design. Key advantages include:

- No open flames, no atmosphere burn-off or front-door flame curtain, no heat sources
- No endothermic gas or endothermic gas generator required
- No methanol or nitrogen/methanol required
- No steel grade changes – oil quenching with conventional oils
- No conditioning – on/off technology
- No fire, environmental or safety-related hazards

- No limitation of hardening or case-hardening temperature to below 950-980°C (1750-1800°F)

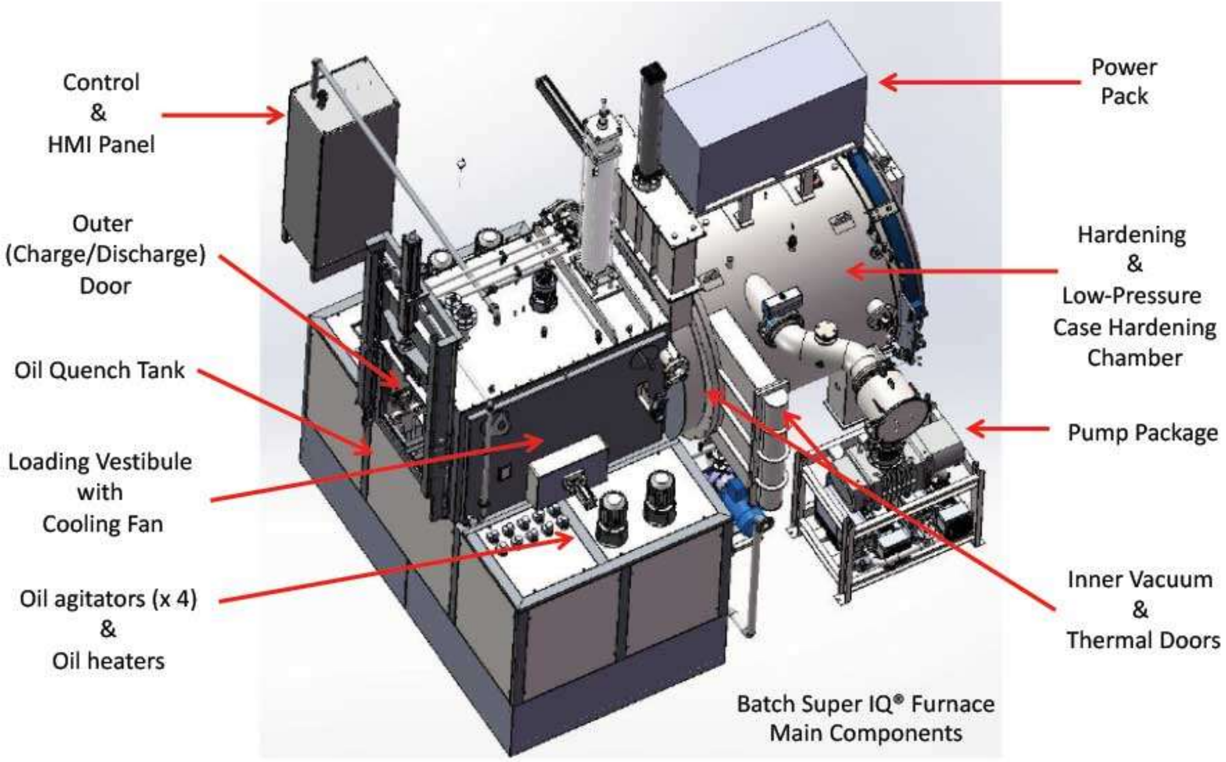

Figure 3. 3-D Model of Super IQ furnace showing the main components of the unit

One of the most notable advantages of the flameless design is its inherent simplicity and safe operation. This feature may also lead to potentially lower insurance premiums.

In addition, the modular design is capable of being placed “in line” with existing atmosphere integral-quench furnaces, and it uses existing furnace loaders. Other key features include a fast (under 30 seconds) load transport time to the quench, a maximum operating temperature of 1205°C (2200°F) and low (nitrogen and acetylene) gas usage. It is also capable of handling heavy 1,510-kg (3,300-pound) workloads in a 915-mm-wide x 1,220-mm-long x 915-mm-high (36- x 48- x 36-inch) work envelope.

Operation of this furnace involves nitrogen purging after introducing the load into the front vestibule over the oil. After the loading door is closed, nitrogen flow increases for a short period of time to reduce the amount of oxygen present. Immediately after purging, the inner door opens and the load is transferred into the heating chamber, which has been backfilled with nitrogen to equalize pressure.

After transfer to the heating chamber, the inner doors close and the load is preheated by use of a carbon-composite convection fan in the heat chamber prior to a vacuum being pulled on the chamber. Once the load has uniformly reached temperature (if carburizing), acetylene or an acetylene mixture is introduced per the requirements of the recipe.

Upon completion of the hardening or case-hardening process, the heating chamber is once again backfilled to atmospheric pressure, the inner doors opened and the load transferred onto the elevator in the oil-quench chamber. The inner door closes, and the elevator either lowers the load into the oil or the load sits on the elevator and is cooled by a recirculating fan.

With respect to operating cost ($/hour) and unit cost ($/pound), the furnace is comparable with traditional atmosphere integral-quench technology (Table 1). These calculations do not incorporate savings that can be achieved by running the new furnace design at carburizing temperatures higher than 950°C (1750°F) to shorten overall cycle time, something that is considered impractical due to increased maintenance with atmosphere gas carburizing technology.

Comparison of Results

Comparison testing was performed at a commercial heat treater in the U.S. using both a traditional atmosphere integral oil-quench furnace and the new atmosphere/vacuum combination design. The workload size of each furnace was 915 mm (36 inches) wide x 1,220 mm (48 inches) long x 915 mm (36 inches) high. Parts were placed in standard rod-mesh stacking baskets and occupied the full workload envelope.

In both cases, the load consisted of 50-mm-diameter x 100-mm-long (2- x 4-inch) rounds of SAE 8620 steel. Trials were run at temperatures of 925°C (1700°F), 950°C (1750°F) and 980°C (1800°F). Two effective (50 HRC) case depths were targeted: 1 mm (0.039 inch) and 2 mm (0.78 inch) respectively.

(a) (b)

Figure 4. Surface-to-core microstructure: (a) atmosphere IQ, (b) Super IQ (100X, 2% Nital)

The results showed typical part microstructures that consisted of finely dispersed carbides in a matrix of tempered martensite (Fig. 4). As would be expected, the atmosphere-carburized samples showed the presence of IGO to a depth of approximately 0.018 mm (0.0007 inch), while the low-pressure carburized samples did not (Fig. 5).

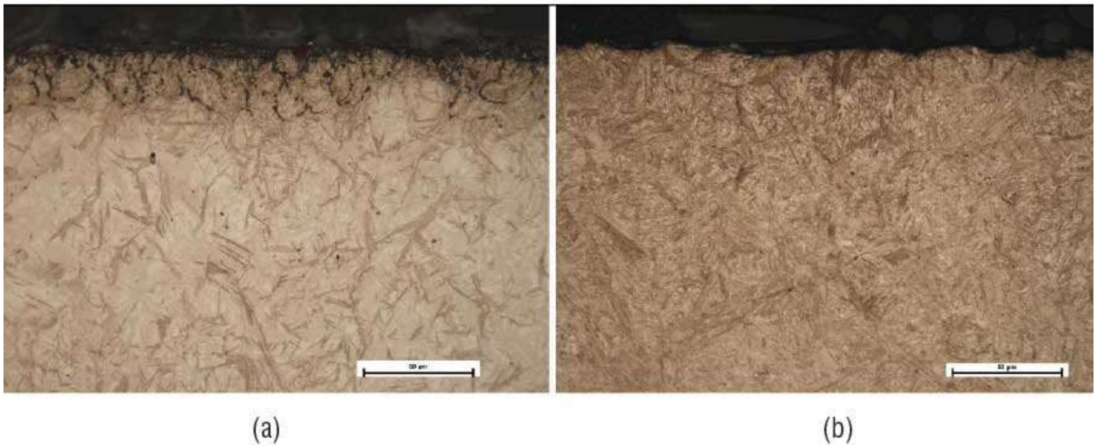

Figure 5. Surface microstructure: (a) atmosphere IQ part with an IGO layer of approximately 0.018 mm (0.0007 inch) deep, and (b) low pressure carburized part with no IGO present (500X, 2% Nital)

Overall, for a given temperature, the atmosphere-carburized parts show a slightly wider spread of case uniformity by approximately 0.1 mm (0.004 inch). The as-quenched surface hardness of the atmosphere IQ quench parts was 59.5-60 HRC due to the presence of higher percentages of retained austenite.

Figure 6. Parts positioned in a basket to illustrate as-quenched surface appearance: (a) atmosphere IQ parts on the left, and (b) Super IQ parts on the right.

Parts run in the atmosphere/vacuum combination design exhibited an as-quenched surface hardness of 65-66 HRC. The appearance of the parts was a characteristic dull-gray/green for the endothermic-gas oil-quenched samples compared to a clean/bright as-quenched appearance from the new design (Fig. 6).

Carburizing uniformity was checked at nine positions throughout the load at each processing temperature, including 980°C (Fig. 7). These uniformity checks included microstructural evaluation, case-depth determination, carbon profiles and hardness (surface and core).

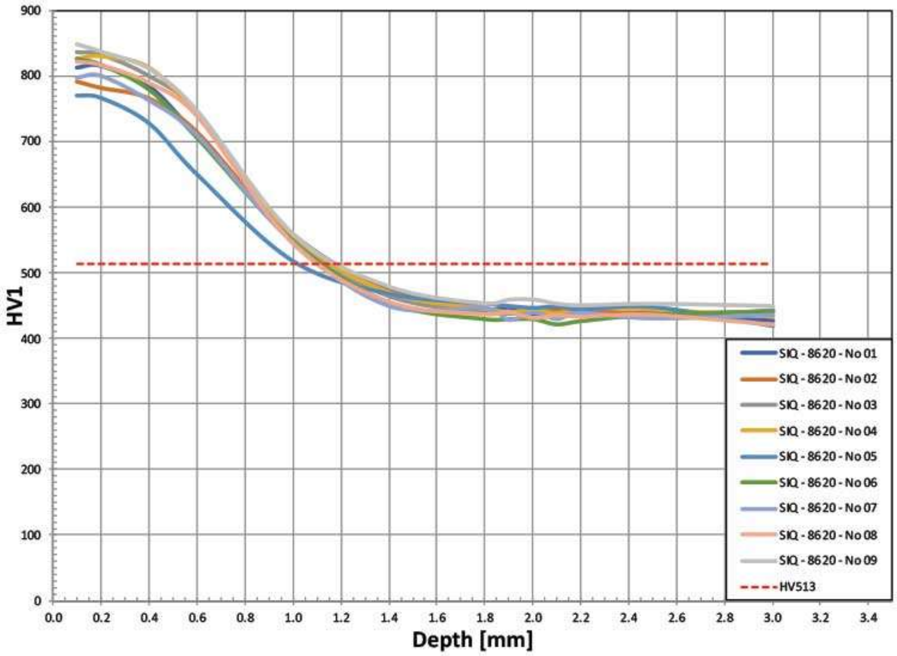

Figure 7. Representative results of Super IQ case uniformity for SAE 8620 carburized at 980°C (1795°F). Net loading was 1121 kg (2,470 pounds) and a gross weight of 1,528 kg (3,369 pounds).

Summary

A cost-competitive solution is now available to the industry that combines the advantages of both atmosphere and vacuum processing into one compact design. It represents a paradigm shift in how we will heat treat going forward and, in this writer's eyes, is well worth investigating.

**Super IQ® is a trademark of SECO/WARWICK*

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