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Precision Quenching – Adding Science to Art

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The socioeconomic state of the U.S. and its trade partners is the primary force driving technology within the tube-and-pipe industry. Global infrastructure expansion, growing demands by economic development and aggressive pursuit of material performance are impacting material choice, chemical composition and heat-treat process control. Adding to the fray is the constant threat of litigation as customers and local law push accountability deeper down the production chain.

Fig. 1. Thermatool Precision Slot Quench™

Navigating the capricious steel industry requires adept business acumen and an ability to respond rapidly to changing demands. With tube-and-pipe inventories drained from the 2009 recession, companies are trying to respond to increasing demands with new production facilities designed to boost harden and temper system efficiencies. But new production is not necessarily smart production. Today's market requires capability for small batch, sustained low inventory, make-to-order capacity, quick change-over times and recipe-driven process control. What are the key technology elements a company can utilize in such a lean manufacturing system to meet the demands of a changing business environment?

Some needs of the market have been addressed by new/improved technologies. Companies are pursuing new technologies for quench and temper, lean manufacturing lines are being installed to improve flexibility in product mix and material-handling control advancements allow individual part tracking for improved record keeping. Still, perhaps the most critical of the heat-treat processes – the quench – has seen little technological advancement in the past 40 years. Most continuous-process quench-and-temper facilities utilize one of two antiquated types of quenching strategies: either a simple barrel quench or a tangential quench.

Barrel Quench

While the barrel-quench design is one of the oldest quench methods for cooling tube and bar product, it has some inherent disadvantages. Chief among these is the utilization of nozzles to emit the quenchant medium. Nozzles do not provide a constant uniform flow and can prompt the formation of a vapor barrier on the surface of the product being hardened. Vapor barriers limit cooling via the Leidenfrost Effect, which describes the emergence of a bubble of gas formed from the vaporization of the quenchant between a quenchant and a metal. This bubble of gas acts as an insulator, resulting in slower cooling and an absence of nucleic boiling – an agitated boiling state that is highly effective for heat transfer. The resulting slower heat transfer reduces the depth and quality of metallurgical transformation.

Martensite, a desirable, hard steel crystalline structure, is formed in a narrow process window dependent on fast cooling rates. If these cooling rates are not sufficiently aggressive, the thermal process will pass through the nose of Bainite on the continuous cooling curve and change the final product microstructure. Barrel-quenching processes that experience the Leidenfrost Effect have lower heat-transfer rates and are thus subject to longer process times and lower percentages of martensite with a shallow depth of penetration (typically less than 8 mm on bar stock, depending on chemical composition).

One means to combat the Leidenfrost Effect is to employ higher pressure and volume of quenchant. Within a barrel quench, however, the flow is limited by the high volume of quenchant that cannot be transported through the nozzles. As a result, barrel quenches require a much longer series of cooling chambers to reach an acceptable temperature and counteract bounce-back, a reheating of a product's surface from its core. This slower cooling results in lower martensitic development and the potential for uneven cooling/hardness distribution around the circumference of the product.

In most cases, such a quench-and-temper line would require a warm re-straightening line for the tube or bar to counteract resultant bowing from adverse distribution of cooling and residual stress. Unfortunately, for product ranging up to 300 mm diameter, this issue can be very cost-intensive and require a large capital investment in a straightener. This situation is so common in existing barrel-quench applications that the API specification refers to "warm re-straightening" as an approved process.

Tangential Quench

A second type of quench frequently used by oil-country tubular goods (OCTG) producers is the tangential quench. As a counterpoint to the barrel-quench limitations, the intent of a tangential quench is to improve the ability of the quenchant to travel on and off of the product quickly. It

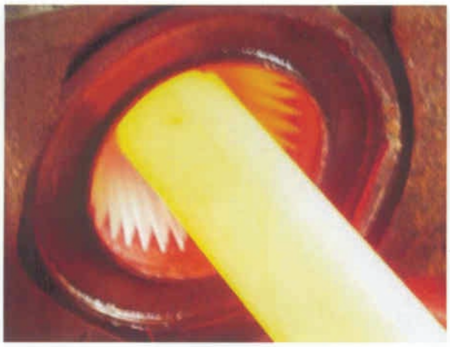

Fig. 2. (above) Typical barrel quench
Fig. 3. (right) Precision Slot Quench™

Fig. 4. Tangential quench

offers an improvement over barrel quenches for light-wall product, as some designs allow nozzle aperture adjustment to focus the spray on varying diameters of tube.

The process is so named because the quenchant is sprayed across the tangent of the tube or bar surface. This provides the advantage of segmented batch processing for tube because the quenchant will not enter the ID of the product. While still limited in its flow due to the use of nozzles, the tangential quench uses the geometry of the spray pattern to try to better cut through the vapor layer of the Leidenfrost Effect.

While effective in its initial contact with the product, quenchant delivered via tangential quenches can experience spray interference. The low angle of contact from each nozzle's spray results in the quenchant deflecting into the spray of adjacent nozzles. This reduces the velocity of the quenchant and limits its agitation effectiveness and its surface impingement. The same metallurgical deficiencies of the barrel quench result – decreased martensite transformation and increased Bainite.

Added challenges with the flow limitation encountered in both barrel and tangential quenches are volume control and a high dependency on equipment maintenance. Nozzle-type quenches are binary, with no control (manual or automatic) of flow or pressure. Additionally, fixed-orifice-size nozzles are subject to clogging. Unfortunately, slower cooling rates tend to generate more scale, which can reduce tonnage output and add more particulate to the quenchant, further increasing the likelihood of clogging. Ultimately, a loss of quality due to clogged nozzles increases potential for bowed product.

Precision Slot Quench™

The latest technology innovation to address these limitations is the Precision Slot Quench™ design (patent pending). Unlike its predecessors, the Precision Slot Quench™ uses a quench ring to apply a single continuous spray around the circumference of the product. The continuous spray is not applied via nozzles but from an annulus between two conical plates with geometry that ensures full, even flow around the tube or bar surface. The resultant symmetric cooling occurs without the discontinuous spray patterns inherent in nozzle quenches, thereby reducing the adverse distribution of stress and improving overall straightness. The quench rings are spaced at intervals to prevent spray interference commonly found in tangential and barrel quenches. The quenchant is then able to contact the product and leave the product's surface without formation of an insulative vapor blanket. With the proper flow rates and quenchant velocities (pressure), any vaporization of the quenchant is quickly repelled away from the surface of the product, thereby boosting heat transfer (Grossman numbers) between the quenching medium and the tube or bar.

Higher heat transfer coincides with improved depth and quality of metallurgical transformation (up to and exceeding 12-mm-deep martensitic transformation), greater flexibility with product chemistries, higher yields through faster processing and improved heat-treat capacity for lines with limited floor space.

Supplementing the modularity of the Precision Slot Quench™ with flow control via variable-flow pumps allows for more efficient processing through recipe creation and retrieval. Once a process is set up and validated using this system, process parameters can be retrieved for easy system setup when running the product at a later date. The quench system can be programmed to provide the right variables for any production rate within the production capacity of the system. Precision Slot Quench™ systems provide the highest reliability and offer the tube-and-pipe industry its first significant technological breakthrough for the quenching process in recent history. **IH**

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If you'd like to learn more about quenching, and how the Precision Slot Quench™ may be able to improve your system, please send an inquiry to Thermatool at: info@ttool.com

References:

1. ThomasWhite International, *Iron & Steel Industry in Brazil: In a Sweet Spot* – Oct 2010 http://www.thomaswhite.com/explore-the-world/bric-spotlight/2010/brazil-iron-steel.aspx
2. AISI - Steel Industry Technology Roadmap, Oct 2003 http://www.steel.org/~/media/Files/AISI/Public%20Policy/YieldReportIkOct7-03.ashx
3. American Society for Metals, The Metals Handbook, 1981
4. Reddy, A.V. "Simple Method Evaluates Quenches" *Heat Treating Progress*, June/July 2001