21st Century Heat Treating Terms

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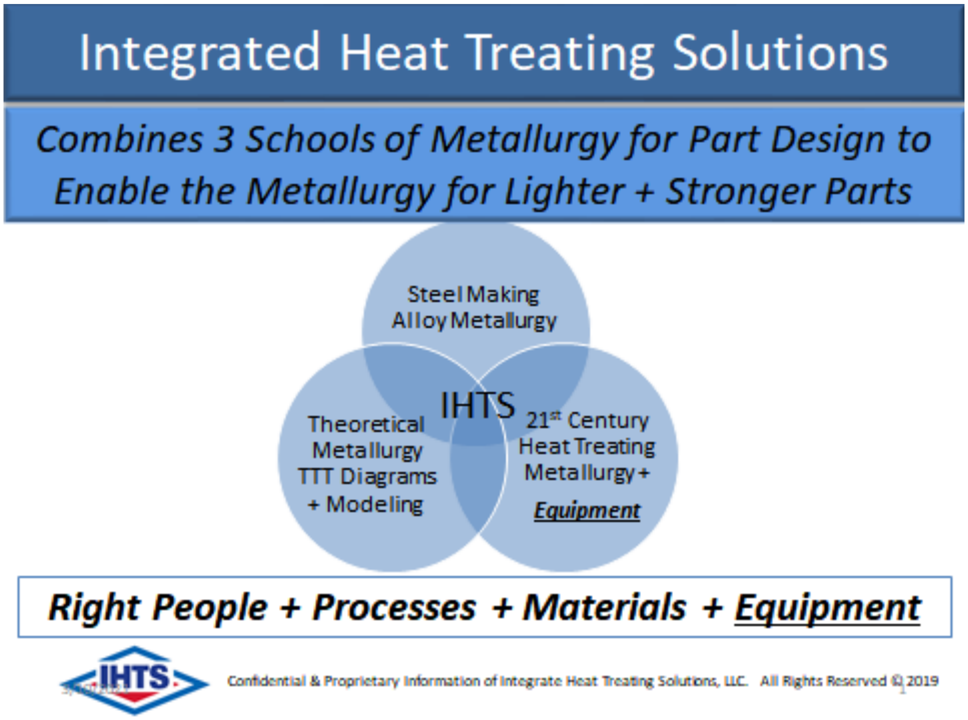
1. Three Dynamic Uniformities at a "Grainular" Level – Heating and cooling are dynamic processes. Practicing good heat treating metallurgy means these "dynamics" must be kept as uniform as possible to obtain all the added value possible from a particular alloy of material and to do so consistently from part to part over time. The modern heat treater must provide these three "dynamic uniformities" on a "grainular" basis, starting at the contiguous surface grains of the given part (Slide #13):
A. Uniformity of Heating Dynamics = a uniform rate of heating at the surface of the part.
B. Uniformity of the "Atmosphere" = a "protective environment" around the hot part surfaces to prevent oxidation, scaling, alloy depletion or decarburization during heating.
C. Uniformity of Quench Cooling Rate = A "Uniform Quench Renewal Rate" (UQRR™) at the part surface shell that is fast enough to "uniformly miss the nose of the curve" to trigger the formation of hardened grains and the desired mechanical properties.

2. Quench2Fit™ – a suite of new heat treating metallurgy technologies that are combined to control heat treating distortion by making thermal expansion, thermal shrinkage and phase change expansion uniform and predictable on a "grainular" level during the heat treating processing to consistently achieve the desired physical properties.

3. A "Z-Dimension" design – A part design that incorporates heat treat treatments, an optimal "Ability to Harden" combined with an optimal "Hardenability" alloy of wrought, cast, forged and powdered metal alloy material that is suitable for the part mass and geometry considering the intended end use.

4. "Value Champions" are heat treating practitioners and steel alloy and ductile iron making metallurgists (including powdered metals) that work with part making engineers, the product end users, and their entire part making value stream, upstream and downstream from their respective processes, to concurrently engineer all the "value added" desired in a product; while at the same time eliminating all the wastes at each step of the value stream – the corrections like grinding and straightening that no part maker pays for as part of the heat treatment.



Integrated Heat Treating Solutions

Combines 3 Schools of Metallurgy for Part Design to Enable the Metallurgy for Lighter + Stronger Parts

Right People + Processes + Materials + Equipment

5. Industry 4.0 as defined in Wikipedia (https://en.wikipedia.org/wiki/Industry_4.0):
Although the terms "industry 4.0" and "fourth industrial revolution" are often used interchangeably, "Industry 4.0" factories have machines which are augmented with wireless connectivity and sensors, connected to a system that can visualize the entire production line and make decisions on its own.
In essence, industry 4.0 is the trend towards automation and data exchange in manufacturing technologies and processes which include cyber-physical systems (CPS), the internet of things (IoT), industrial internet of things (IIOT)[2], cloud computing [3][4][5][6], cognitive computing and artificial intelligence.
The concept includes smart manufacturing that takes a part design for making a part, and integrates and aligns all of the various steps, in the proper order, and data at each manufacturing step, eliminates the waste, and then over the Internet of Things, cyber-physical systems communicate and cooperate with each other and with humans in real-time both internally and across organizational services offered and used by participants of the value chain.[3]
In 20th Century heat treating, batch heat treating methods and the equipment are generally not integrated with the part making value chain; most heat treating is done in captive heat treating departments of the part maker some distance from where the part is made, or at a commercial heat treater that is located in the area and heat treats parts for various part makers. Clean 21st Century single-part flow heating and water or gas quenching processes can enable heat treatments to be more integrated into Industry 4.0 part manufacturing.

6. IntensiQuench® – IQ Technologies Inc trademark for "uniform and intensive" water quenching applied after Austenitize heating. Very high intensity quenchant flow is needed at the part surface shell to eliminate non-uniform film boiling and prevent the part from cracking. IQ-2™ is IntensiQuench done in a tank with the hot parts presented in batches; IQ-3™ is single part quenching usually at a more intensive "high velocity" flow of 5 to 20 meters per second.

7. Uniform Quench Renewal Rate (UQRR™) is the dynamics for the proper application of quench cooling during heat treatment; using agitated air, inert gas, molten salts, oil or polymer-water, or water or water-brine quenchants, to create a uniform rate of cooling in the "contiguous grains" of Austenite as the grains cool to the Martensite start temperature and harden. The rate of cooling must be fast enough and uniform enough at the hot part shell to "miss the nose of the curve" for the Martensite start temperature for a particular alloy's Hardenability (as shown on the TTT Diagram) while at the same time the quenchant must be "renewed" to not overheat the quenchant at the part surface.

8. Alloy "Hardenability" and the heat treaters' "Ability to Harden" are related concepts that are interrelated defined together in 21st Century part design.

All alloys of Martensitic steel or ductile irons have a certain inherent ability to develop hardness (strength) to a depth into the part mass based upon the type and percentage of alloying elements added to the base iron metal.
Carbon is the main hardenability alloying element. Manganese, Nickel, Silicon, Molybdenum, Vanadium and Chrome are other common alloying elements for Martensitic steels.

Ability to Harden is the heat treaters ability to harden a part of a certain mass and geometry to a level of hardness (strength) and develop mechanical properties desired by the part makers and valued by the end user customer. E.g., hardness, tensile strength, ductility or yield strength, impact resistance, wear resistance, cyclic fatigue resistance, as well as corrosion resistance.

The heat treaters' Ability to Harden a part of a particular mass and geometry is directly related to two factors:
A. How much Hardenability there is inherent in the alloy of steel (or ductile iron) that was used to make the part; and
B. How fast and how uniformly can the heat treater remove the high heat from the Austenitized part surface shell during the quenching process. The faster the removal rate the higher the ability to drive hardness deeper into the part mass for a given Hardenability of alloy.

9. Dante Controlled Gas Quench (DCGQ™) – a patent pending gas quench cooling method with all the cooling dynamics controlled by Dante's Finite Element Analysis (FEA) metallurgical modeling tool that takes into account the part mass, the geometry (the finite element mesh), and the material characterization -- a particular alloy's Hardenability. All of the foregoing are built into the DCGQ cooling recipe.

10. "Current" and "Residual" compressive surface stresses (Slide # 21)**:** A "current" compressive surface stress state occurs when a part surface shell is "uniformly and intensively" quenched from the Austenitizing temperature, and then to the Martensite start temperature, while the part core is still hot and fully Austenitic. Once the contiguous grains on the part shell expand in volume, the "swollen" Martensite grains press against each other and put the shell under compression. This hardened shell under high compression holds the part shell like a "die" as the hotter layers below thermally shrink in volume; this thermal shrinkage pulls the shell into a higher level of compressive stress.

When enough of the “layers of the onion” below the hardened surface quench cool to the Martensite start temperature, the surface compression peaks, and there is not enough plasticity or thermal shrinkage left in the mass of the part core, as the layers cool by uniform conduction through the part mass, the transformation to Martensite creates “core swelling” that pushes back the layers above and reduces the “current” compression at the surface shell.

At the end of the quench process, if the core swelling overrides the level of current compression, the residual stress state of the part surface can be put into tension. If the tensile stresses exceed the strength of the material, the as-quenched part will crack.

11. Explanation of the Bell-Shaped Curve: The Relationship of Quench Cooling Rate versus Probability of Part Cracking or Distortion

Traditional “Left-Side” of the Bell Curve of the relationship between Quench cooling rates and the probability of quench cracking or distortion are shown on Slide #23.

The traditional theory on how to control distortion from heat treat quenching is to slow the quench rate down as slow as possible, but still fast enough to attain the desired mechanical properties from the given Hardenability of alloy material used to make the part.

If higher strength and hardness was needed deeper into a particular part’s mass, the part designer could still slow the quench rate and select an alloy chemistry with higher Hardenability.

The downside to the selection of higher Hardenability material is it will create more Martensite “core swelling” that can reduce the levels of beneficial residual compressive surface stresses. Also, generally, the higher the Hardenability, the more alloying elements are present, the higher the cost and the lower the machinability and weldability of the material.

Quench cooling rates on the “Right-Side” of the Bell Curve are depicted in Slide #25.

21st Century heat treating metallurgists have discovered that the relationship between faster quench cooling rates and probability of part distortion or part cracking is not linear. The relationship is more about the “uniformity” of whatever quench cooling is happening at the surface of the part shell than speed of the quench cooling rate.

The fact is as long as the quench cooling rate is “uniformly” applied over the entire surface shell of the hot part, the heat treater can either quench relatively slowly, using a gas or molten salt quenchants, or apply a very intensive water quench cooling rate, and the probability of part cracking in the quench will be low.

The relationship of quench cooling rate to Part Distortion is a therefor a Bell-Shaped curve. Either a very slow and uniform cooling rate or a very intensive and uniform cooling rate will yield predictable size changes in the part after quenching.

The key to controlling distortion and avoid part cracking is to apply the quenchant with a Uniform Quench Renewal Rate (UQRR). The problem with oil, polymer water and traditional water or brine quenching is at the initiation of quenching, there is a film boiling (a steam blanket of interconnected large bubbles) that insulates the hot part surface. As the quench cooling continues, almost immediately the film boiling gas vapor blanket will begin to chaotically collapse, and the film boiling gives way to another phase of boiling called nucleate boiling.

Nucleate boiling cooling phase is comprised of many very tiny bubbles that form very quickly at the hot part surface (like Champaign bubbles) and quickly evaporate. This evaporative cooling makes for a very fast cooling rate - like sweat evaporating from skin. When the very fast cooling rate of nucleate boiling is juxtaposition to the very slow and erratic gas cooling rate of film boiling, the hot (Austenitic) part grains undergo non-uniform thermal shrinkage; and when the contiguous hot grains cool to the Martensite start temperature, a rapid and non-uniform Martensite phase change expansion occurs.

A UQRR that simultaneously “instantly-impacts” the entire hot part shell can “set” the part shell geometry, prevent part cracking and provide a uniformly higher as-quenched surface hardness (for the given material’s Hardenability).

Once the shell of the part is hardened uniformly, the part geometry is set, and the layers below will cool by very uniform conduction. The combination of the UQRR at the part surface, and the uniform cooling of the core by conduction through a part’s given mass, transforms the part predictably into its final hardened shape and addresses the problem of heat treating distortion.