21st Century Heat Treating Solutions: A New Dimension in Lean Manufacturing for Industry 4.0

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Z-Dimension Design, LLC

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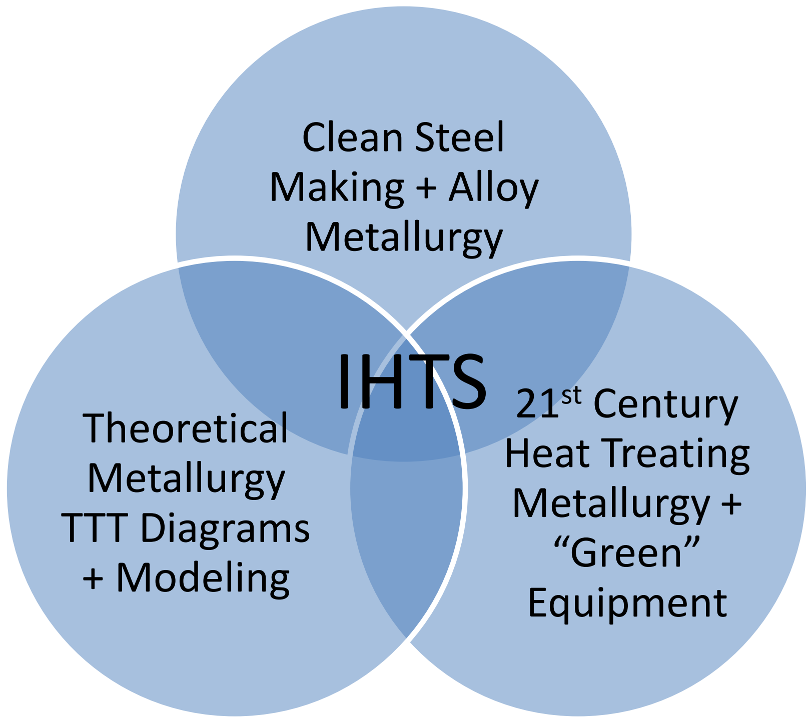
What is Heat Treating for Industry 4.0?

Heat Treating for Industry 4.0 is ***grainular-level***
of ***heating and cooling rate control for*** metals
often to extreme temperatures and with fast cooling rates
to refine the metal alloys' crystalline grain structure to
obtain a desired *set* of mechanical properties for a part =
A balanced hardness + ductility plus all the added value from
optimal residual *compressive surface stresses.*

Added Value of Compressive Surface Stress is Distortion Control.

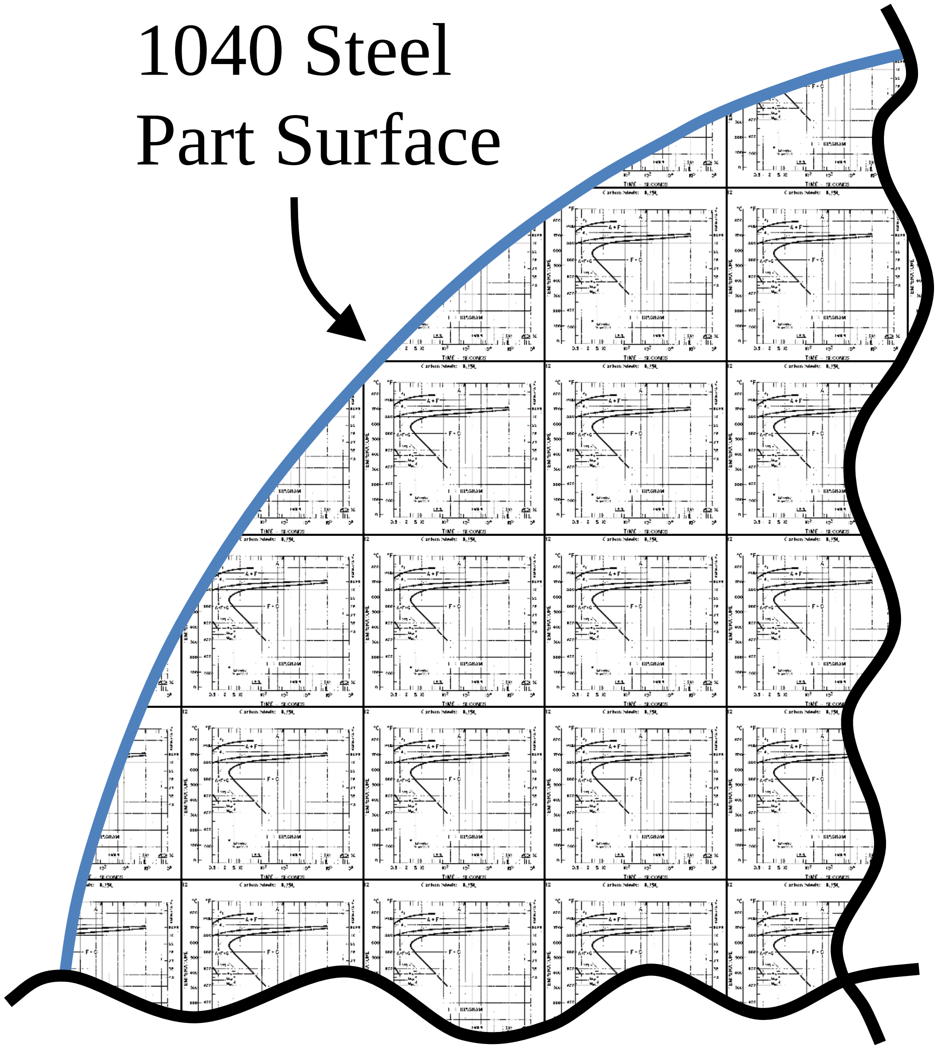
Integrated Heat Treating Solutions

Combines 3 Schools of Metallurgy for Part Design



Right People + (Processes + Materials) + <u>Equipment</u>

Z-Dimension Design of Heat Treatments



- Select CLEAN, leanest alloy – Optimal **Hardenability** for part geometry + mass; considering end use (***"Grainular Di Control"***)
- **<u>Follow Dr. Quench™ Perscriptions:</u>** <u>Instantaneously</u> Eliminate Film Boiling with a Highly **Uniform** or **Uniform <u>and</u> Intensive Shell Cooling** = Optimal **"Ability to Harden"**
- Form a **Uniform "Shell Die" of Martensite =** ***"<u>Current</u>"*** Compressive Surface Stresses, then
- Control Ms to Mf **"Core Swelling"** for Higher "***<u>Residual</u>***" Compressive Surface Stress +
- **<u>RESULTS:</u>**
- Finer Grains + more Uniformly Hardened
- Higher Residual Compressive Surface Stress +
- **Predictable Distortion for a Given Alloy Hardenability**
- **Longer Wearing, Lighter + Stronger Parts =**
- **More Customer Value = Customer Pull**
- **Strategic Advantages in the Market for All Supply Chain Partners**

"Grainular Di" (Hardenability Selection) + Optimal Ability to Harden

Z-Dimension Designs = SuperValue™ from Balanced *Hardness, Ductility + Compressive Residual Surface Stress*

SuperValue™

Heat Treated Parts

Higher Power Density

Longer Wearing, Lower Alloy

Enabled Quench2Fit™

Less Post-HT Processing

Optimal Hardenability

(Di) + (Clean Steel)

Balanced Hardness +

Core Ductility

Given Part Mass + Geometry

(Steel Making Metallurgy)

Z-Dimension Designs:

A Value Map for

Lean Part Making

FEA Part Modeling and

Optimal Lean + Green Equipment

(Theoretical Metallurgy)

IHTS Enables Optimal

Ability to Harden

Finer, Stronger Grains +

Compressive Surface Stress =

(A New Dimension for

Heat Treating Metallurgy +

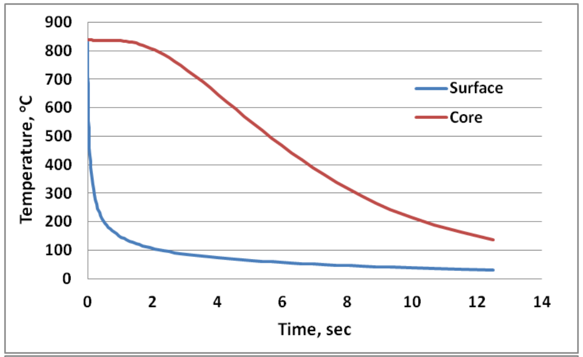
Equipment (CFD Modeled)

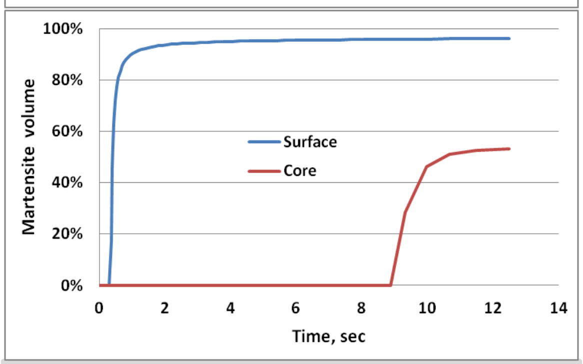
Right People + (Processes + Materials) + Equipment

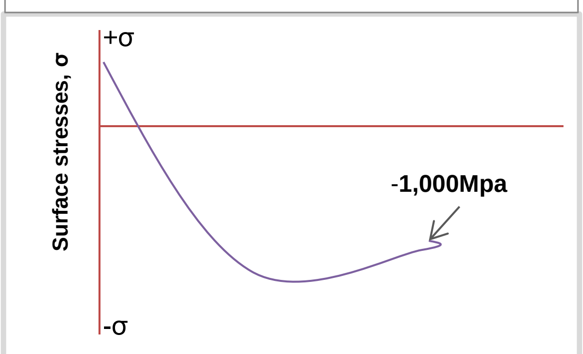
Dynamics of Uniform and Uniform + Intensive Quenching (DANTE FEA Model, Probe + XRD Data)

Ø25mm cylinder made of AISI 1045 steel (Ms=320ºC)

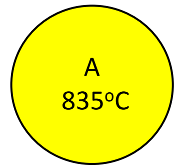
IntensiQuench® in Water



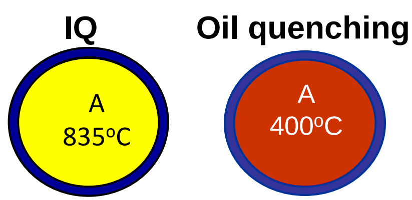




T = 0 seconds

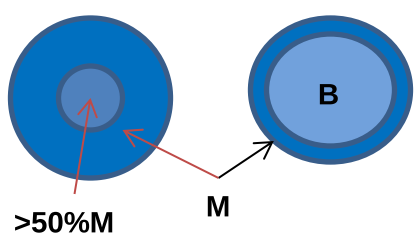


Start of martensite formation

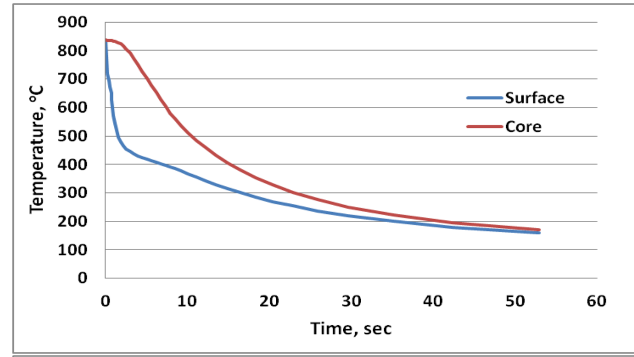


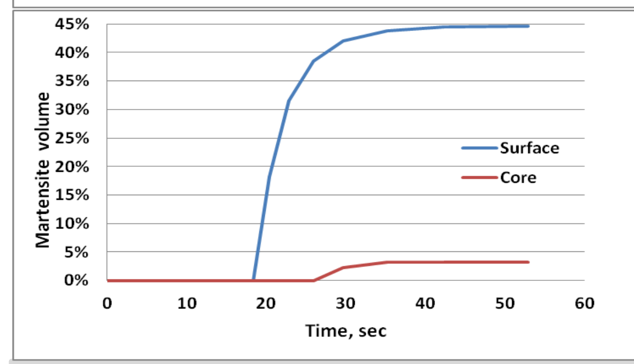
T <0.2 seconds **T = 18 seconds**

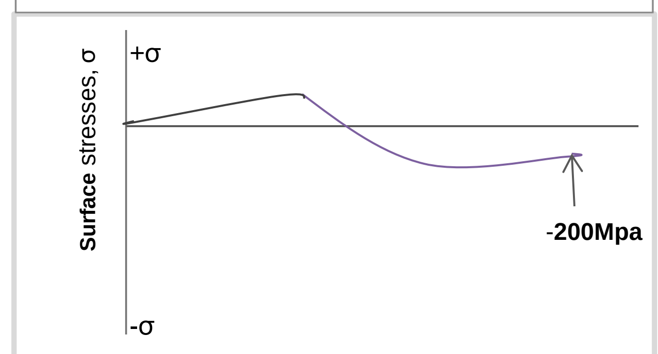
Final steel microstructure



Traditional Quench in Oil/Polymer s

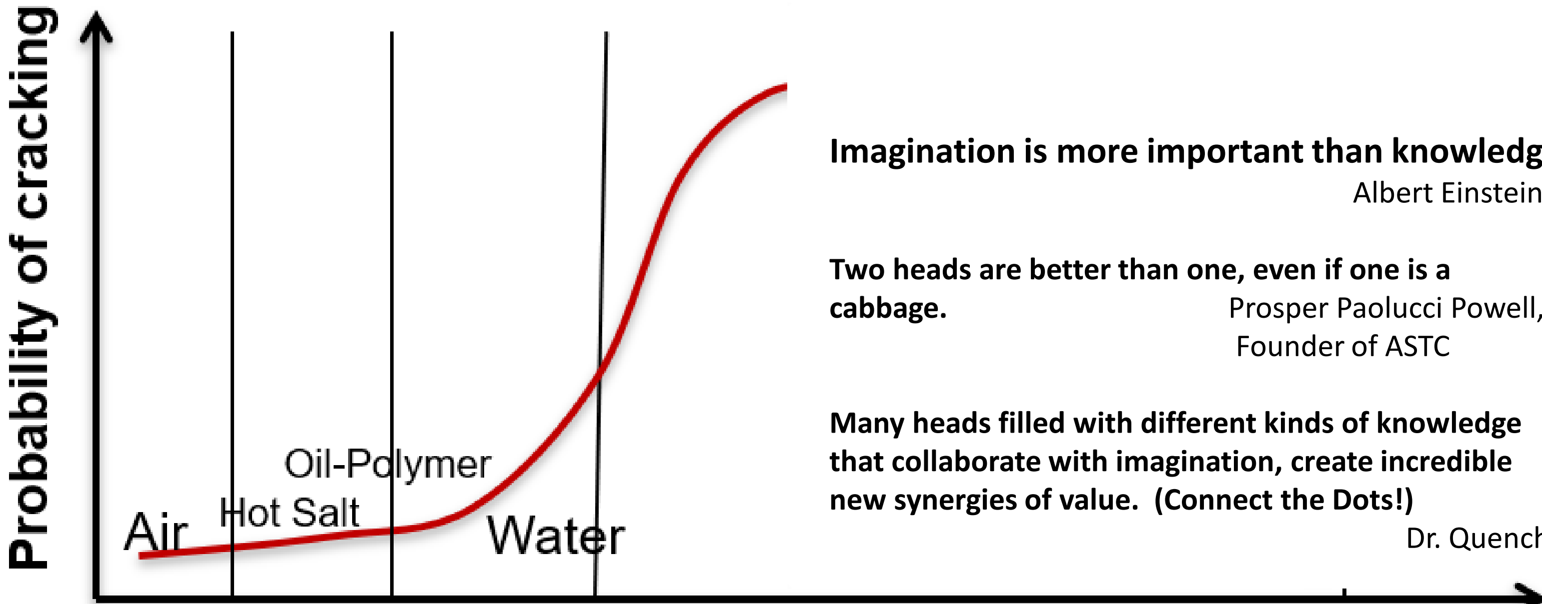






Traditional Heat Treat Thinking

Slow the quench rate to eliminate part cracking + produce “acceptable distortion” + Balanced Hardness with Ductility (Toughness)

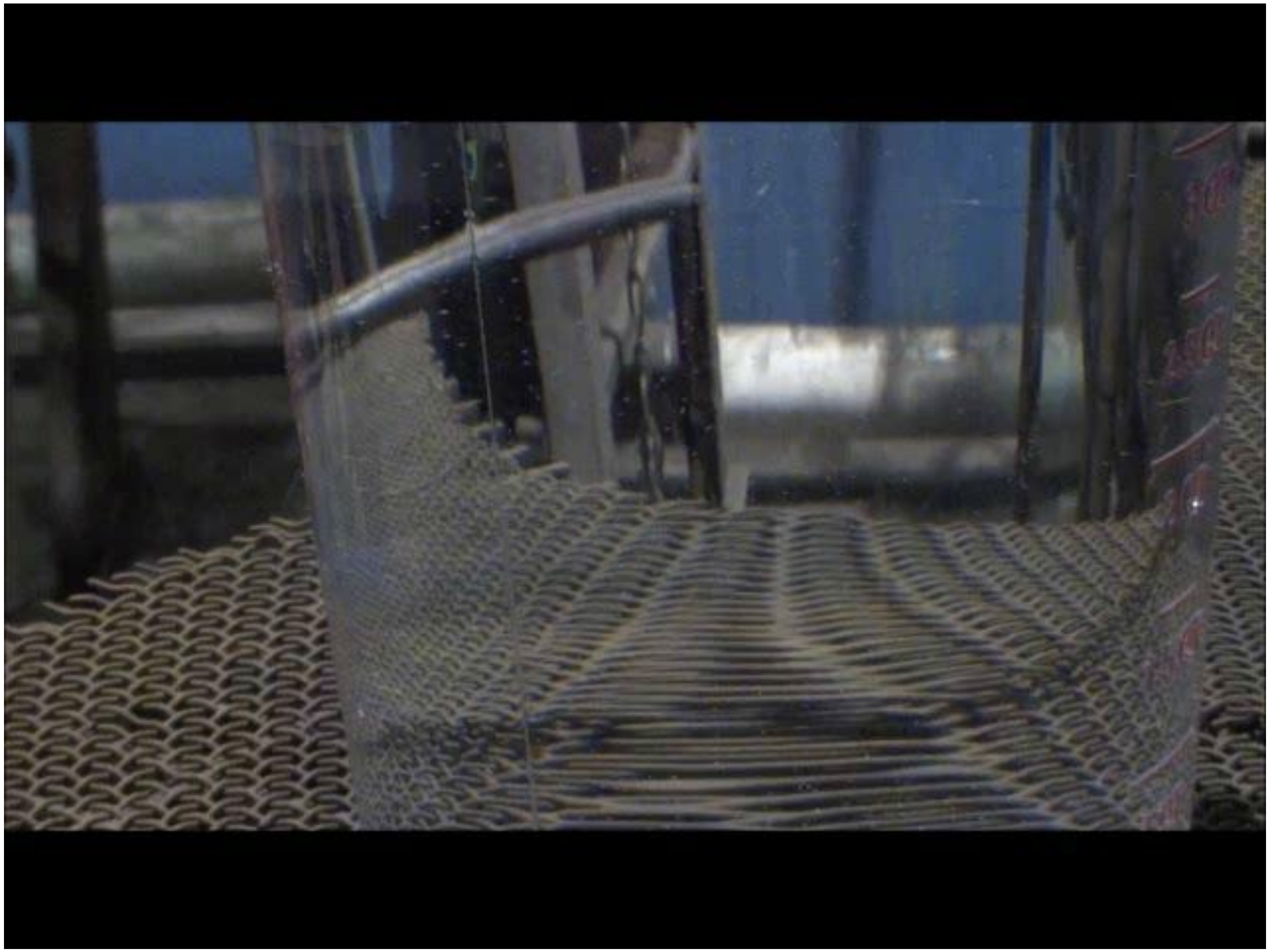


Imagination is more important than knowledge.
Albert Einstein

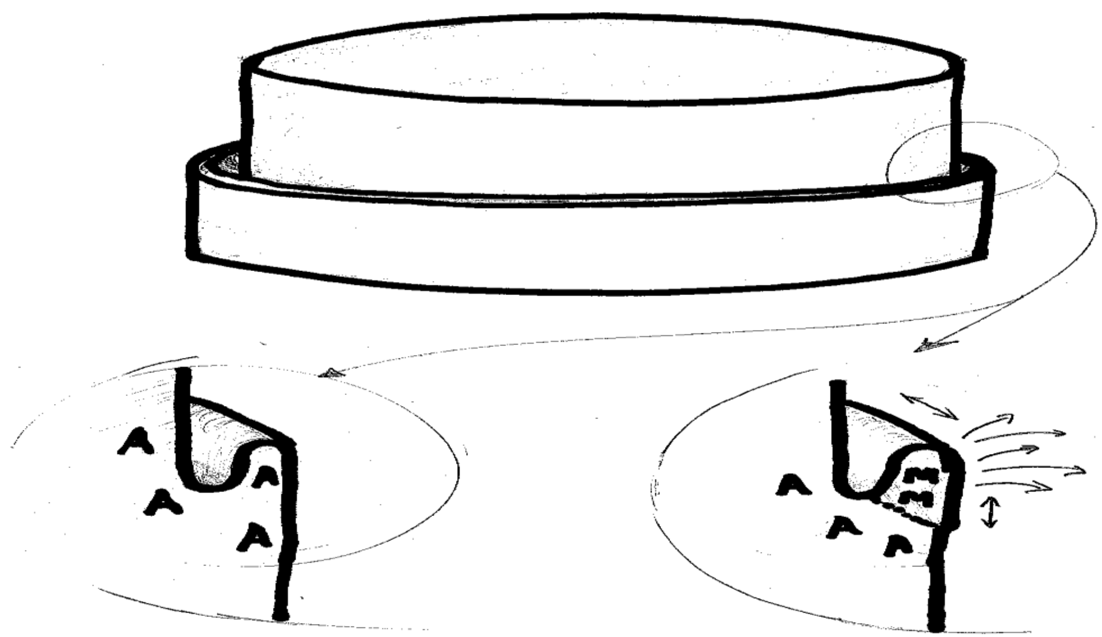
Two heads are better than one, even if one is a cabbage.
Prosper Paolucci Powell, Founder of ASTC

Many heads filled with different kinds of knowledge that collaborate with imagination, create incredible new synergies of value. (Connect the Dots!)
Dr. Quench™

3 Modes of Heat Transfer During Quenching



The Dynamics of Film Boiling in Groove ("Gas Quench") = <u>Non-Uniformity</u> (Thermal + Ms Phase Change Changes) = No Shell with "Current" Compressive Surface Stress = Unpredictable Size Changes (Distortion + Cracking) + No Benefits from "Residual" Compressive Surface Stresses Dr. Quench

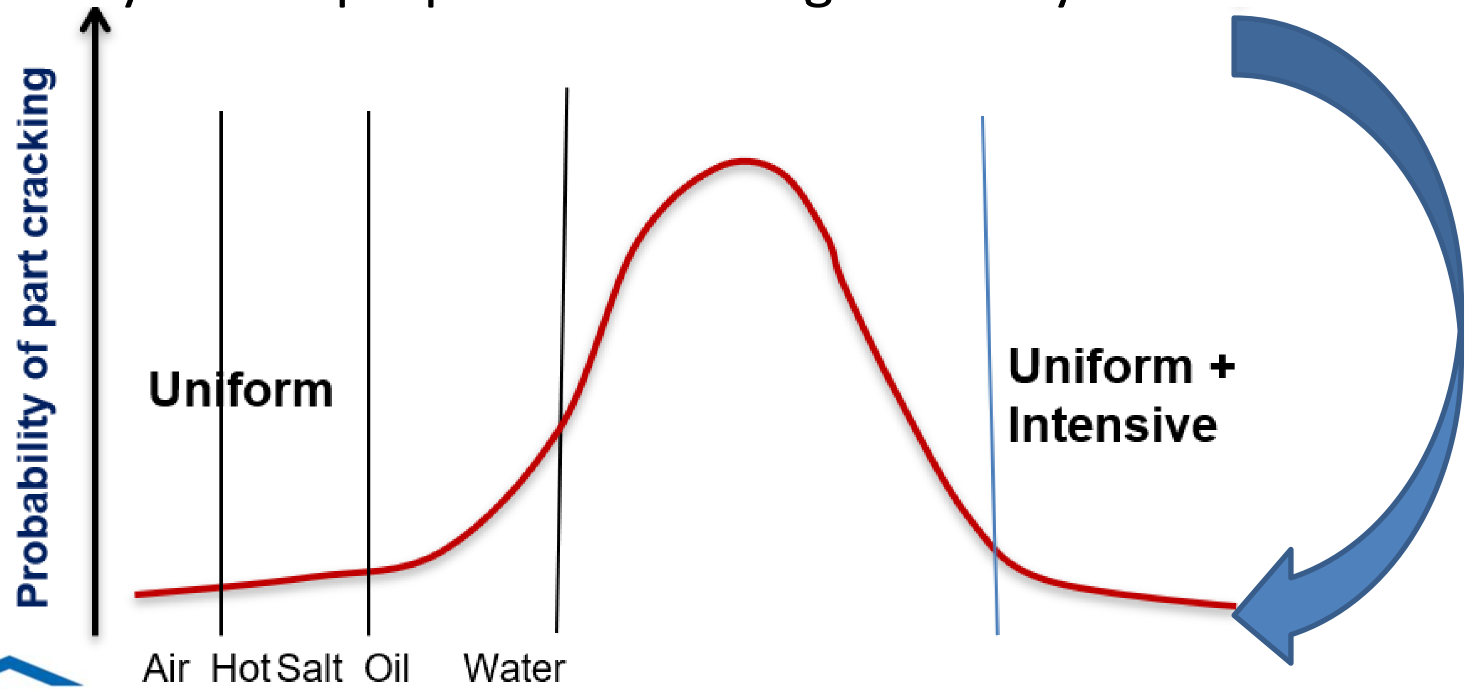


Dr. Quench's 21st Century Solutions

A "Bell Curve" Paradigm: ***Uniform Quench Renewal Rates (UQRR™)***

1. Using Gas or a Molten Salt Quenchants, or
2. ***Uniform + Intensive Water Quenchant*** =

predictable size change (Quench2Fit™ net shape parts) + Consistently better properties from a given alloy of steel.



Uniform Quench Renewal Rate (UQRR™) = NO Film Boiling

Z-Dimension Designs Maximize Residual Compressive Stress

Punch Mechanical Properties: Compressive Stresses @ Work

IQ Increased S-5 Steel Punch Life

2X to 9X more holes

Compared to Traditional Oil Quench

S-5 Steel chemistry:
C-0.55; Mn-0.8;
Si-2.0; Mo-0.4

Benefits of Compressive Surface Stress

- Punch mechanical prosperities – Compressive Stresses vs Tensile Stresses

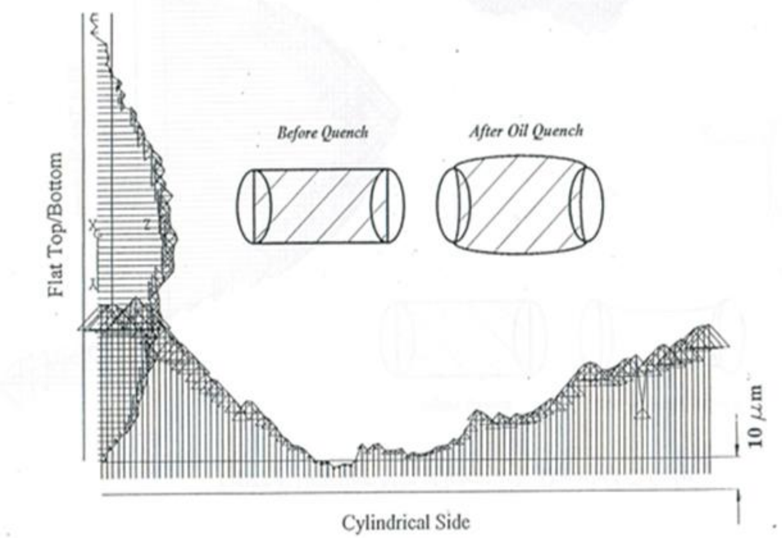
Property		Oil Quench	Intensive Quench
Hardness, RC	As-quenched	62-63	63-64
	As-tempered	**60-61***	**60-61***
Impact	@20°C	1.0	3.0
strength, ft·lb	@100°C	2.5	4.5
Residual surface stresses, Mpa (PSI)		**200 (29,007)**	**-900 (130,534)**

*1999 Study conducted by Prof Jack Wallace, et al, at Case Western Reserve University of Cleveland, Ohio ASM Paper
* Same Hardness after Temper

Z-DD for Predictable Size Change

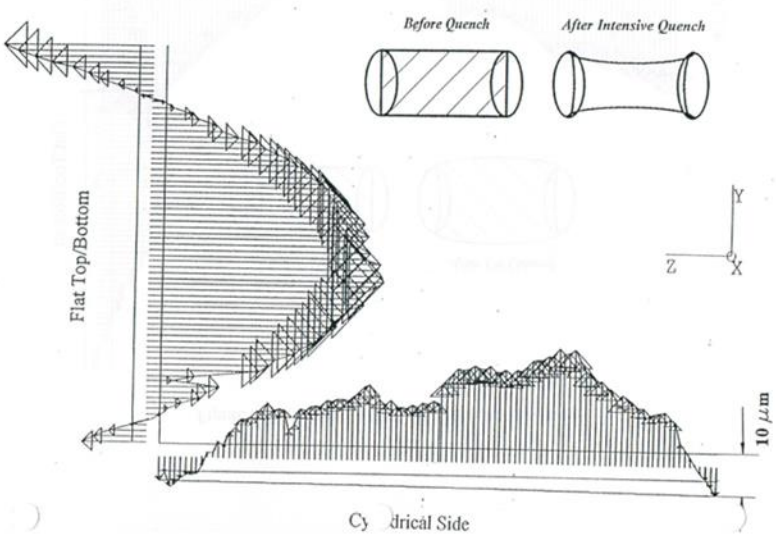
- S-5 punches intensively quenched in batch IQ2 IntensiQuench® System

Distortion Map of Oil Quenched Punch



"Barrel" shape is due to residual surface ***tensile*** stresses.

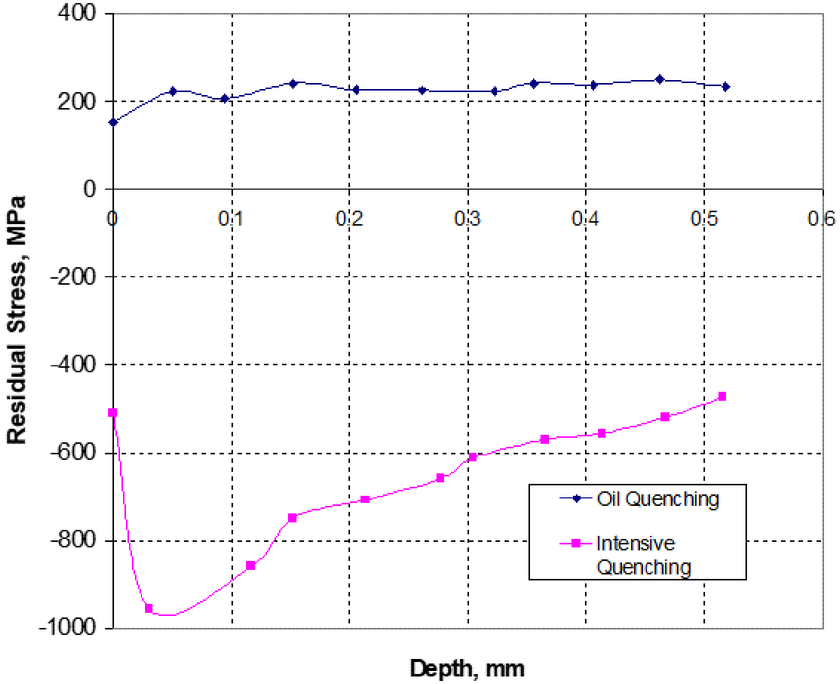
Distortion Map of Intesively Quenched Punch

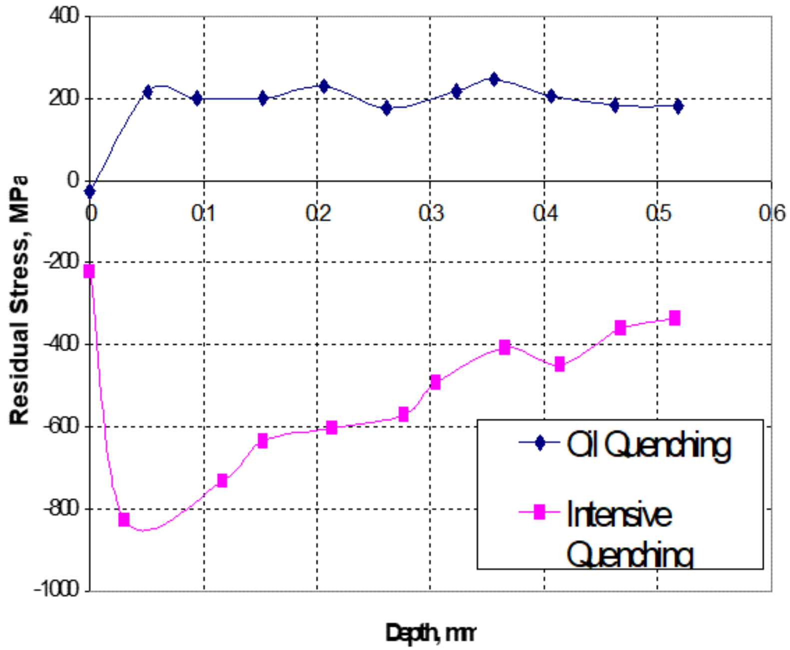


"Concave" shape is due to residual surface ***compressive*** stresses.

Z-Dimension Design for Higher Compressive Residual Surface Stress

- Hoop stresses and Axial stresses



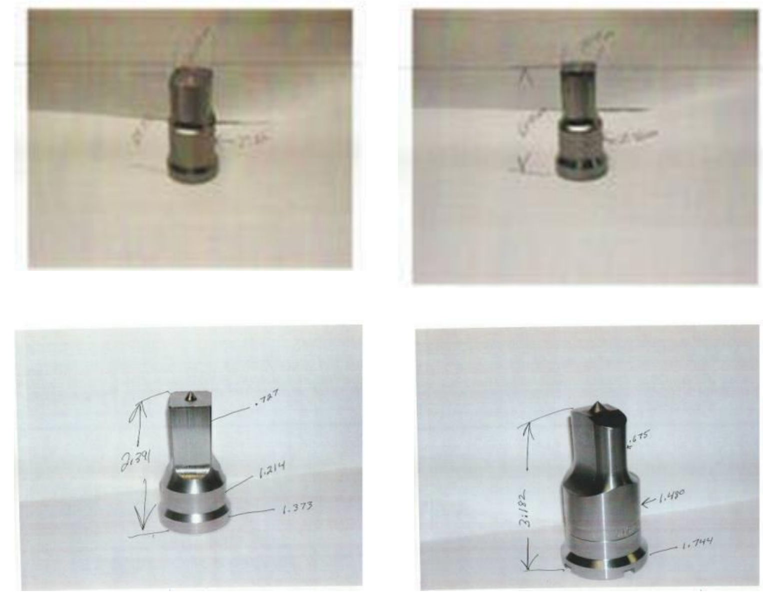


Max Compressive Surface Stresses = Longer Part Life

S5 Tool Steel Punches

Round punches

Square punches



- Intensively water quenched punches make up to 9 times more holes compared to oil quenched punches due to:
  - high residual surface compressive stresses
  - improved material mechanical properties (finer grains)

Punch failure mode changed from chipping/spalling to becoming undersized.

Lean Part Design + Manufacture:
Subtractive, Additive + Transformative (HT)
All Working in Collaboration

- Three different heat treating solutions for a ball stud:
- 1. 8620 Carburized, oil quench + temper
- 2. 52100 core toughened (Q+T) then induction case harden ball to max hardness
- 3. 52100 hardened with HPIQ™ then induction temper threaded end to taper

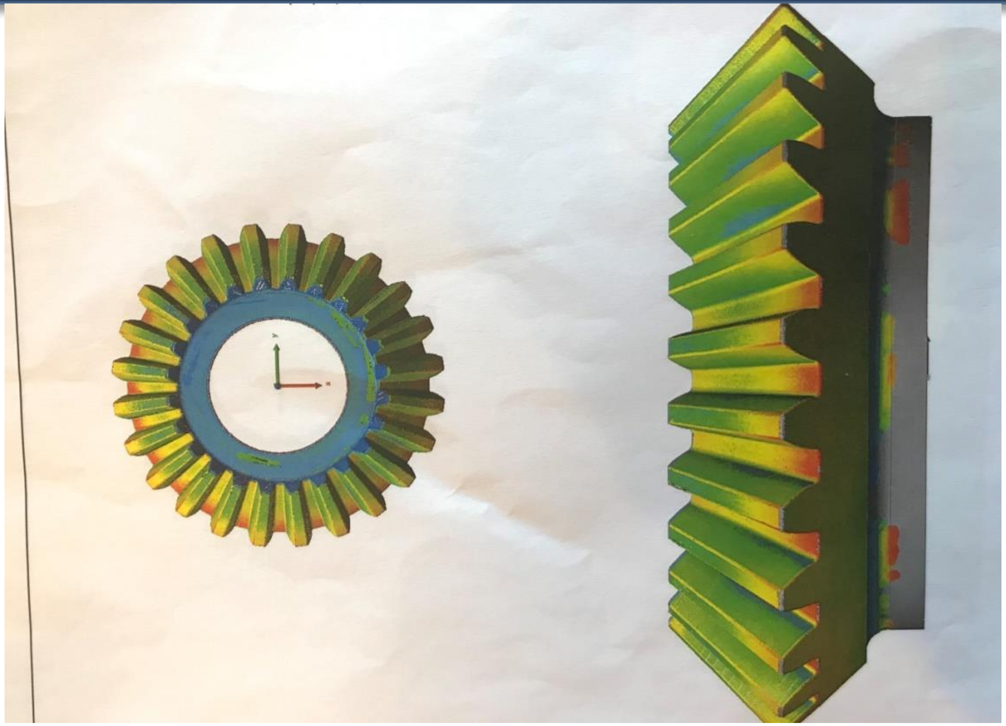
IHTS Enables Z-Dimension Design Modeling

Lean Part Design + Manufacture:
Subtractive, Additive + Transformative (HT)
All Working in Collaboration

IHTS Enables Z-Dimension Design Modeling

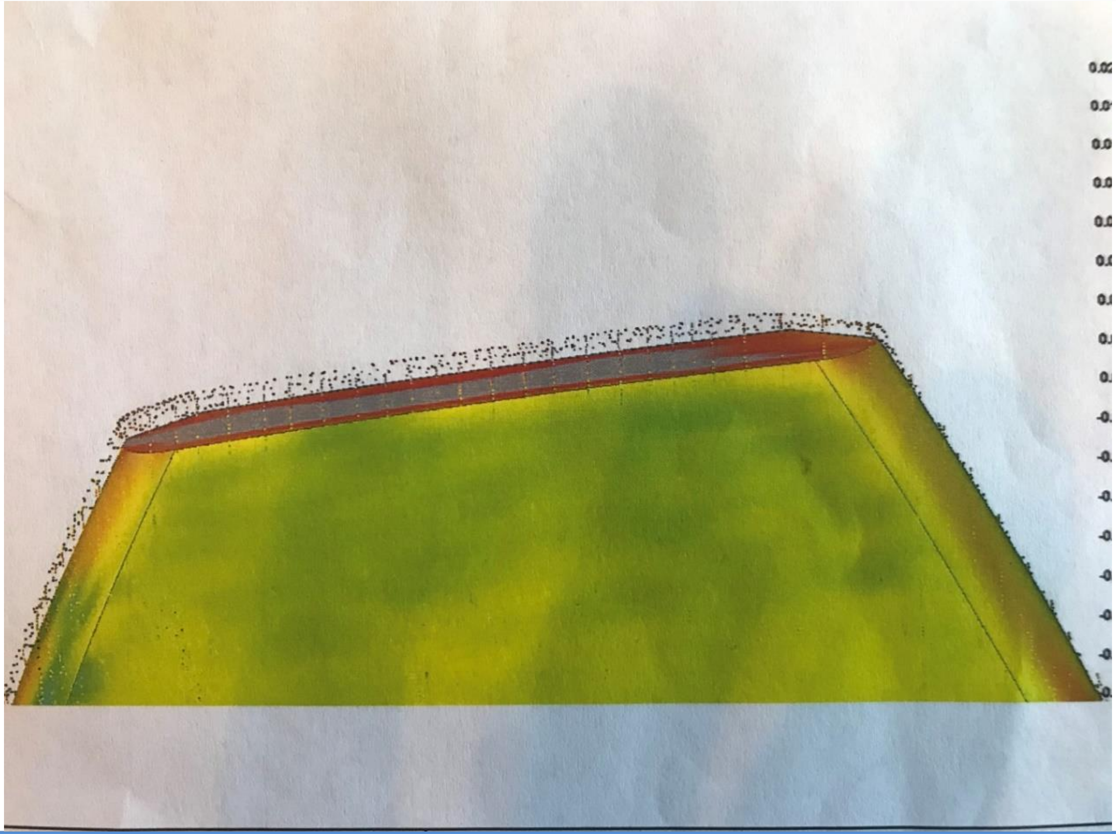
IHTS

Lean Part Design + Manufacture: Consistently uniform quench + Laser-based Metrology = Quench 2Fit™ Gears



IHTS Enables Z-Dimension Designs

Lean Part Design + Manufacture:
Quench 2Fit Gear saves $750 in grinding cost



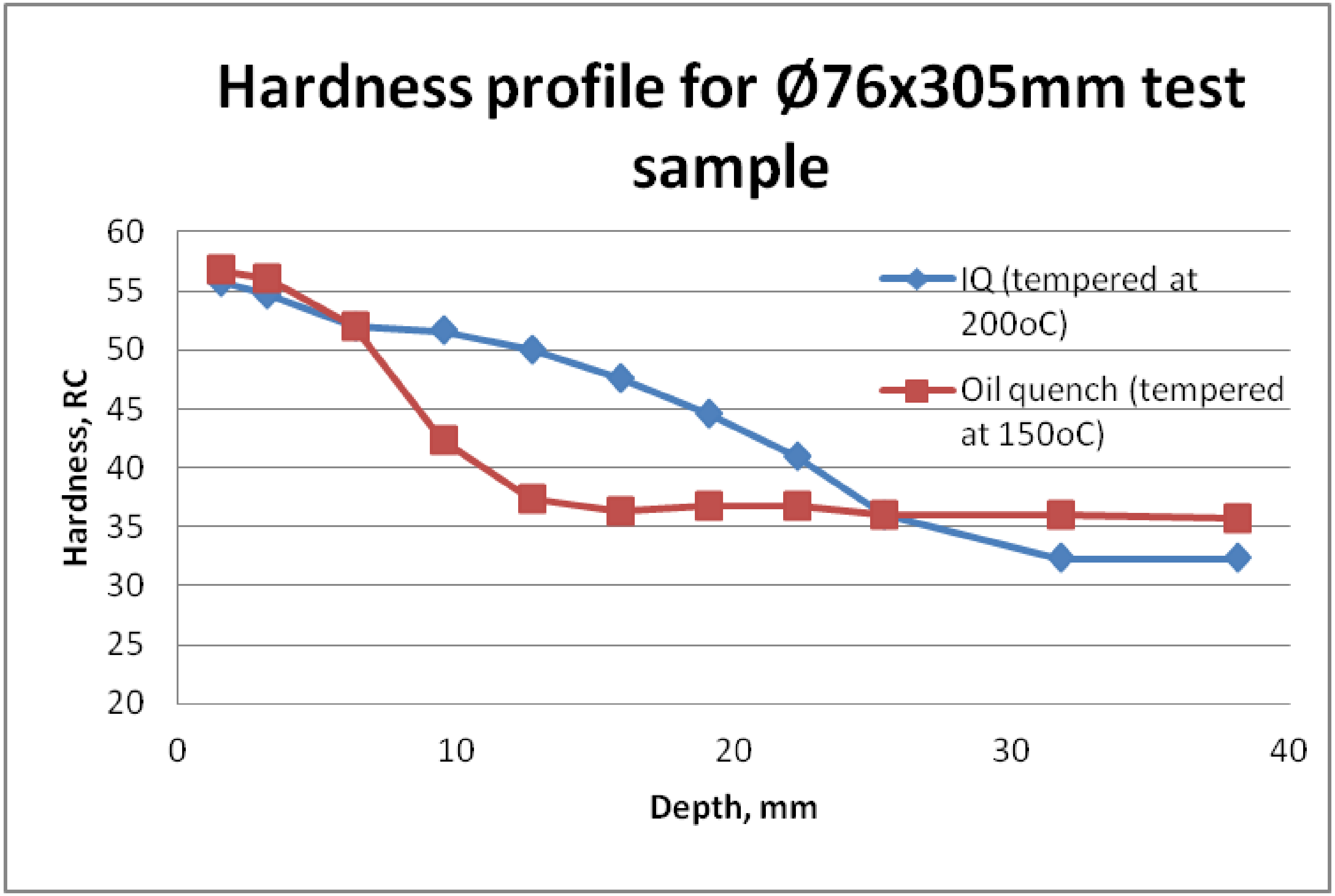
IHTS Enables Z-Dimension Design

Intensively Quenched Ductile Iron - IQDI®

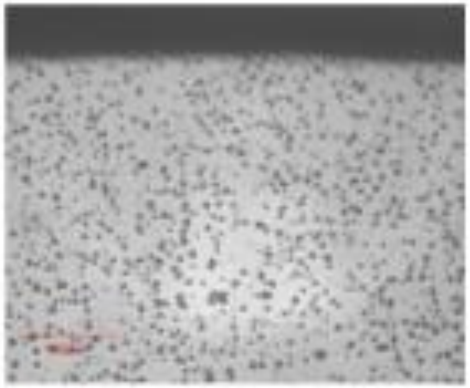
- IQDI benefits are numerous
  - Deeper hardened layer with beneficial compressive residual surface stress
  - No long carburizing cycle
  - Cheaper that steel
  - Better lubricity than steel
  - Machines 3 X faster than steel
  - 8% to 10% lighter
  - Carbide-like hardness AND Hammer-proof Tough

Better parts at lower cost!

IQDI® Benefits – Deeper Hardness Depth

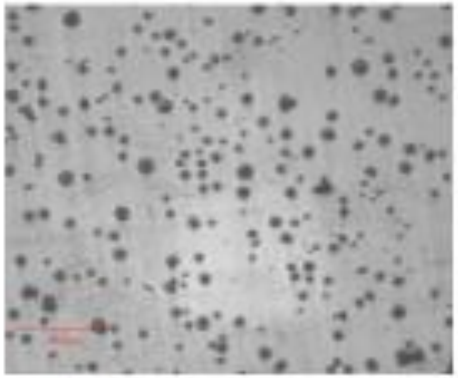


IQDI® Benefits – Grain Refinement

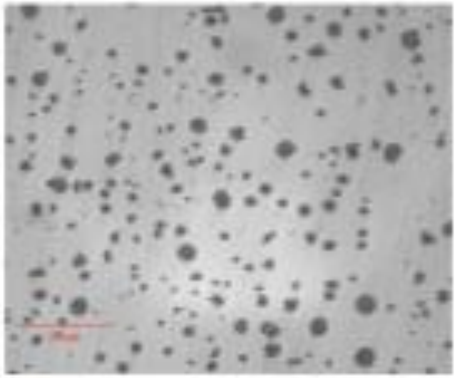


IQ surface X100

Oil surface X100

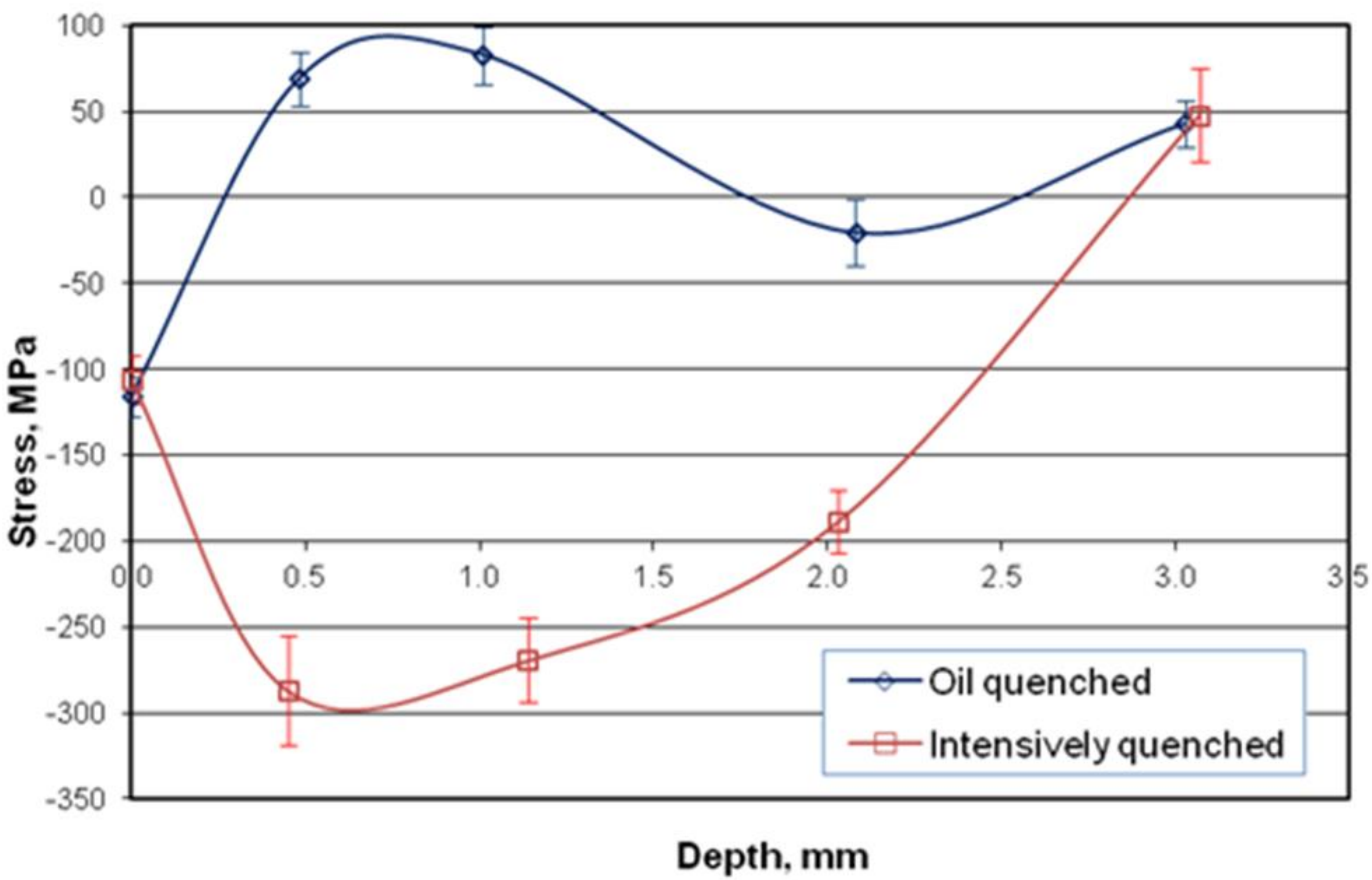


IQ core X100

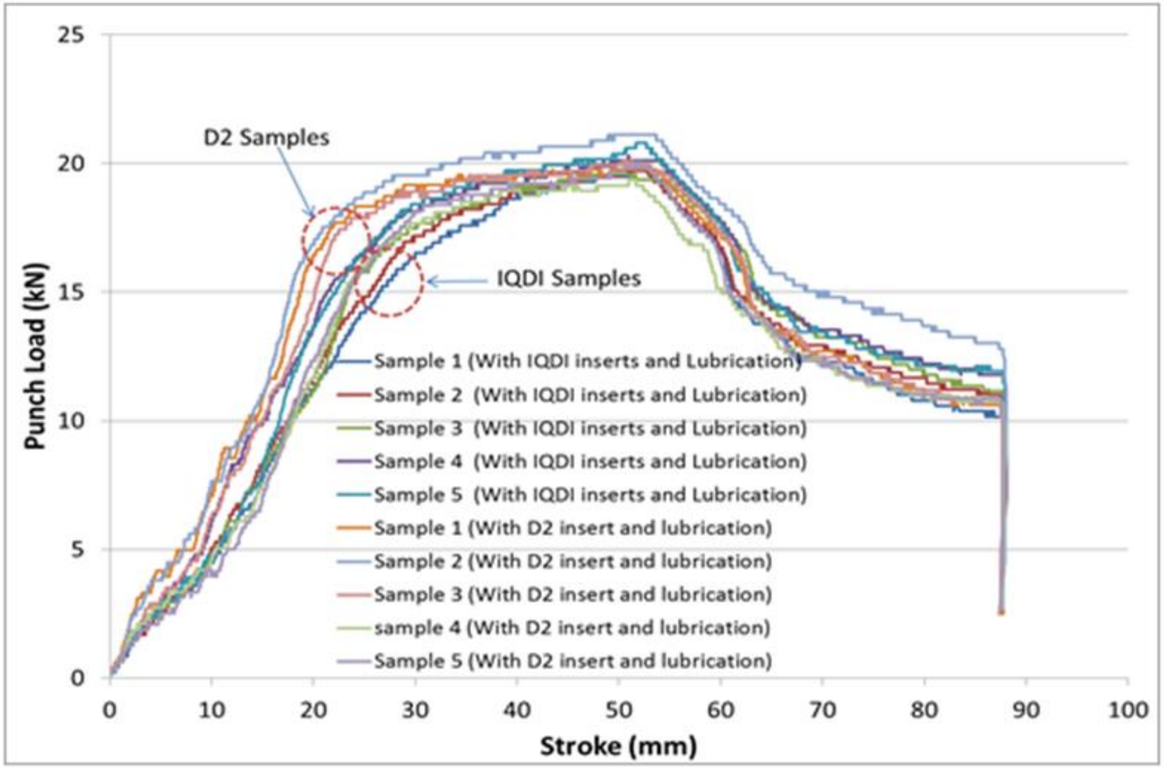


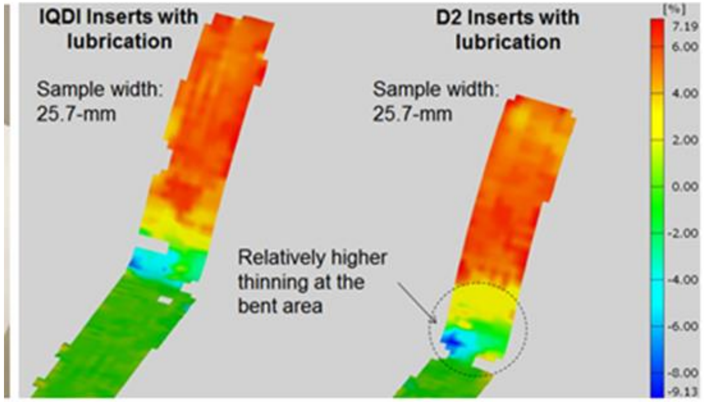
Oil core X100

IQDI® Benefits – Stress State



IQDI® Benefits – Lubricity vs D-2 Tool Steel





Intensively Quenched Ductile Iron (IQDI®) Production Parts

Benefits of Z-Dimension Designs

- <u>Better parts at a total lower cost:</u>
  - Enables Higher Residual Compressive Surface Stresses
  - Consistently longer wear and fatigue cycle life
  - Higher Power Density Parts = lighter AND stronger too
  - Supports hard surface coatings
  - Enables in-line, single part flow for “case hardened ***and*** core toughened” parts in one step
  - No separate core conditioning needed before induction case hardening
  - Enables carbide-like hardness + “hammer tough” ductility
  - Eliminates the need for mechanical shot peening

More HT value flows to product end users!

Benefits of Z-Dimension Designs

- <u>Promotes robust LEAN manufacturing:</u>
  - Reduces HT related Wastes
  - Predictable size change virtually eliminates heat treat distortion and . . .
  - Enables "green-size" parts that "Quench2Fit™" to a desired net shape
  - Saves hundreds of millions of dollars per year in downstream manufacturing costs:

    E.g., eliminates or reduces press quench fixtures;

    post-heat treat grinding, hard turning, hot or cold straightening, flattening, etc.

Substantially reduces downstream manufacturing costs!

Benefits of Z-Dimension Designs

- <u>Promotes robust LEAN manufacturing:</u>
  - Direct from the Forge Intensive Water Quenching (DFIQ™) eliminates 2 subsequent heating processes: one for normalize and a second before Quench and Temper
  - Provides finer grains after forging for more uniform carburization (PyroWear 53®)
  - Mechanical properties same or better than normalize, reheat, quench and temper

Substantially reduces downstream forging manufacturing costs & allows for single part flow!

Benefits of Z-Dimension Designs

- Promotes robust LEAN manufacturing:
  - Direct from the Forge Intensive Quench allows closer to net shape forging reducing material usage and less post-forge machining and wasted material
  - Enables use of lower hardenability, less costly alloys, with same or better mechanical properties
  - Lower alloy enables “field reparability” – no pre- or post-heating for welding.

Less final machining required!

Benefits of Uniform + Intensive Quench

- Promotes robust LEAN manufacturing:
  - **No Oil Quenching** = no quench fires
  - Less part cleaning (1¢ to 2¢ pound savings) – no soaps or solvents
  - Safer and cleaner plant environment
  - One less waste stream to manage

Enables single part flow and HT in the Mfg Cell!

Benefits of Z-Dimension Designs

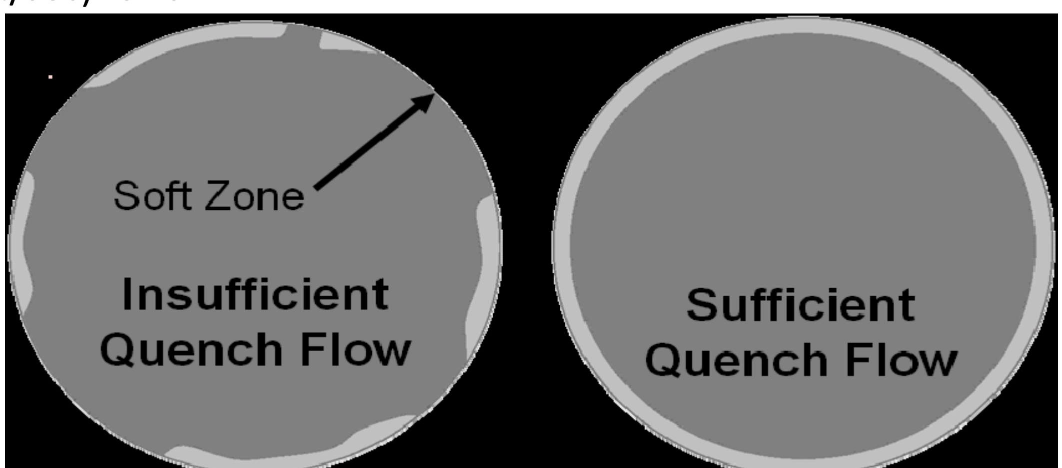
- Promotes robust LEAN manufacturing:
  - Reduces or even eliminates long batch carburizing cycles and enables smaller lots or single-part manufacturing flow
  - Facilitates Heat Treating in the manufacturing cell or at the hot forge for lean mfg. and reduced WIP inventories

Substantially reduces downstream manufacturing costs

Z-Dimension Design Equipment:
Direct from Forge Intensive Quench
DFIQ™ Prototype Unit
(Patents Pending)

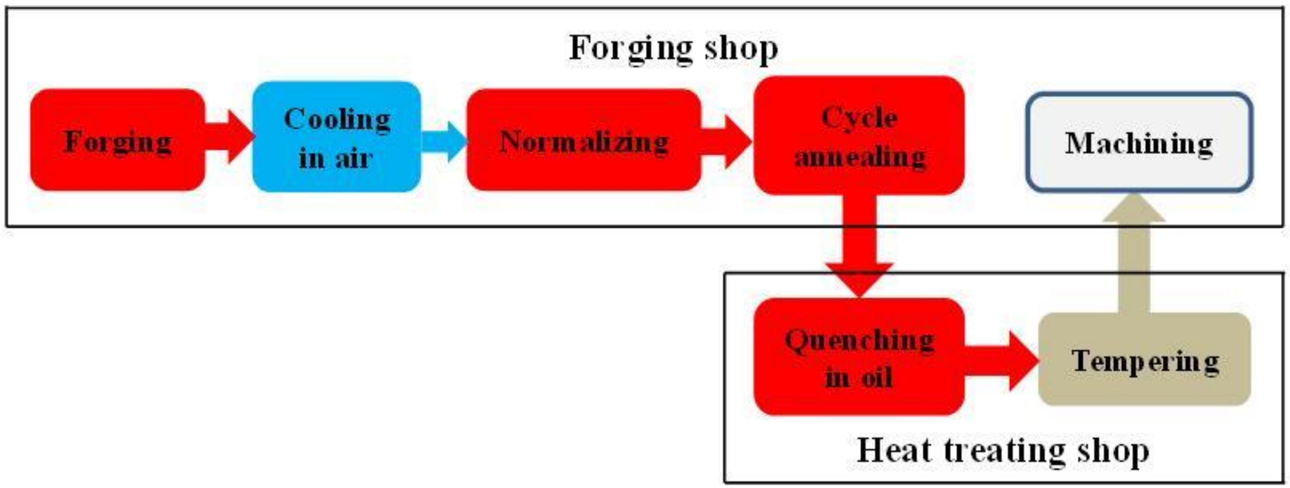
Newer HT Specification Addressing Quench *Uniformity + Intensity*

- **"3.X.1 -** Parts shall be quenched with **the maximum possible severity that can be achieved without quench cracking**, to produce the maximum expected as-quenched surface hardness and depth of hardening. A uniform martensitic structure shall be produced on all surfaces,. . . to a depth commensurate with material hardenability and section size.
- Spotty hardening shall not be permitted and is evidence of insufficient quench flow velocity (Figure 1 gives a schematic of spotty hardening shown by a mixture of light and dark etching at the part surface, and a uniform martensitic structure shown by light etching at the part surface)."
- **"3.X.2** Achieving this microstructure specification typically requires an impingement quench flow velocity on the entire surface of a part in excess of 0.76 m/s (2.5 ft/sec) for water and 1.07 m/s (3.5 ft/sec) for oil."

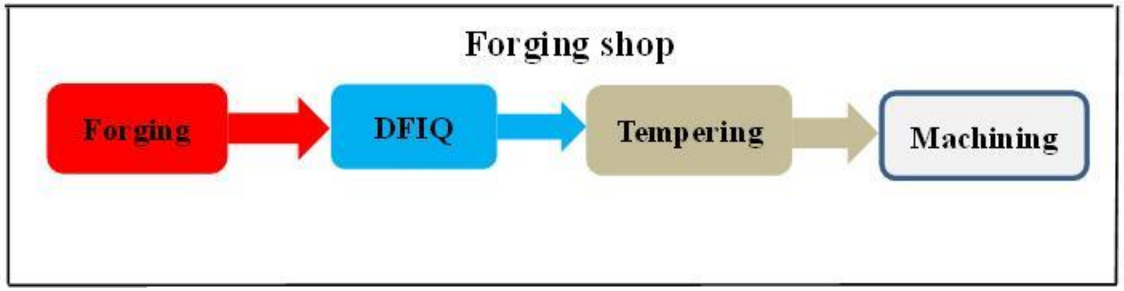


Direct from the Forge Intensive Quench
The DFIQ™ Lean Forge Solution

Current Manufacturing Process Flow Chart



Proposed Manufacturing Process Flow Chart



Key

Pintle adapter

Tine

Lug

DFIQ Project Test Parts (2017)

Field Tested Z-Dimension Designs SuperValue™ HT Parts for the Product End Users

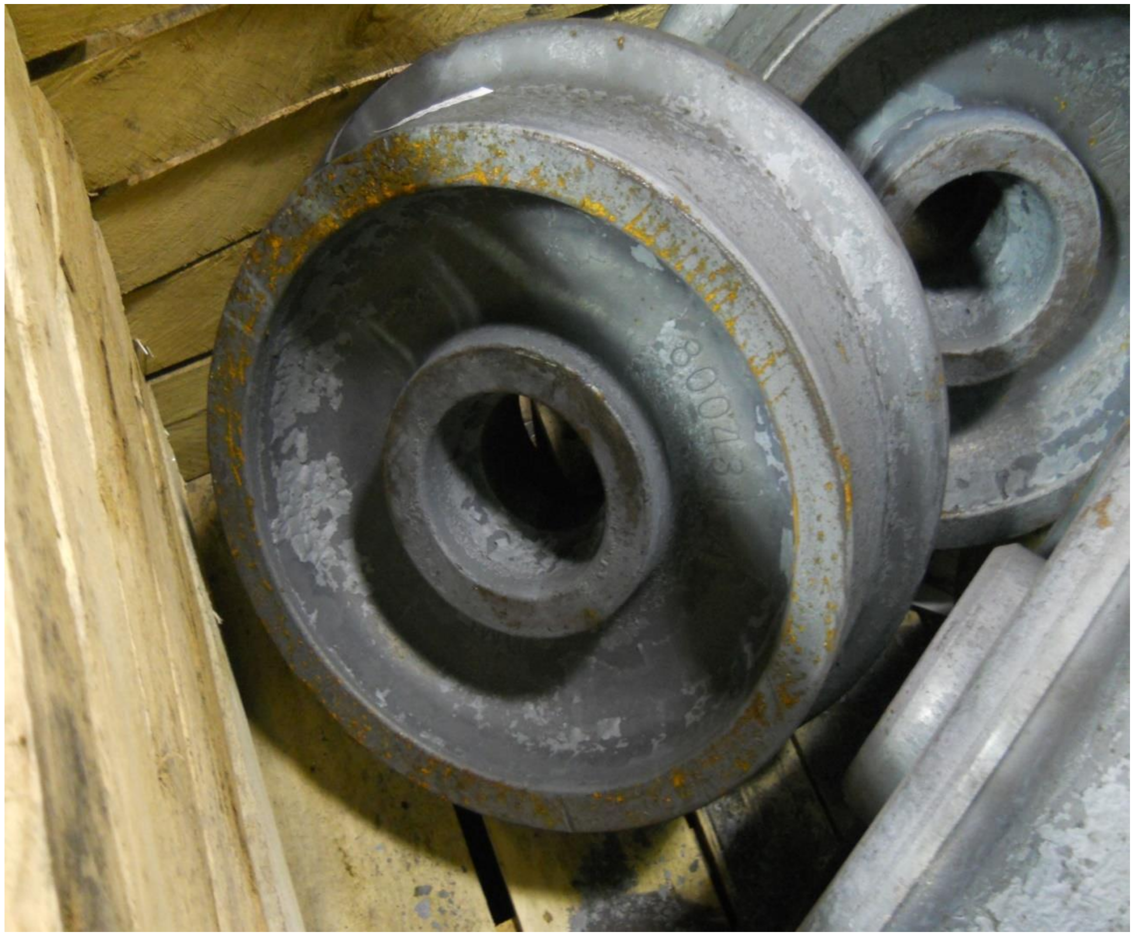
See ASM Paper "Everything Matters to Reach ASM Heat Treating Society Vision 2020 Goals" with 5 Case Studies

IHTS Enables Z-Dimension Design Solutions:

Deeper Hardness with 4130 vs 4330 + Lower Cost Alloy for "Field Reparability"

IHTS Enables Z-Dimension Design Solutions:
Higher Power Density Parts

IHTS Enables Z-Dimension Design Solutions: Low cost alloy forging + IQ-2™ replaces low quality sand casting = More Customer Value



Alloy "Hardenability" versus "Ability to Harden"

1040 Oil-quenched

SINGLE HEAT RESULTS

	C	Mn	P	S	Si	Grain Size
Grade	.37/.44	.60/.90	.040 Max	.050 Max	—	
Ladle	.39	.71	.019	.036	.15	5-7

Critical Points, F: Ac_1 1340 Ac_3 1445 Ar_3 1350 Ar_1 1250

MASS EFFECT

Size Round in.	Tensile Strength psi	Yield Point psi	Elongation % 2 in.	Reduction of Area, %	Hardness HB
Annealed (Heated to 1450 F, furnace-cooled 20 F per hour to 1200 F, cooled in air.)					
1	75,250	51,250	30.2	57.2	149
Normalized (Heated to 1650 F, cooled in air.)					
½	88,250	58,500	30.0	56.5	183
1	85,500	54,250	28.0	54.9	170
2	84,250	53,000	28.0	53.3	167
4	83,500	49,250	27.0	51.8	167
Oil-quenched from 1575 F, tempered at **1000** F.					
½	104,750	72,500	27.0	62.0	217
1	96,250	68,000	26.5	61.1	197
2	92,250	59,750	27.0	59.7	187
4	90,000	57,500	27.0	60.3	179
Oil-quenched from 1575 F, tempered at **1100** F.					
½	100,500	69,500	27.0	65.2	207
1	91,500	64,250	28.2	63.5	187
2	86,750	56,875	28.0	62.5	174
4	82,750	52,250	30.0	61.6	170
Oil-quenched from 1575 F, tempered at **1200** F.					
½	95,000	66,625	28.9	65.4	197
1	85,250	60,250	30.0	67.4	170
2	82,500	54,500	31.0	66.4	167
4	78,750	50,000	31.2	64.5	156

As-quenched Hardness (oil)

Size Round	Surface	½ Radius	Center
½	HRC 28	HRC 22	HRC 21
1	HRC 23	HRC 21	HRC 18
2	HRB 93	HRB 92	HRB 91
4	HRB 91	HRB 91	HRB 89

96

1040 Water-quenched

SINGLE HEAT RESULTS

	C	Mn	P	S	Si	Grain Size
Grade	.37/.44	.60/.90	.040 Max	.050 Max	—	
Ladle	.39	.71	.019	.036	.15	5-7

Critical Points, F: Ac_1 1340 Ac_3 1445 Ar_3 1350 Ar_1 1250

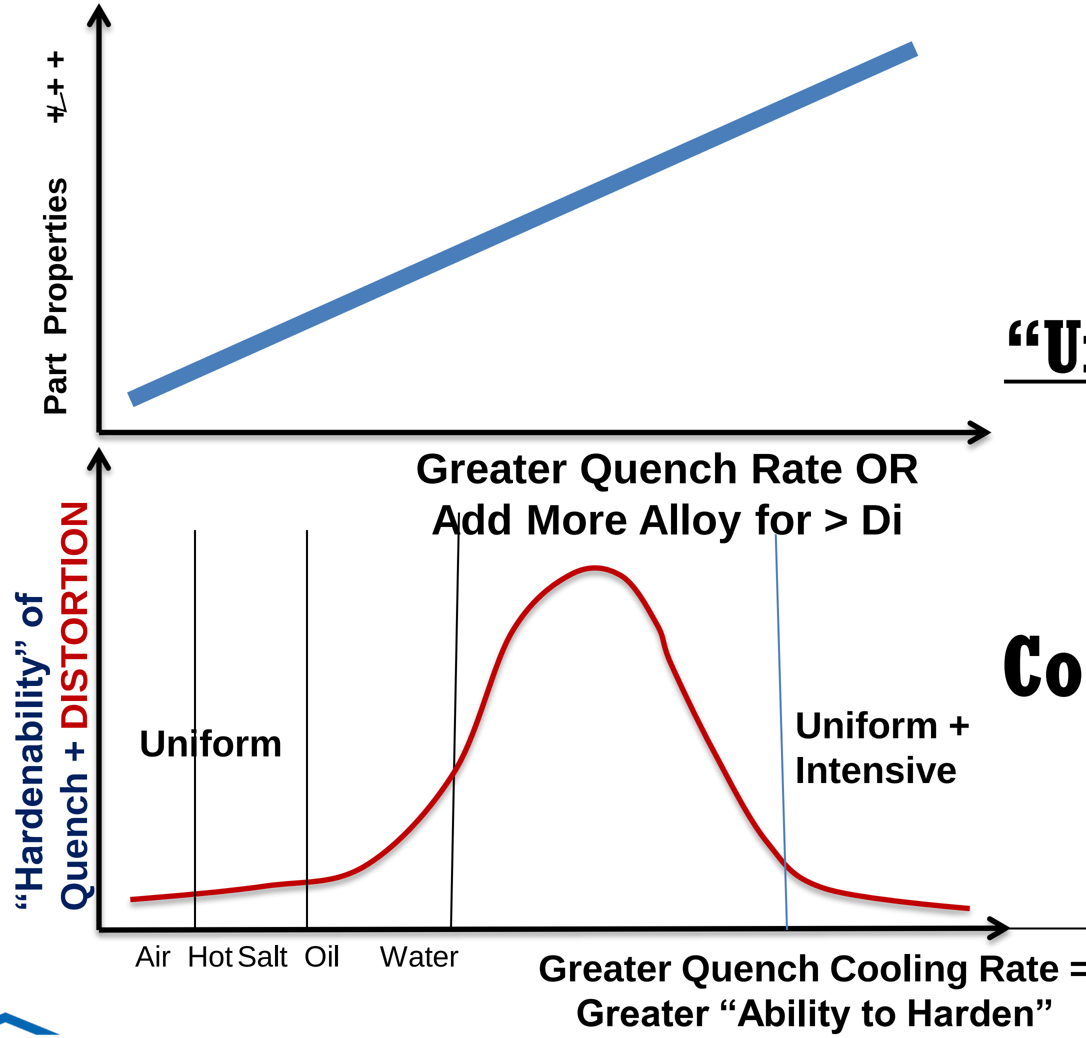
MASS EFFECT

Size Round in.	Tensile Strength psi	Yield Point psi	Elongation % 2 in.	Reduction of Area, %	Hardness HB
Water-quenched from 1550 F, tempered at **1000** F.					
½	109,000	81,500	23.8	61.5	223
1	107,750	78,500	23.2	62.6	217
2	101,750	69,500	24.7	63.6	207
4	99,000	63,826	24.7	60.2	201
Water-quenched from 1550 F, tempered at **1100** F.					
½	101,250	71,000	26.4	65.2	212
1	100,000	69,500	26.0	65.0	207
2	95,000	68,000	29.0	69.2	197
4	94,250	59,125	27.0	63.4	192
Water-quenched from 1550 F, tempered at **1200** F.					
½	96,000	69,000	27.7	66.6	201
1	93,500	68,000	27.0	67.9	197
2	89,000	59,875	28.7	69.0	183
4	85,000	54,750	30.2	67.2	170

As-quenched Hardness (water)

Size Round	Surface	½ Radius	Center
½	HRC 54	HRC 53	HRC 53
1	HRC 50	HRC 22	HRC 18
2	HRC 50	HRB 97	HRB 95
4	HRB 98	HRB 96	HRB 95

Dr. Quench's Ability to Harden a Part Mass: Alloy Hardenability + **Uniform** Quench Rate



"Uniform"

Gas or Hot Salt

or

"Uniform + Intensive"

Water Quench =

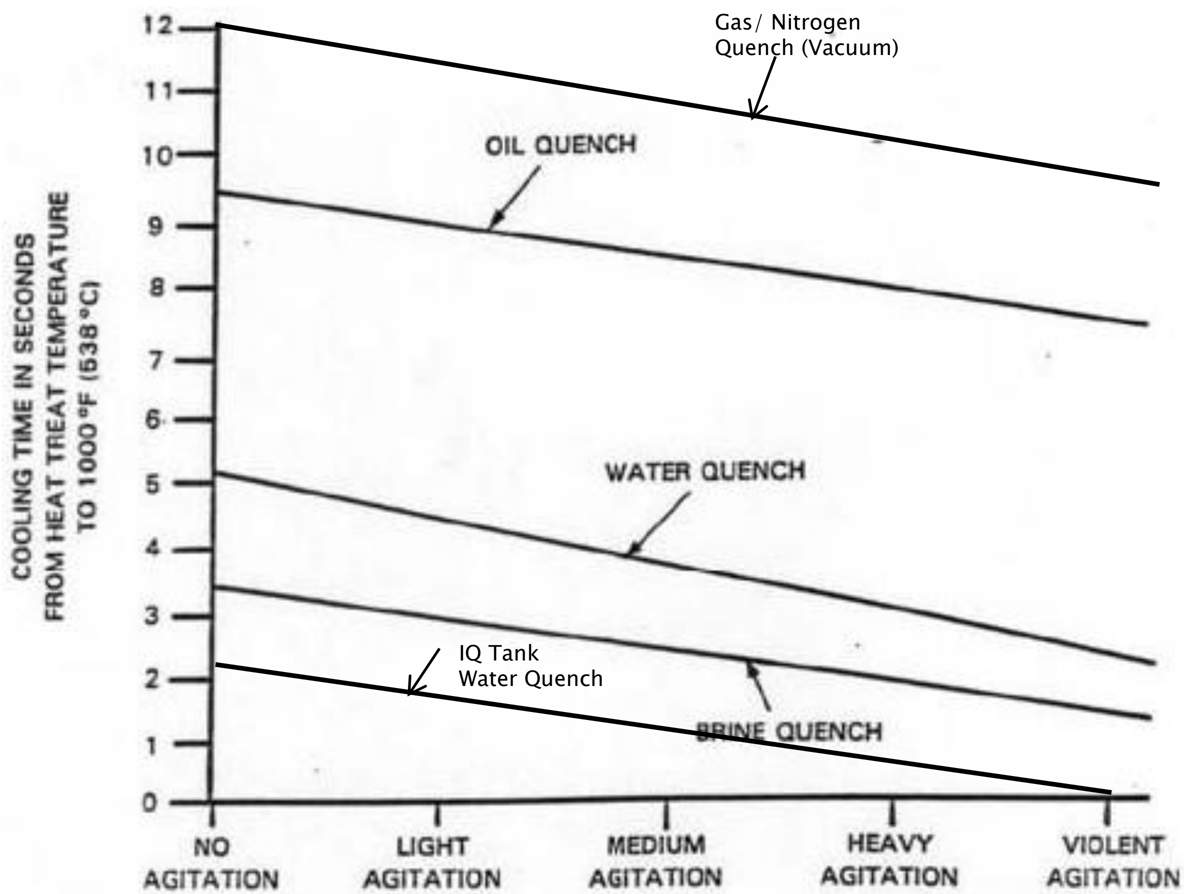
Finer Grains + Compressive Surface Stress and Predictable Distortion

IHTS

Dr. Quench™ says: Greater Average Value Cooling Intensity = Higher **Ability to Harden** for a Given Alloy's **Hardenability**

Quench Media	Average -value	Instantaneous -value
Brine or caustic	3500 - 4500	> 15000
Water	3000 - 3900	> 12000
Oil, highly agitated	2000 - 2500	4000 - 6000
Polymmer	1500 - 2000	3000 - 4500
Oil, agitated	1500 - 1750	3000 - 4000
Oil, still	1000 - 1500	
Gas, high pressure	300 - 1000	1000 - 2000
Salt	400- 500	
Air	100 -300	

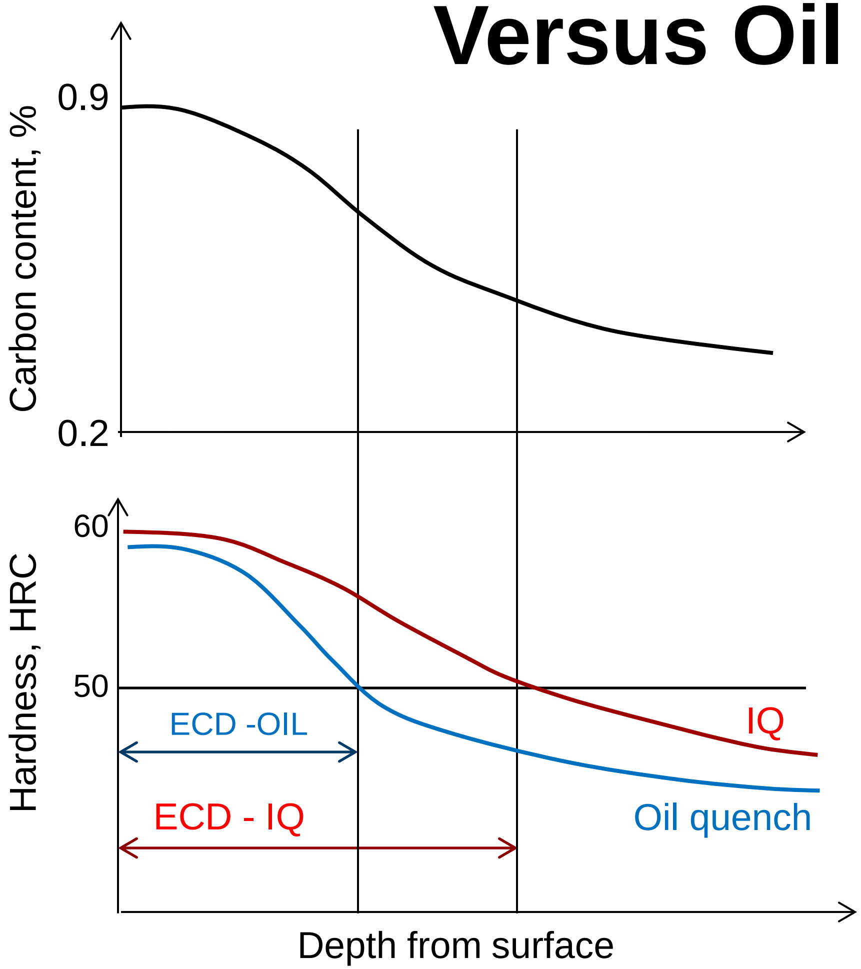
W/(m²·°C)

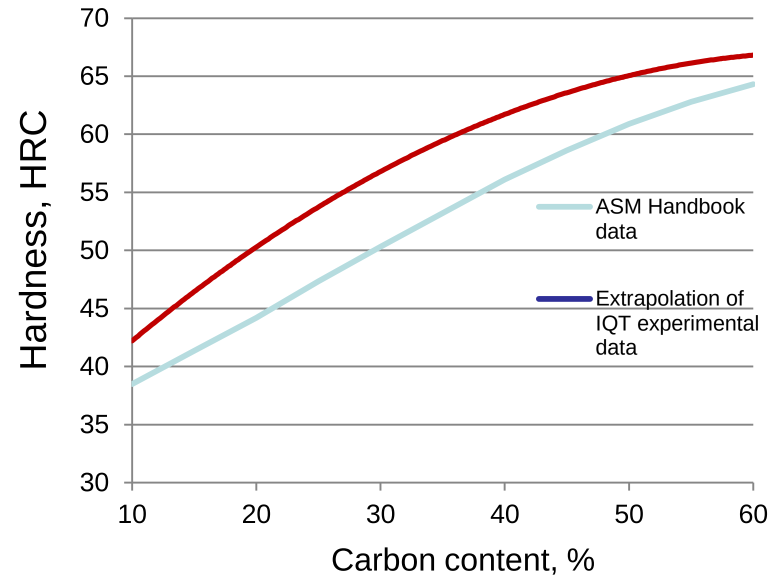


Agitation of part being quenched reduces cooling time.

Greater "Instantaneous Value" = Higher Probability of Part Cracking and Non-Uniformity of As-Quenched Properties

IQ Reduces Carburization Cycle Time Versus Oil Quenching

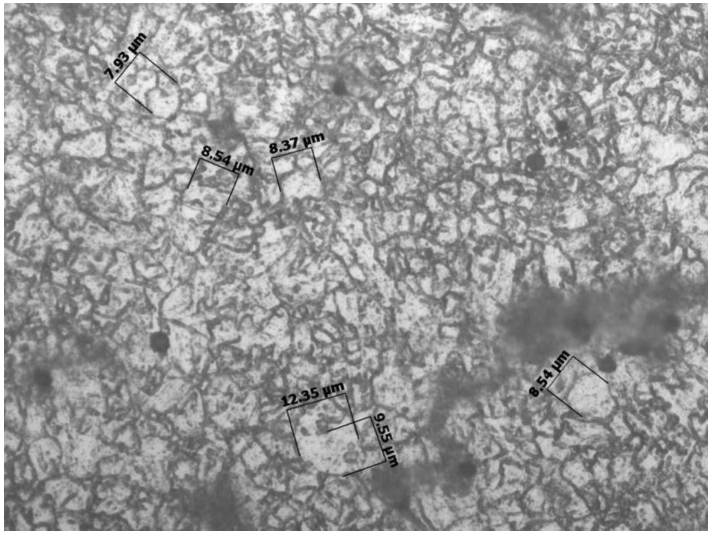




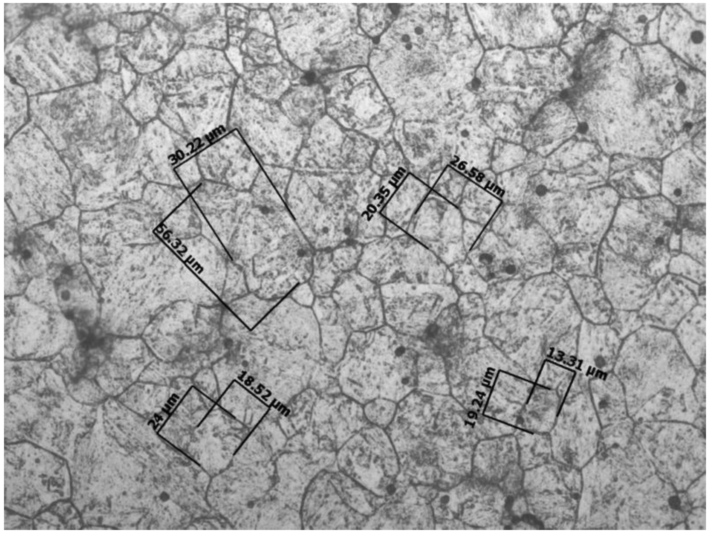
IQ process provides greater hardness for the same carbon content in the case carburized layer compared to oil quenching, resulting in a deeper ECD for the same carburizing cycle.

Optimal ***Ability to Harden*** HT Process “Better” ***Hardenability*** for Di

Core microstructure for Ø27mm rod made of 43XX steel after IQ and oil quenching (data provided by Benet Labs)



Intensively quenched X1000



Oil quenched X1000

Martensite structure was obtained for both rods. Micrographs show significant grain refinement (smaller grains) from IQ-2™ process versus traditional oil quenching = Finer Grains = “Better” Parts @ Total Lower Cost

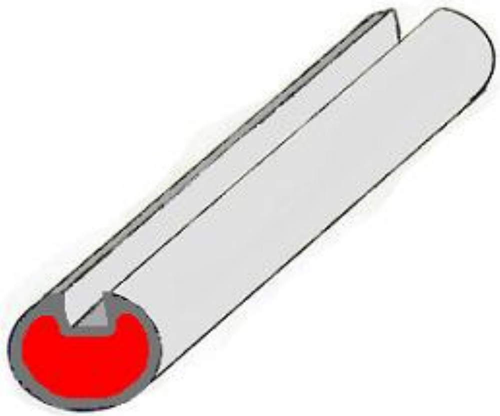
Dr. Quench's 3 Different Causes for Size Changes (AKA "Distortion") During Heat Treating and Forging

1. <u>Thermal Expansion + Shrinking</u> with Heating (BCC to Ac) or Cooling (FCC to Ms)

2. <u>Phase Change Expansion</u> - Austenite (FCC) to Martensite (BCT) Grain Transformations

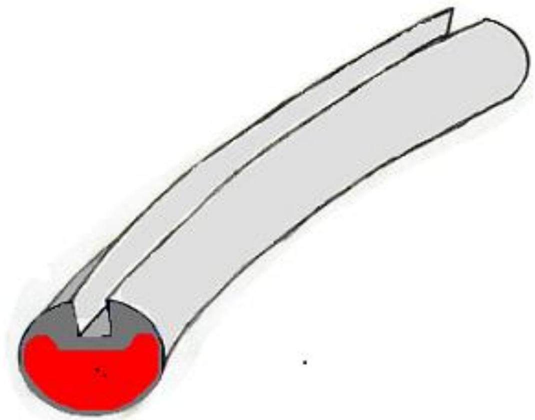
3. "Latent" Size Change of <u>Retained Austenite Stress State Changes</u> - RA to untempered Martensite phase changes over time (Grains expand and are brittle!)

Uniform + Intensive Quench Renewal Rate (UQRR™) = ***Predictable*** Size Change



Intensive water quenching

Uniform hardened layer with "current" + "residual" **COMPRESSIVE** stresses holds part together reducing part distortion and eliminates cracking



Conventional oil quenching

Non-uniform hardened layer with residual **TENSILE** stresses results in excessive part distortion and possible quench cracking

Ø25x300mm key-way shaft distortion data

Batch oil	Single oil	Single IQ
0.25-0.51mm	0.20-0.36mm	0.08-0.12mm

1st Generation Steel Treaters = Blacksmiths

For centuries metal smiths refined various combinations of metal ores into combinations of different metal alloys.
When iron is alloyed with < 1% carbon "steel" was created.

1st Generation Heat Treaters of steel began as blacksmiths that used heat and rapid cooing to "urge" a plain carbon steel into parts with the desired form, fit and function with balance hardness and ductility. Blacksmithing was an art usually performed by one person who designed the part shape, then selected the material and heated the metal until it was red hot and pliable enough to hammer it into a desired part.

Once the shape was set, the part was "heat treated" – re-heated to a "controlled temperature" (just below the melting point) and cooled quickly – quenched in water or brine for high hardness and strength. To remove brittleness and to add ductility, some of the hardness was "drawn out" by another heating cycle at a still lower temperature for "tempering" then air cooled and sent for machining or grinding.

2nd Generation Heat Treaters = Blacksmiths + Evolving 20th Century HT Metallurgy

Early 20th Century heat treaters had no thermometers or temperature controllers for their furnaces, and just like the blacksmith they still looked at the color inside their furnace for judging by eye the temperature of the parts they were heating.
(This is why the windows in the many early heat treating departments were covered or blackened out to see the color of the part.)

Blacksmiths judged high heat treating temperatures "by eye" – the "colors": from a dull yellow, to glowing red, to white hot indicating higher temperatures. Since the hot zones in the blacksmithing forge depended on the amount of oxygen blown in from the bellows, the control of part temperature was likewise by placement in different color heating zones in the hot forge. Uniformity of heating was not consistent.

More Added Value for Our End User Customers

2nd Generation Heat Treaters = Blacksmiths + Evolving 20th Century HT Metallurgy

Quench cooling by blacksmiths was also not uniform. As with every form of art, the end result was highly dependent on the skills and experience of the blacksmith-artist-heat-treater.

The quenching process was also pretty much unchanged from blacksmithing with early 20th Century heat treaters still using water or brine quenchants until oil quenchants and gas pressure quenching were invented in the mid-20th Century.
Most water or oil quenchants having three different phases of cooling: film boiling (slow cooling vapor blanket), nucleate boiling (fast evaporative cooling) and convection cooling (medium rate, NO boiling).
Three different rates of quench cooling at the part surface makes for non-uniform thermal shrinkage then Martensite phase change expansion.
[Attach link to video: Quenching "Three Little Springs" + "IHTS" stamps.)

More Added Value for Our End User Customers

2nd Generation Heat Treaters = Blacksmiths Evolving with 20th Century Metallurgy

During the first half of the 20th Century steel makers began making larger quantities and more varieties of carbon steels. Steel Making Metallurgists learned how to combine various alloys of metal into different grades of steel with the ability to harden (if heat treated properly) more uniformly and more deeply into the mass of larger parts. These new combinations of metal alloys provide higher Hardenability for higher yield strength, more surface wear resistance and core toughness. The various hardenability steels are loosely classified by what media is used as a quenchant: low alloy, plain carbon "water hardening" steels (blacksmithing steels); higher alloy, medium carbon, "oil hardening" steels and finally highly alloyed "air hardening" steels.

The new categories of steels opened up new heat treating processes and allowed the part designer to obtain more value from the heat treating processes.

More Added Value for Our End User Customers

2nd Generation Heat Treaters: Blacksmiths Evolve with 20th Century Steel Making Metallurgy

As steel Making Metallurgists learned how to control the combinations of various metal alloys into higher alloys with better Hardenability, the heat treater needed to find better ways to control the heating and quench cooling processes. With new higher Hardenability alloy steels, the heat treater found the tried and true water or brine quenching used by his blacksmithing predecessors cracked the part. The heat treater had to develop new methods of quenching besides non-uniform water quenching to avoid part distortion and to consistently develop the hardness deeper into the part mass.

2nd Generation Heat Treaters = Blacksmiths Evolving with 20th Century Metallurgy

This segmentation of material making and blacksmithing arts allowed Steel Making Metallurgy and Heat Treating Metallurgy to go down two separate paths of development.
With tighter temperature controls on the heating equipment and the development of new quenchants for the new alloy grades, heat treating processes became able to add more value for the end users: stronger and longer life heat treated parts. Unfortunately, one of the unintended consequences was heat treating became further removed from the other part manufacturing processes; a fragmentation that still exists today.

More Added Value for Our End User Customers

2nd Generation Heat Treaters = Blacksmiths Evolving with 20th Century Metallurgy

With the availability of new alloys and cleaner materials, blacksmithing began to evolve from an art into the science of Heat Treating Metallurgy.

As the blacksmith moved part making away from the hot forge to their furnaces and molten salt baths in the new heat treating departments, their blacksmithing arts took a step away from part making artistry toward the science of heat treating metallurgy applied to parts designed and made by others.

This fragmentation of part design, material alloy selection and heat treating has slowed the development of modern heat treating metallurgy – both the lean-driven processes that eliminate heat treat related waste and the development of efficient new heat treating equipment.

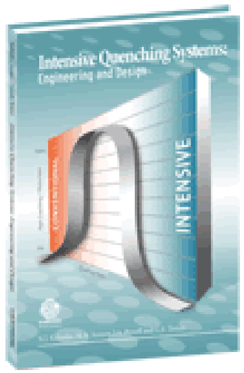
More Added Value for Our End User Customers

3rd Generation Heat Treating for Industry 4.0 Integrated Metallurgies for the 21st Century

Usually the last dimension of part design is the specifications for the heat treating processes – we call it the "Z-Dimension" of part design.
For heat treating to become a full partner in the lean part manufacturing value stream and to deliver more value to the product end user, the part design, including the material selection and all the manufacturing steps upstream and downstream from the heat treating processes need to be fully integrated into the part design.
When optimal heat treating solutions are concurrently engineered into the part design and aligned with all the steps in part manufacturing supply chain, 100% of the part value is realized in the product. The supply chain drives SuperValue to the end user and creates a strategic advantage for all members of the supply chain.

Integrated Heat Treating Solutions enable Z-Dimension Designs that deliver the many proven benefits of 21st Century Heat Treating methods and equipment for Industry 4.0.

***SuperValue™* Heat Treated Products for Our End User Customers**



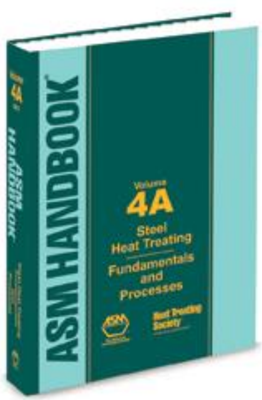
For more about IHTS's Solutions for IntensiQuench + Equipment . . .

ASTM International's

"Intensive Quenching Systems: Engineering and Design"

by N.I. Kobasko, M.A. Aronov, J.A. Powell and G.E. Totten

For more about different IQ Process Methods . . .



ASM Handbook Series *

"Steel Heat Treating Fundamentals and Processes"

by N.I. Kobasko, M.A. Aronov, J.A. Powell and G.E. Totten

Chapter on *"Intensive Water Quenching of Steel"*

with IntensiQuench® Theory , Practice Methods + Equipment

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