How IntensiQuench® Works
(The Short Version)

Presented by:

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Steel Phase Transformation and Part Cooling Rate

Conventional quenching:
- Rapid cooling within austenite phase
- Slow cooling within martensite range
“My personal thoughts are that there is really no excuse to use oils, polymers, etc. Water (or water-salt) works fine, is cheaper, and better; if the system is properly engineered. This means IQ should be rightfully featured.”

~ Dr. George Totten, 2013, Fellow of ASM International, SAE, IFHTFE, and ASTM; past president of International Federation for Heat Treating and Furnace Engineering (IFHTFE) and worldwide quenching authority
Three Most Important Things for Quality Heat Treating

UNIFORMITY, UNIFORMITY, and UNIFORMITY!

1. UNIFORMITY of Heating!

2. UNIFORMITY of Atmosphere!

3. UNIFORMITY of Cooling!
Modes of Heat Transfer During Quenching

I. Film boiling – a vapor blanket develops on the part surface due to a very high rate of vapor bubbles formation. This is a sporadic and non-controllable mode of heat transfer resulting very often in part excessive distortion.

II. Nucleate boiling – vapor bubbles do not merge. This mode of heat transfer is characterized by very high heat extraction rate.

III. Convection (no boiling).
## Modes of Heat Transfer During Quenching

<table>
<thead>
<tr>
<th>Time</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Film boiling</td>
</tr>
<tr>
<td>II</td>
<td>Nucleate boiling</td>
</tr>
<tr>
<td>III</td>
<td>Convection</td>
</tr>
</tbody>
</table>

### I. IQ-2 = No film boiling
   - Batch IntensiQuench®

### II. IQ-3 = No film boiling and No nucleate boiling
   - Direct convection cooling
   - Single part, high velocity IntensiQuench®
Conventional Quench Trade-Off

- The higher the part cooling rate during quenching the greater the probability of part distortion or cracking.
- The higher the cooling rate during quenching of steel the better the mechanical properties of part.
- Heat treaters always balance between getting high hardness and low distortion.
Intensive Quenching Phenomena

The probability of cracking and distortion is reduced at extremely high cooling rates when quenching is uniform and then interrupted at the time of optimum hardened depth under compressive surface stresses.

Original data obtained by Dr. Kobasko in 1964 for Ø6mm bars made of plain carbon and low alloy steels.
Part Mechanical Properties and Cooling Rate

- **Cooling rate**: The greater the cooling rate, the deeper the hardened layer, the greater the core hardness and the stronger the part.

- **Part properties**:
  - Air
  - Oil
  - Water
  - Stay away zone
  - IQ zone

- **Hardened depth, L**: 50% martensite
Dynamics of Temperature, Structural and Stress Conditions (by DANTE modeling)

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

Intensive quenching

<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>Time, sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>Core</td>
</tr>
<tr>
<td>900</td>
<td>800</td>
</tr>
<tr>
<td>800</td>
<td>700</td>
</tr>
<tr>
<td>700</td>
<td>600</td>
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<tr>
<td>600</td>
<td>500</td>
</tr>
<tr>
<td>500</td>
<td>400</td>
</tr>
<tr>
<td>400</td>
<td>300</td>
</tr>
<tr>
<td>300</td>
<td>200</td>
</tr>
<tr>
<td>200</td>
<td>100</td>
</tr>
</tbody>
</table>

Surface stresses, σ

-1,000 Mpa

Surface stresses, σ

-σ

Start of martensite formation

IQ

Oil quenching

Oil quenching

T = 0 seconds

T < 0.2 seconds

T = 18 seconds

Final steel microstructure

A 835°C

Oil quenching

A 400°C

Oil quenching

Intensive quenching

Surface stresses, σ

>50%M

M

B

-200 Mpa
1045 Steel Ø25mm Rod Surface Final Microstructure

Intensive quenching

![Intensive quenching microstructure image]

Fine martensite 1000X

Oil quenching

![Oil quenching microstructure image]

Coarse Martensite/Bainite 1000X

Very high cooling rate of part surface layer results in finer martensitic structure. “Explosive” rate of formation of martensitic plates deforms the super-cooled austenite layers, creating a high density of dislocations and strengthening of the material – “super-strengthening” effect.
Surface Stresses During Conventional and Intensive Quenching

Surface stresses, $\sigma$

Time

Thermal tensile stresses

Conventional quenching (alloy steels)

Conventional quenching (plain carbon steels)

Intensive quenching

Optimum cooling time is IQT Know How
Optimum Hardened Depth

Optimum hardened depth is the depth when surface compressive stresses are at maximum value. It depends on part shape, dimensions and steel chemistry.

Determining the time of interruption is a crucial part of IQT’s “Know-How.”
What are the steps in the IntensiQuench® Process?

1. IntensiQuench® (IQ) is an **TIMED** quench method – 1st in **highly agitated water**, then **air**;

2. Very high water flow provides **uniform** cooling to part shell with the **required high heat extraction rate**; and

3. IntensiQuench® is interrupted at the **proper time** – when “**current**” surface compressive stresses are at their maximum value and the hardened layer is also optimal to **maximize part properties for a given alloy of steel**
What are the steps in the IntensiQuench® Process?

4. Optimum cooling times and required “intensive cooling” rates for specific part sizes and part applications are determined by IQT’s proprietary computer programs (*IQT’s “Know-How”*)

5. No part washing needed – IntensiQuench® is green – *environmentally friendly* – process using plain water or a low concentration of minerals in water (No quench oil or polymers needed)
Types of IQ Processes

Three types of IQ processes:

- IQ-3 = one-by-one/ single part quenching in very high-velocity water
- IQ-2 = batches of parts are quenched in IQ water tanks
- Continuous processing with IQ submerged spray

Production IQ equipment will be discussed in detail later
Heat Transfer Data from Actual IQ-3 Process

Both the film boiling process and the nucleate boiling process is fully eliminated by IQ-3 (the water is flowing so fast along the part surface that it does not have a chance to reach the boiling temperature).

Convective heat transfer takes place from the very beginning of quenching ("direct convection cooling")
Film boiling is almost completely eliminated due to intensive quenchant agitation in the IQ water tank.

Nucleate boiling quickly initiates from the beginning of quench, followed by uniform convective heat transfer.

Part surface temperature stays just above water boiling temperature during nucleate boiling mode of heat transfer.
Intensive Quenching Under Elevated Pressure

The greater the gas pressure, the higher the water boiling temperature and the higher the part surface temperature during nucleate boiling process.

At 7 bar pressure, the part surface temperature is close to $M_s$ temperature.

Elevated pressure makes water “act more like oil or a salt quench” reducing the rate of martensite formation by raising the nucleate boiling temperature, thus minimizing distortion in parts with more complex geometries.

CTT diagram for high carbon steel (similar to W2 tool steel, $M_s=180^\circ$C) and experimental cooling curves for Ø20mm rod:
Improvement of Microstructure for Through Hardened Steels

Core microstructure for Ø19mm rod made of 1045 steel after IQ and oil quenching

Intensively quenched X250

Oil quenched X250

The finer martensitic microstructure after IQ, yields better mechanical properties than the oil quenched steel’s “mixed” microstructure.
Improvement of Microstructure for Through Hardened Steels

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

Martensitic structure was obtained for both rods. Micrographs clearly indicate significant grain refinement and smaller grains from the IQ process versus traditional oil quenching.
## Improvement of Microstructure for Spring Steels

<table>
<thead>
<tr>
<th>Part</th>
<th>Quenching</th>
<th>Bainite content, %</th>
<th>Grain size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Surface</td>
<td>½ radius</td>
</tr>
<tr>
<td>Ø36mm 5160 steel torsion bar</td>
<td>Intensive</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Oil</td>
<td>3.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Ø21mm wire 9259 steel coil spring</td>
<td>Intensive</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Oil</td>
<td>5.0-10.0</td>
<td>-</td>
</tr>
</tbody>
</table>
Both microstructures show typical mixed martensitic morphology as would be expected in carburized steel:

- Martensite plates are readily discernible
- Carbides are well dispersed

Martensite plates more discernible in IQ processed steel

* Data obtained by Deformation Control Technology, Inc.
IQ Process Produces Residual Surface Compressive Stresses in Parts Made of Through-Hardening Steels

<table>
<thead>
<tr>
<th>Part</th>
<th>Steel</th>
<th>Stresses, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing roller Ø3”</td>
<td>52100</td>
<td>-840</td>
</tr>
<tr>
<td>King pin Ø1.8”</td>
<td>4140</td>
<td>-563</td>
</tr>
<tr>
<td>Punch Ø1.5”</td>
<td>S5</td>
<td>-750</td>
</tr>
<tr>
<td>Torsion bar Ø1.4”</td>
<td>5160</td>
<td>-311</td>
</tr>
<tr>
<td>Output shaft Ø1.6”</td>
<td>1050</td>
<td>-660</td>
</tr>
</tbody>
</table>

IQ process provides high residual surface compressive stresses, even when the part is quenched through. This is in contrast to conventional quenching when residual surface compressive stresses are usually tensile or neutral.
**Effect of IQ Process on Residual Surface Compressive Stresses for Parts made of Carburized Steels**

<table>
<thead>
<tr>
<th>Part</th>
<th>Steel</th>
<th>Stresses, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Oil</td>
</tr>
<tr>
<td>Helicopter gear</td>
<td>Pyrowear-53</td>
<td>-470</td>
</tr>
<tr>
<td>Helicopter gear</td>
<td>9310</td>
<td>-117</td>
</tr>
<tr>
<td>Pinion</td>
<td>8620</td>
<td>-336</td>
</tr>
</tbody>
</table>

For carburized parts, residual surface compressive stresses are usually much greater after intensive quenching than that after conventional quenching.
**Improvement of Part Mechanical Properties**

Data obtained by Dr. Kobasko in former Soviet Union (Samples were taken from the core of Ø50mm specimens)

<table>
<thead>
<tr>
<th>Soviet Steel (AISI Steel)</th>
<th>Quenching</th>
<th>Tensile Strength, MPA</th>
<th>Yield Strength, MPA</th>
<th>Impact Strength, J/sm²</th>
<th>Hardness, HRB</th>
</tr>
</thead>
<tbody>
<tr>
<td>40X (5140)</td>
<td>In oil</td>
<td>780</td>
<td>575</td>
<td>113</td>
<td>217</td>
</tr>
<tr>
<td></td>
<td>Intensive</td>
<td>860</td>
<td>695</td>
<td>168</td>
<td>269</td>
</tr>
<tr>
<td>35XM (4130)</td>
<td>In oil</td>
<td>960</td>
<td>775</td>
<td>54</td>
<td>285</td>
</tr>
<tr>
<td></td>
<td>Intensive</td>
<td>970</td>
<td>820</td>
<td>150</td>
<td>285</td>
</tr>
<tr>
<td>25X1M (4118)</td>
<td>In oil</td>
<td>755</td>
<td>630</td>
<td>70</td>
<td>229</td>
</tr>
<tr>
<td></td>
<td>Intensive</td>
<td>920</td>
<td>820</td>
<td>170</td>
<td>285</td>
</tr>
</tbody>
</table>

- While intensive quenching improved all the mechanical properties, IQ improved *the impact strength by 2 to 3 times versus oil.*
- Higher strength AND higher ductility.
# Improvement of Part Mechanical Properties

Data obtained by customers of IQ Technologies Inc

<table>
<thead>
<tr>
<th>Part</th>
<th>Property</th>
<th>Oil quench</th>
<th>Intensive quench</th>
</tr>
</thead>
<tbody>
<tr>
<td>1340 steel M22x123mm bolt</td>
<td>Tensile strength, MPa</td>
<td>1,093</td>
<td>1,176</td>
</tr>
<tr>
<td>1045 steel Ø19x125mm bar</td>
<td>Tensile strength, MPa</td>
<td>996</td>
<td>1,201</td>
</tr>
<tr>
<td>S5 steel Ø38x56mm punch</td>
<td>Impact strength, Nxm</td>
<td>6.8</td>
<td>12.2</td>
</tr>
<tr>
<td>4140 steel hand tool socket</td>
<td>Torque to failure, Nxm</td>
<td>168</td>
<td>223</td>
</tr>
<tr>
<td>4140 steel Ø45mm kingpin</td>
<td>Ultimate strength, kN</td>
<td>313</td>
<td>414</td>
</tr>
</tbody>
</table>

The IntensiQuench® process provides parts with better mechanical properties due to enhanced hardenability and finer martensite structure.
Part Distortion from the IQ Process: General Considerations

1. As with conventional quenching of martensitic parts, part distortion during IQ is a combination of size changes – both thermal shrinkage (prior to phase transformation) and the material volume expansion due to martensitic formation.

2. More uniform cooling during IQ (due to elimination of non-controllable, sporadic film boiling at the beginning of quench) provides more uniform part shrinkage followed by more uniform martensite formation in the part surface layer.

3. Since nucleate boiling and the subsequent convective mode of heat transfer during IQ are stable and controllable, part distortion after IQ is “repeatable”.

4. When distortion is “repeatable” it can be managed by adjustment of the part “green size” (before heat treat dimensions).
IQ Process Minimizes “Key-Way” Shaft Distortion

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

<table>
<thead>
<tr>
<th></th>
<th>Batch oil</th>
<th>Single oil</th>
<th>Single IQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distortion</td>
<td>0.25-0.51mm</td>
<td>0.20-0.36mm</td>
<td>0.08-0.12mm</td>
</tr>
</tbody>
</table>
Part distortion after batch quenching in 11,000-gallon IQ water tank

1040 steel shafts of about Ø2 x 26"

Shaft distortion:
- After oil quenching: maximum-0.245”; average-0.140”.
- After IQ: maximum-0.081”; average-0.040”.
- Shaft distortion was reduced by more than 3 times.

1045 steel forged rings of 9.5"OD, 7.5"ID, 0.5”thick

- Previously, the parts were quenched from a belt type furnace into a polymer/water quench.
- The quality defects exceeded 18% due to an excessive part distortion,
- By using the IQ process defects dropped to 6%.
For a given carbon content, the IQ process provides greater hardness compared to conventional oil quenching processes; Effective Case Depth (ECD = 50 HRC) achieved with lower % Carbon in the case gradient.

Less carburizing time = money saved
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.
IntensiQuench® for Most Metals

1. Uniform IntensiQuench® equipment can be used to water quench any type of metals requiring a fast quench – Aluminum, Stainless Steels, Titanium – *and*...

2. IQ processes can be applied to virtually any steel experiencing martensitic transformation:
   a) Plain carbon (ball studs, automotive shafts, wear plates, etc.)
   b) Low alloy (coil springs, torsion bars, shafts, rollers, etc.)
   c) High alloy (armor plates, gun barrels, tool products, etc.)
   d) Carburized grades (gears, shafts, bearing products, etc.)

3. Application of IQ process to “optimal hardenability” (OH) steels allows **full elimination** of the carburization process (OH steels are medium to high carbon steels with a very low content of alloying elements – Mn, Cr, Ni, etc.) For OH+IQ Processes, the steel chemistry is optimized for specific parts by proprietary IQT software.
IntensiQuench® Process Limitations

1. Part thickness:
   - For through hardened steels, part thickness should be greater than 10-15mm depending on the steel chemistry.
   - For carburized grades and OH steels, there is practically no limitation for minimum part thickness.

2. Part geometry:
   - There should be a certain ratio between thickest and thinnest sections of the part (“IQ know-how”).
   - Parts having holes or blind holes may not be suitable for IQ process in some cases.
   - “IQ under pressure” will open up more opportunities for obtaining IQ’s benefits.
IntensiQuench® Process Benefits

1. Increased surface and core hardness and greater hardened layer resulting in stronger or lighter part, higher power density; possibility of the use of less costly, lower alloy steels

2. Higher residual surface compressive stresses resulting in stronger parts with longer fatigue life

3. Low part distortion – (predictable distortion)

4. Reduction of carburization cycle by 30-40% resulting in reduced heat treatment cost due to higher furnace production rate, less energy cost, no oil

5. Full elimination of carburization cycle (with the use of IQ + OH steels) allows single part processing of heat treatment operations within manufacturing cell (lowers inventory requirements)

6. Green, environmentally friendly processes
Proven IntensiQuench® Applications

1. Automotive parts
2. Heavy trucks and off-highway vehicles
3. Aerospace parts
4. Mining equipment
5. Railroad equipment
6. Agricultural equipment
7. Weapon systems
8. Tools and dies
To learn more about different IQ processes, methods for developing cooling recipes and specifics of IQ equipment, read the 2010 handbook published by ASTM International:

“Intensive Quenching Systems: Engineering and Design”

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