Summary of Intensive Quenching Processes: Theory and Applications

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October 2011

IntensiQuench® Process Executive Summary

In this paper, IQ Technologies Inc presents a brief overview of intensive quenching (IQ) processes and their applications to provide a better understanding of these effective quenching techniques.

The purpose of quenching steel parts is to achieve the desired metallurgical structure, usually hardened "martensite," while keeping distortion to a minimum. The heat treater must usually balance the trade-off of hardness for distortion (or part cracking). Stated another way, the faster the steel part is quenched, the higher the "as quenched" hardness, and the deeper into the part the hardness is driven, but also the higher the probability of part distortion or even cracking. About 47 years ago, Dr. Nikolai Kobasko of the Ukraine discovered this is not always true. His research shows that ***very fast and very uniform part cooling***, intensive quenching (IQ), actually reduces the probability of part cracking and distortion, while improving the surface hardness and durability of steel parts.

The rapid cooling rate of IQ also provides greater hardened depth and high residual surface compressive stresses which in turn improve part mechanical properties and overall strength. IQ also allows the use of less alloy steels, or making the part smaller (lighter), and yet stronger, while making the quenching process more cost-effective. In addition, since IQ uses plain water or a low concentration water/salt solutions as the quenchant, IntensiQuench® is a clean and an environmentally friendly method of quenching.

This paper describes the following:

- Basics of IQ processes.
- IQ process computer models that are a part of IQ Technologies Inc "know-how" and are used for development of optimal cooling recipes for various part shapes.
- Different types of intensive quenching equipment.
- Numerous examples of implementation of the IntensiQuench® processes.

The following benefits of the IntensiQuench® processes were proven by numerous experimental studies conducted by Dr. Kobasko and IQ Technologies Inc during the recent years:

- Increases the depth of hardness.
- Minimizes surface cracking.
- Minimizes part distortion.
- Achieves the same or better metallurgical properties with lower alloy steel resulting in significant material cost savings.
- Provides an optimum combination of high surface compressive stress; a high-strength, wear-resistant quenched layer of optimum depth; and relatively soft but properly strengthened core; all factors that result in longer part service life, with no increase in part cost.
- Reduces considerably the duration of the carburization cycle or fully eliminates the carburization process by the use of optimal hardenability ("OH") steels (medium carbon steels with very low content of alloy elements).
- Uses less costly, environmentally friendly quenchant (usually plain water) instead of expensive and hazardous quench oils, resulting in the significant reduction of the heat treatment costs, and in cost savings from environmental waste stream management, cleaner plant, cleaner parts, lower insurance, better work environment, etc.

- Allows conducting heat treatment operations within the manufacturing cell for in-line, single-part production.

1. The Basics of Intensive Quenching

1.1 Intensive Quenching Process Theory

There are several different quenching techniques used in common practice today, including, direct quenching, timed quenching, selective quenching, etc. The selection is based on the effectiveness of the quenching process considering the materials, part shapes, and quenching objectives (usually high hardness with acceptable distortion). In most cases, the quenching process is controlled to prevent a high cooling rate when the material is in the martensite phase transformation. This rule is based on the belief that a slower quench cooling rate will avoid high tensile, residual stress, distortion, and the possibility of part cracking.

Extensive research conducted by Dr. Nikolai I. Kobasko has shown that avoiding a high cooling rate when material is in the martensite phase is not always necessary, or optimal, to obtain the best part properties. His studies showed that a very high cooling rate within the martensite range would actually prevent quench cracking, if done correctly. This phenomenon was discovered first by laboratory experiments and then was supported by computer simulation (References 1 and 2). A large number of field experiments on a variety of steel parts validated both the theory and the computer simulations (References 3 and 4).

Figure 1 shows experimental data obtained for a cylindrical specimen made of low alloy steel with a diameter of 6 mm (0.25"). The bell-shaped curve clearly illustrates the general effect of the cooling rate within the martensitic phase on crack formation: the probability of quench cracking is low for both slow cooling and ***very rapid and uniform*** cooling, known as the IntensiQuench® process. The curve also shows that once quenching is in the "intensive zone," or above, the benefits of the IntensiQuench® process – high hardness *and* low distortion – will be attained. One cannot quench "too fast" because once the surface temperature of the part reaches the quenchant temperature, the part simply cannot cool any more quickly; cooling is limited by the ability of the part to conduct the heat energy from the core to the surface. IntensiQuench® processes are robust.

Why does the IntensiQuench® process minimize cracking and distortion? Imagine a steel part with a varying thickness (Figure 2). During conventional quenching, the martensite forms first in the thinner section of the part since this section cools faster and reaches the martensite range earlier than the thicker one (Figure 2a). The martensite specific volume is greater than the specific volume of the remaining austenite. Therefore, the thin section expands while the thick section of the part continues contracting due to cooling until it too becomes martensite. This creates non-uniform stresses during traditional quenching resulting in the distortion and possible part cracking. Now imagine that the same steel part is cooled very rapidly and uniformly. In this instance, the martensite forms simultaneously, over the entire part surface, creating a hardened "shell" (Figure 2b). Dr. Kobasko's research showed that this uniform, hardened shell creates high residual surface compressive stresses resulting in lower distortion and lower probability of cracking.

A simplified mechanism of the formation of residual surface compressive stresses in the parts after intensive quenching is described in detail in Reference 5. There are two major reasons for the development of high residual surface compressive stresses: (1) very fast formation of martensite in the part surface layers while the part core is still austenitic due to a significant temperature gradient throughout the part cross-section, and, (2) an interruption of the quench when surface compressive stresses are at their maximum value. This is in contrast to a conventional oil or gas quench when the temperature gradient across the part thickness in much less and martensite forms practically simultaneously through the part cross-section.

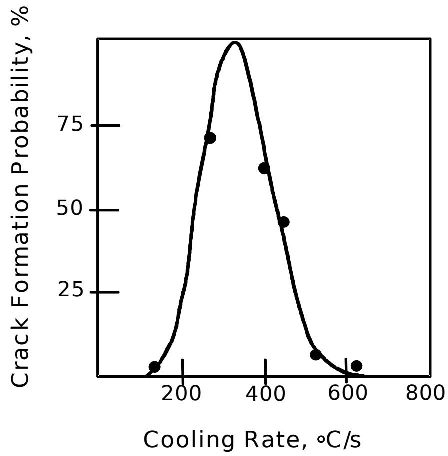


Figure 1 Effect of Cooling Rate on the Probability of

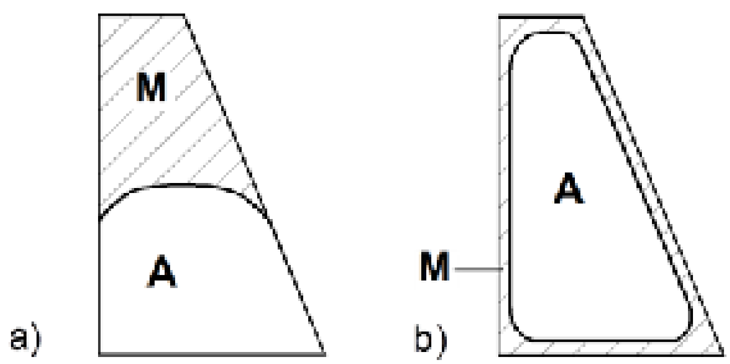


Figure 2 Martensite formation during quenching (M – martensite, A – austenite)
a) Conventional quenching, b) Intensive quenching

Dr. Kobasko's testing shows that, for best results from intensive quenching, cooling should be interrupted when surface compressive stresses are at maximum value. In this case, the "optimum hardened depth" is also obtained. Note that the optimum cooling time is a function of the part dimensions, part geometry, and type of steel.

For steel alloys with hardenability tailored to the IntensiQuench® method, intensive quenching will provide an optimum combination of high compressive surface stress; high-strength, wear-resistance; quenched layer of optimum depth; and a relatively soft, but properly strengthened core (Reference 4). This combination is ideal for part applications requiring high strength, and resistance to static, dynamic, or cyclic loads. Dr. Kobasko and IQ Technologies' customers have also demonstrated that by applying the intensive quenching method, the desired properties of the part could be obtained using less expensive steels (steels containing two or three times less alloying elements than conventional alloy grades quenched in oil).

1.2 Types of Intensive Quenching Methods

Two IntensiQuench® (IQ) processes are currently used in heat treatment practice: a batch IQ method and a single-part IQ method.

1.2.1 Batch IQ Method. The batch IQ technique is implemented in IQ water tanks with a very high quenchant agitation rate. The water flow velocity is usually about 2m/sec (or 6-7ft/sec); that is much greater compared to the quenchant agitation in conventional oil or polymer/water quench tanks. In contrast to conventional oil or water quenching, when quenching parts intensively in IQ water tanks, the film boiling process is either minimized or completely eliminated. From the beginning of the quench, the nucleate boiling mode of heat transfer takes place, followed convection heat transfer. Since film boiling is a sporadic and non-controllable mode of heat transfer, it often causes part distortion or cracking during quenching. IQ eliminates the film boiling by a very high water flow velocity ("intensive" flow), uniformly as possible around the entire part; a low water temperature (usually about 65°F); and by adding small amounts of mineral salts to water. Note that the water/salt solution contains negatively charged ions that are attracted to the part surface since the heated part (at austenitizing temperature) is always positively charged. The salt ions together with intensive quenchant flow physically destroy the vapor blanket. Various low concentrations of mineral salts in the water are also used to help eliminate part and quench tank corrosion.

The batch IQ technique is usually a one step procedure. Parts are kept in the quench for a certain period of time until the part's surface compressive stresses reach their maximum value in the part's shell (see Section 1,1 above). Then, the parts are removed from the quench and the cooling process continues in the air.

For parts of complicated shapes, a three-step IQ procedure is used: (1) fast cooling under quenchant nucleate boiling heat transfer conditions on the part surface, (2) slow cooling in the air, and (3) convection cooling in the quench tank. During the first stage of intensive cooling, martensite forms rapidly in the part surface layer. To avoid surface cracking in the batch IQ process, the fast cooling is interrupted when there is less than 50% of martensite formed in the surface layer of the part and the surface layer is still relatively "plastic." The steel part is removed from the intensive quench bath. Note, for this type of IQ to be most effective, the temperature where the alloy's CCT or TTT diagram shows approximately "50% martensite" should correspond to the boiling point of the quenchant on the part surface.

After "interruption" of the intensive stage of cooling, the part cooling continues in the air. During this second stage of the batch IQ process, the part surface layer or "shell" is self-tempered by the heat coming from the hot core. The part temperature equalizes throughout the cross sectional area. Also, in this second stage, the part "current" compressive surface stresses (developed in the first stage of intensive cooling) are "fixed." As a result of the self-tempering process, the martensitic surface layer strengthens eliminating possible cracking during final stage of the batch IQ process. In the third phase of the quench, the part is returned to the intensive quench tank for further convection cooling (very uniform cooling with no boiling) to complete the hardening in the surface layer and in the part core.

1.2.2 Single-Part IQ Method. This intensive quenching technique is the "most intensive" and best hardening method in terms of creating the highest compressive surface stresses to an optimum depth into the part. Single-part IQ method yields the highest amount of "super strengthening" of the part for a given material or alloy. Simply stated this quench process gives the most "bang for the buck" for a given hardenability of alloy. The single-part IQ method involves one-step "intensive" cooling in a cooling chamber with water flow rates many times faster than even the batch IQ method. When the single-part IQ process is applied, part surface cooling is so fast that both the film boiling and nucleate boiling are completely avoided, and the basic heat transfer mode on the part surface is simply convection cooling. Therefore, uniform “direct convection cooling” is the first key element to the single-part IQ process.

In the single-part IQ method, cooling is uniform over the entire part surface and should be interrupted when the “current” compressive stresses on the part surface reach their maximum value and optimal depth depending on part geometry. (This is similar to a one-step batch quenching method). These very high, “current” compressive surface stresses will be diminished if the core of the part is allowed to cool further, e.g., to the quenchant temperature. Therefore, the second key element of the single-part IQ process is to interrupt intensive cooling at the proper time – when the “current” compressive surface stresses during the intensive quench are at their maximum value and to the optimum depth.

In practice there are two major issues to implementation of the single-part IQ method. The first one is that it is not always possible to provide a high-velocity water flow *uniformly* around the *entire* part surface area. This is especially difficult to do for a part with complex geometry. The second limitation relates to quenching of relatively thin parts with the thickness of less than about ½”. With such thin parts it is very difficult to provide the proper temperature gradient within the part; the proper temperature gradient is needed to optimized compressive surface stresses with a 100% martensitic structure in the surface layer and at the same time have an intermediate hardened structure in the part core. For very thin parts, the short time to “interruption” and the required high water flow velocity to quench the surface first is in many cases impractical – the thin part quenches through almost instantaneously.

1.3 What Is The Difference Between Induction Case Hardening and IntensiQuench® Processes?

This is a very commonly posed question. Like IntensiQuench®, induction case hardening (ICH) provides the part with residual compressive surface stresses, and with a wear resistant, martensitic surface. However, unlike intensive quenching processes, the ICH process only strengthens the part surface layer. The part core does not experience any phase transformations. If “core conditioning” is required, the part must be through heated, quenched and tempered prior to conducting ICH. This is in contrast to the IntensiQuench® methods that provide high compressive surface stresses and *at the same time* properly strengthen the core. Secondly, the ICH process creates a hardness profile and residual stress profile that are much steeper than those after intensive quenching. And finally, intensive quenching is interrupted when residual surface compressive stresses are at their maximum value providing the part with an optimum hardened depth. The smoother hardness profile, the high residual stresses and the optimum depth of hardness after IQ processes result in better part performance characteristics – all in one process.

2. Intensive Quenching Process Computer Model

With IQ Technologies’ computer models, the IntensiQuench® process can be adapted to almost any steel part. The process begins by analyzing the thermal and stress profiles within the part during quenching using a finite element approach. A proprietary computer model was developed to conduct this analysis (Reference 2). This model includes a non-linear transient heat conduction equation and a set of equations describing the thermoplastic-plastic flow with kinematic strengthening on the parts’ surface.

An iterative technique is used to solve the system of equations. At each time and space step, the calculation results are compared with the thermokinetic diagram of the supercooled austenite transformation (for the given alloy), and new thermophysical and mechanical characteristics for the next step are chosen. This analysis seeks the point along the cooling curve where compressive surface stresses are maximized. The calculation results are:

- Temperature field
- Material phase composition
- Stress distribution
- Distortion distribution
- Duration of each cooling step for IQ processing methods –The "Cooling Recipe."

Data from numerous laboratory and field experiments has been used in the validation of this model. A similar software package, the DANTE model, was developed by a collaborative research program managed by the National Center for Manufacturing Science (Reference 6**).** However, in contrast to the computer model developed by Dr. Kobasko, this software does not calculate the heat transfer boundary conditions on the part surface during the various stages of the quench. An accurate evaluation of the heat transfer on the part surface is a key element in this type of calculation leading to greater accuracy in predicting real world results.

A simplified computer program was also developed to calculate cooling recipes for batch and single-part IQ techniques. This computer program uses generalized correlations between the cooling time and part characteristics (geometry, dimensions, type of steel, etc.). These correlations were obtained by using an extended experimental and computational database for steel parts of various geometries and alloy hardenability.

3. IntensiQuench® Equipment

Currently there are two general types of IQ equipment. The first type of IQ system is designed for intensive quenching of multiple steel parts in a batch. The second type of the IQ system is designed for the implementation of the single-part (or part-by-part) IQ technique.

3.1. IQ Equipment For Batch Quenching. Batch IQ systems are similar to conventional oil quench tank designs used in batch and continuous furnace heating operations. The differences are the following: As mentioned in Section 1.2.1, the batch IQ technique uses a low concentration (less than 10%) mineral salt/water solution, instead of oil, or polymer/water. Secondly, batch IQ systems must have a significantly higher quench agitation rate. For example, a full-scale 6,000-gallon batch IQ system, installed at Akron Steel Treating Co. of Akron, Ohio, is equipped with four props rotated by four 10 horsepower motors. A similar oil-quench tank would be equipped with only two props rotating by two 5 hp motors. Batch IQ systems should be equipped with a very fast elevator mechanism to minimize the difference in cooling times between the parts placed in the upper layer of the load and parts located in the bottom layer of the load. And finally, the batch IQ system should be automated to control the duration of each steps of the batch IQ recipe - "intensive" to form properly the "shell," then to "air" cooling, then back to "intensive" cooling. (See Section 1.2.1).

Existing oil tanks in integral quench furnaces or continuous furnaces can be modified relatively easily to accommodate the batch IQ method. When retrofitting an existing integral quench atmosphere furnace (for example, an All-Case™ Surface Combustion furnace), extra care should be taken to seal the door between the furnace and the cooling chamber to maintain the integrity of the furnace atmosphere from contamination by water vapors.

Note that AFS-Holcroft integral polymer/water or salt quench furnaces use a three-chamber approach to maintain atmosphere integrity: an intermediate, nitrogen gas, purge chamber, between the furnace and the quench tank, is equipped with a handling mechanism. Using this approach, AFC-Holcroft designed and built a first integral quench, intensive quench furnace with IQ water tank with a load size of 36"× 36"× 72" (Figure 5), installed at Euclid Heat Treating Co. of Cleveland, Ohio. The 11,000-gallon IQ tank is equipped with four powerful propellers and a fast elevator mechanism providing a full immersion of the entire load into the quench tank in only 2 seconds.

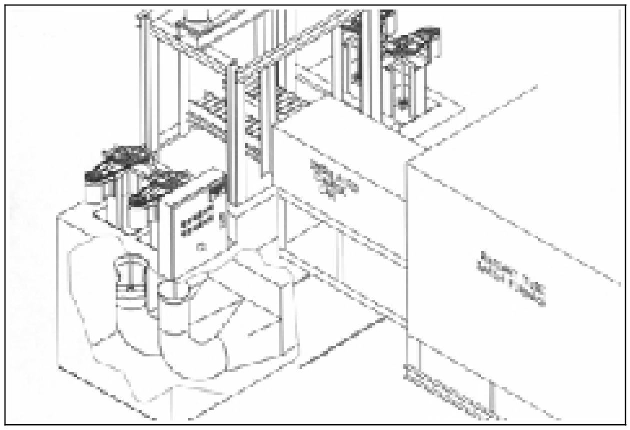


Figure 3 Layout of IQ system at Akron Steel Treating Co.

Figure 4 6,000-gallon IQ tank across the aisle from 36"x36"48" atmosphere furnace installed at Akron Steel Treating Co.

Figure 5 AFC-Holcroft Integral Quenched Furnace Equipped With 11,000-gallon IQ Water Tank and Installed at Euclid Heat Treating Co.

Akron Steel Treating Co. of Akron, Ohio is using its stand-alone 6,000-gallong IQ water tank for implementing a batch IQ process. The parts are austenitized in a Surface Combustion Radiant Tube Batch (RTB) atmosphere furnace (36"x36"x48") located across the aisle from the IQ water tank. A schematic of this IQ system is presented in Figure 3. Figure 4 presents a picture of the IQ quench tank.

3.2. Single-Part Processing IQ Equipment. To implement the IQ technique on more complex shaped parts or parts with thinner cross-sections, a very high velocity intensive quench is necessary to provide uniform and intensive heat extraction from the entire part surface, and to create a "shell" with maximum compressive stresses to an optimum depth to prevent part cracking during the quench. Once the shell is properly formed the intensive water quench is interrupted and the part is cooled in the air, with the core cooling by uniform conduction through the cold shell. Over the last years, IQ Technologies Inc designed and manufactured several production IQ systems for implementing a single-part intensive water quenching in a very high-velocity water flow – sometimes referred to as IQ-3. A general schematic of a high-velocity IQ unit is presented in Fig. 6.

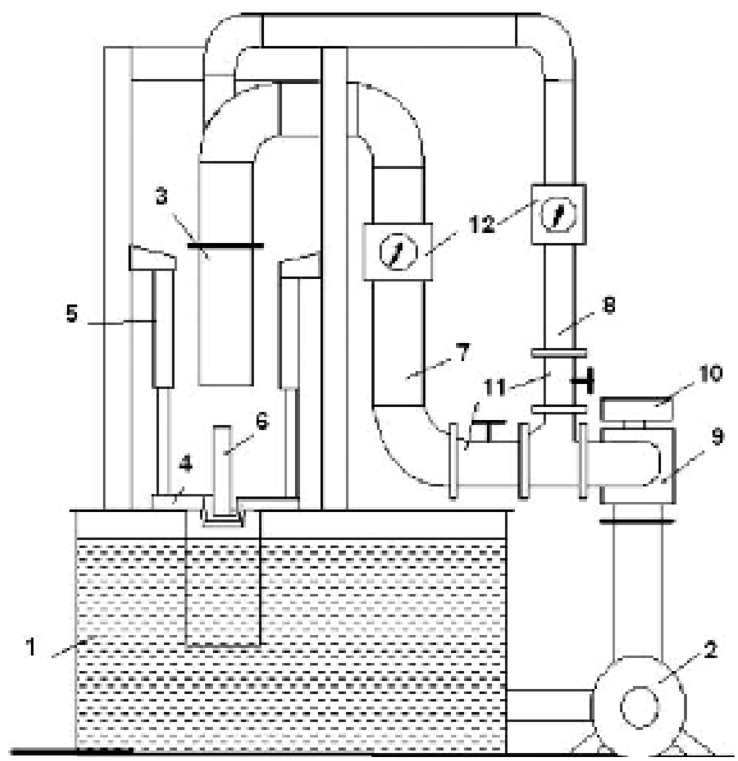


Figure 6 General schematic of high-velocity IQ unit

The IQ-3 system consists of the following major components:

- Water tank, 1
- Pump, 2
- Vertical quench chamber that consists of two sections: the stationary upper section, 3, and the movable loading lower section, 4.
- Four air cylinders, 5, that move up and down the lower section, 4, with the part, 6, to be quenched.

- Three water lines: two lines, 7 and 8, that provide the water flow through the quench chamber and one “bypass” water line (not shown on the sketch) that is used in “idle” conditions immediately before or after the intensive quenching is done.
- 3-way valve, 9, with actuator, 10, that provides water flow from the pump either through the quench chamber or through the bypass line.
- Two control valves, 11, and two flow meters, 12, installed on the water lines leading to the quench chamber and used for controlling the water flow.

The IQ-3 quench sequence is as follows. With the pump operating and the three-way valve in the bypass position, an austenitized part is placed in the lower section of the quench chamber. The air cylinders move the lower section up to the stationary upper section and lock (seal) the quench chamber in place. The 3-way valve switches from the “bypass” to the “quench” position, and high velocity water starts flowing through the quench chamber and over the part. When intensive quenching is completed, the 3-way valve switches back to the bypass position, and the water stops flowing through the quench chamber and flows through the bypass line. The air cylinders open the quench chamber by moving the lower section down. The part is removed from the quench chamber lower section.

Fig. 7, Fig. 8, and Fig. 9 presents pictures of production high-velocity IQ systems. The high velocity IQ system (Fig. 7) is installed at Euclid Heat Treating Co. (EHT) of Cleveland, Ohio, USA. This unit is designed for processing parts of up to 200mm diameter and 500mm length. These parts include gears, shafts, bearing rings, etc. The IQ system is equipped with a chiller for maintaining the water temperature and with an atmosphere box furnace for austenitizing the parts prior to quenching.

The high-velocity IQ system presented in Fig.8 is installed also at EHT Company. It is designed for processing long shafts of up to 50mm diameter and up to 910mm length. The IQ unit is equipped with a chiller and with an induction heating station for through-heating (austenitizing) the shafts. Induction heating of the parts can be conducted in a protective atmosphere.

The high-velocity IQ system shown in Fig. 9 is installed in one of the automotive plants in Canada and is designed for processing torsion bars of up to 50mm diameter and 1520mm length. In contrast to the above high-velocity IQ units, torsion bars are quenched in horizontal orientation.

Figure 7 High-velocity IQ system for processing parts of up to 200mm diameter and 500mm length installed at Euclid Heat Treating Co.

Figure 8 High-velocity IQ system for processing shafts of up to 50mm diameter and 910mm length installed at Euclid Heat Treating Co.

Figure 9 High-velocity IQ system for processing torsion bars

4. IQ Process Application to Production Parts

The IntensiQuench® process has been validated by hundreds of laboratory and field experiments. A number of published technical papers present data on the improvement of steel mechanical properties, material microstructure and residual surface compressive stresses. Tables 1–3 present some examples of this information. Note that all the metallurgical data was obtained by the customers of IQ Technologies Inc, or generated by Case Western Reserve University of Cleveland, Ohio. Stress measurements, by X-ray diffraction, were conducted by Lambda Technologies Inc.

Table 1 Microstructure Improvement

Part	Quenching	Bainite Content, %				Grain Size
		Surface	Near Surface	½ Radius	Core	
∅36 mm 5160 Steel Torsion Bar*	Intensive	0	0	2.0	2.5	-
	Oil	3.0	5.0	12.0	29.0	-
∅21 mm Wire 9259 Steel Spring**	Intensive	0	-	-	2.0-5.0	ASTM 9
	Oil	5.0-10.0	-	-	15.0-20.0	ASTM 8

Note: *) Reference 7
**) Reference 8

IntensiQuench® process provides better near surface and core microstructures, with a finer grain size.

Table 2 Mechanical Properties at the Core of Conventional and Intensively Quenched Steels (Samples were taken from the core of ∅50 mm specimens, References 9 and 10)

Soviet Steel (AISI Steel)	Quenching	Tensile Strength, MPa	Yield Strength, MPa	Impact Strength, J/sm^2	Hardness, HRB
40X (5140)	In oil	780	575	113	217
	Intensive	860	695	168	269
35XM (4130)	In oil	960	775	54	285
	Intensive	970	820	150	285
25X1M (4118)	In oil	755	630	70	229
	Intensive	920	820	170	285

While intensive quenching improved all the mechanical properties, *the impact strength increased by 2 to 3 times.*

Table 3 Mechanical Properties Improvement for Different Parts (Reference 7, 11, 12 and 13)

Part	Property	Oil Quench	Intensive Quench
1340 steel M22× 123mm bolt	Tensile strength, MPa	1093	1176
1045 steel ∅19× 125 mm bar	Tensile strength, MPa	996.7	1201.3
S5 steel ∅38× 56 mm punch	Impact strength, N× m	6.8	12.2
4140 steel hand tool socket	Torque to failure, N× m	168.6	223.3
4140 steel ∅45 mm king pin	Ultimate strength, kN	313.6	414.8

The IntensiQuench® process provides parts with better mechanical properties due to enhanced hardenability and finer martensite structure.

Table 4. Experimental Residual Surface Compressive Stresses for Different Steel Parts

Part	**Residual Surface Compressive Stresses, MPa**	**References**
52100 Ring ∅8.5”	-136	7
52100 Roller ∅3”	-840	13
52100 Roller ∅1.8”	-900	13
4140 Kingpin ∅1.8”	-563	7
S5 Punch ∅1.5”	-750	7
5160H Torsion Bar Sample ∅1.4”	-311	7
1045 Cylinder ∅1.5”	-430	14
1547 Cylinder ∅2.87”	-626	7
1547 Cylinder ∅2”	-515	7
Pyrowear-53 carburized gear: Oil IQ	-350 -800	15
5160 steel ∅1” rod: oil, shot peened IQ, shot peened	-563 -839	16

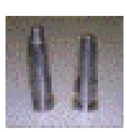
The IntensiQuench® process provides the steel parts with significantly greater surface compressive stresses resulting in longer part service life. IQ also can reduce or eliminate the need for carburization to achieve residual compressive surface stresses.

More examples of the application of the IntensiQuench® processes to production parts are summarized below. Note that the part makers conducted all metallurgical analysis and fatigue testing. Some metallurgical and fatigue tests were performed by Case Western Reserve University of Cleveland, Ohio and by Gear Research Institute of Pittsburgh, Pennsylvania. The details of the data summarized below are available upon request from IQ Technologies Inc.

4.1 Part Performance Improvement

Intensively quenched parts have better performance characteristics compared to conventionally quenched parts. For a given alloy of steel, IQ provides a deeper hardened layer, higher residual surface compressive stresses and better steel microstructure, that combine to result in stronger parts with greater fatigue resistance versus conventional quenching methods.

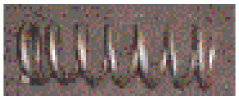
<u>4.1.2 Punches</u>



Service life of intensively quenched cold work punches made of S5 steel and hot work punches made of H-13 steel improves by at least 2 times (Reference 17).

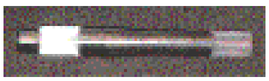
Cold work punch Hot work punch

4.1.2 Automotive coil springs



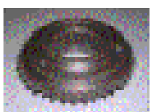
Automotive coil springs made of 9259 and 9254 steels and quenched intensively have longer fatigue life by13 to 27% compared to the same springs quenched conventionally in oil (Reference 8). While intensively quenched **lighter** automotive coil springs have the same fatigue life as standard springs quenched in oil.

4.1.3 Output shafts



Heavy truck output shaft made of plain carbon 1040 steel and intensively quenched outperformed standard output shaft made of alloy 5140 steel and quenched in oil. Note that the use of plain carbon steel provides also material cost savings.

4.1.4 Helicopter test gears

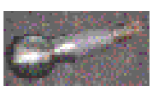


Intensively quenched helicopter test gears made of carburized Pyrowear-53 steel withstand 14% greater load for the same fatigue life as standard gears quenched in oil (Reference 18).

4.2 Material Cost Reduction

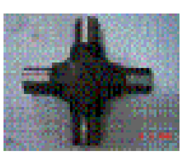
The enhanced hardenability provided by the intensive quenching process means part designers can reduce alloy content and lower overall part costs.

4.2.1 Ball studs



Ball studs made of plain carbon 1040 and 1045 steels and intensively quenched have the same fatigue life as a standard ball studs made of alloy 4140 steel and quenched in oil.

4.2.2 Universal joint crosses



Universal join crosses made of plain carbon 1018 steel and intensively quenched have the same or better performance characteristics as standard crosses made of alloy 5120 steel and quenched in oil. Note that the carburization cycle for the intensively quenched crosses was reduced by 15% compared to the standard cycle resulting in process cost reduction as well.

4.3 Part and Process Cost Reduction

Intensively quenched automotive side pinions made of limited hardenability steel with no carburization and shot peening outperformed standard carburized pinions quenched in oil. The elimination of a long carburization cycle, the use of quenched oil and shot peening process allow conducting heat treatment operations within the manufacturing cell and implementation of in-line production of the parts.

5. Summary of IQ Process Benefits

In summary, IntensiQuench® processes have been shown to increase part hardness and strength, ***while at the same time providing less part distortion*** on typical products made of various steel types versus traditional quenching methods. IQ Technologies Inc offers computer process modeling and proven design tools for implementing intensive water quenching technology for a wide variety of steel alloys with varied part geometry. Manufacturers of steel parts can **improve their product quality *and* reduce their costs** utilizing IQ Technologies' proprietary software and processes. Some of the proven advantages of intensive quenching include:

- ⇒ Elimination of cracking
- ⇒ Minimization of distortion and associated costs
- ⇒ High residual compressive surface stresses for greater part durability
- ⇒ Reduction or full elimination of carburization cycles
- ⇒ Improved mechanical properties (yield and ultimate strength, wear resistance, depth of hardness, etc.)
- ⇒ Reduction of part size/weight with comparable physical properties
- ⇒ Longer part life with no cost penalty
- ⇒ Usage of lower alloy steels while maintaining physical properties (enhanced value engineering)
- ⇒ Replacement of hazardous quench oil with environmentally friendly water or salt/water solutions
- ⇒ Better integration of the heat-treating process into single-part production process flow.

For detailed information concerning application of the IntensiQuench® processes and equipment to your heat-treating operations, please contact us at:

IQ Technologies Inc
P.O. Box 1787, Akron, Ohio 44309
Phone. (330) 773-4850, Fax: (330) 773-0772

Or visit our web site: **www.IntensiveQuench.com**

We will be glad to provide you with specific information on how IQ Technologies can significantly improve your part quality and strength, optimize your material selection, while lowering your total part costs.

References

1. Kobasko, N. I. and Prokhorenko, N. I., "Quenching Cooling Rate Effect on Crack Formation of 45 Steel," in *Metallovedenie and Termicheskaya Obrabotka Metallov* (in Russian), No. 2, 1964, pp. 53-54.
2. Kobasko, N. I. and Morganyuk, V. S., "Numerical Study of Phase Changes, Current and Residual Stresses in Quenching Parts of Complex Configuration," *Proceedings of the 4th International Congress on Heat Treatment of Materials*, Berlin, Germany, 1985, Vol. 1, pp., 465-486.
3. Kobasko, N. I., "Method of Overcoming Self-Deformation and Cracking During Quenching of Metal Parts," *Metallovedenie and Termicheskay Obrabotka Metallov* (in Russian), No. 4, 1975, pp. 12-16.

4. Kobasko, N. I. “Intensive Steel Quenching Methods. Theory and Technology of Quenching”, Springer-Verlag, New York, N.Y., 1992, pp. 367-389.
5. Aronov, M.A., Kobasko, N.I., Powell, J.A., “Basic Principals and Metallurgy of Intensive Quenching Methods”, Proceeding of 13th IFHTSE Congress, Columbus, Ohio, 2002.
6. “Predictive Model amd Methodology for Heat Treatment Distortion”, Phase 1 Project Summary Report, National Center for Manufacturing Science report No. 0383RE97, September 30, 1997.
7. Aronov, M.A., Kobasko, N.I., Powell, J.A., “Practical Application of Intensive Quenching Process for Steel Parts”, Proceeding of The 2000 Heat Treating Conference, St. Louse, 2000.
8. Aronov, M.A., Kobasko, N.I., Powell, J.A., “Application of Intensive Quenching Methods for Steel Parts”, Proceeding of The 2001 Heat Treating Conference, Indianapolis, Indiana, 2001.
9. Muhina, M. P., Kobasko, N. I., Gordejeva, L. V., “Hardening of Structural Steels in Chloride Quench Media”, Metalovedenie I Termicheskaya Obrabotka Metallov (in Russian), September 1989, pp. 32-36.
10. Kobasko, N. I., “Steel Quenching in Liquid Media Under Pressure”, (in Russian), Naukova Dumka, Kiev, 1980.
11. Aronov, M. A., Kobasko, N. I., Wallace, and J. F., Schwam, D., “Intensive Quenching Technology for Steel Parts,” Proceeding of The 1998 Heat Treating Conference, Chicago, 1998.
12. Aronov, M.A., Kobasko, N.I., Powell, J.A. et al, “Practical Application of Intensive Quenching Technology for Steel Parts and Real Time Quench Tank Mapping”, Proceeding of The 1999 Heat Treating Conference, Cincinnati, 1999.
13. Aronov, M. A., Kobasko, N. I., Powell, J.A., Wallace, and Y. Zhu., “Effect of Intensive Quenching on Mechanical Properties of Carbon and Alloy Steels”, Proceedings of The 23d ASM Heat Treating Conference, Pittsburgh, Pennsylvania, 2005.
14. Hernandez Morales et al., Residual Stress Measurements in Forced Convective Quenched Steel Bars by Means of Neutron Diffraction”, Proceedings of the 2nd International Conference on Quenching and the Control of Distortion, ASM, 1996, pp. 203-214.
15. Freborg, A.M., Li, Z., Ferguson, B.L., Schwam, D., “Bending Fatigue Strength Improvement of Carburized Aerospace Gears”, Proceedings of 23rd ASM Heat Treating Conference, Pittsburgh, Pennsylvania, 2005.
16. Hubbard, C.R., Tang F., Aronov, M.A., Kobasko, N.I., et al, “Effect of Intensive Quenching on Residual Stress”, Proceedings of 23rd ASM Heat Treating Conference, Pittsburgh, Pennsylvania, 2005.
17. Aronov, M.A., Kobasko, N.I., Powell, J.A., “Intensive Quenching Technology for Tool Steels”, Proceeding of The 2002 IFHTSE Congress, Columbus, Ohio, 2002.
18. Ferguson, B.L, Freborg, A.M., Li, Z., “Improving Gear Performance by Intensive Quenching”, Proceedings of 24th ASM Heat Treating Conference, Detroit, Michigan, 2007.