ENVIRONMENTALLY FRIENDLY INTENSIVE WATER QUENCHING IS EFFECTIVE ALTERNATIVE TO CONVENTIONAL QUENCHING

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Abstract

Paper discusses major principals, properties and metallurgy of an intensive quenching (IQ) process that is an alternative way of hardening steel parts. The IQ method uses environmentally friendly plain water for quenching steel parts instead of hazardous quench oil. The paper describes the value propositions offered by the IQ technique: improvement of part performance, reduction of the part cost and improved environment. The paper considers in detail one of the major benefits of the IQ technology: the reduction or full elimination of the carburization cycle that results in significant improvement of the productivity of heat-treating furnaces and in energy savings.

Introduction

Every metallurgist knows that the higher the cooling rate during quenching the better the part mechanical properties. On the other hand, it is a well-known fact that the higher the cooling rate the greater the probability of part distortion or cracking. Heat treaters are always balancing in trying to provide better steel properties while not cracking the parts. An intensive quenching (IQ) process, known as IntensiQuench®, is an alternative way of hardening steel parts originated by Dr. Kobasko of the Ukraine. The IQ method uses highly agitated water as a quenchant and provides much greater cooling rates compared to conventional quenching in oil or in a polymer.

An experimental graph presented on Figure 1 and obtained for low alloy steel ∅6 mm specimens illustrates a general idea of the IQ process (Reference 1). As seen from the figure, a very high cooling rate actually reduces the probability of part cracking. Significant greater cooling rates provided by the IQ process compared to conventional quenching methods result in better steel microstructure after intensive quenching and improved part mechanical properties and performance characteristics.

1. Why Does IQ Process Work?

Let us consider a tapered ring (Figure 2). During quenching, the ring thin sections cool faster compared to the rest of the part. Therefore the martensitic structure starts forming first in these areas of the part. As known, the martensite has a greater specific volume than that of the austenite. A non-uniform formation of the martensite throughout the part surface results in the expansion of the part material in the thin sections while the

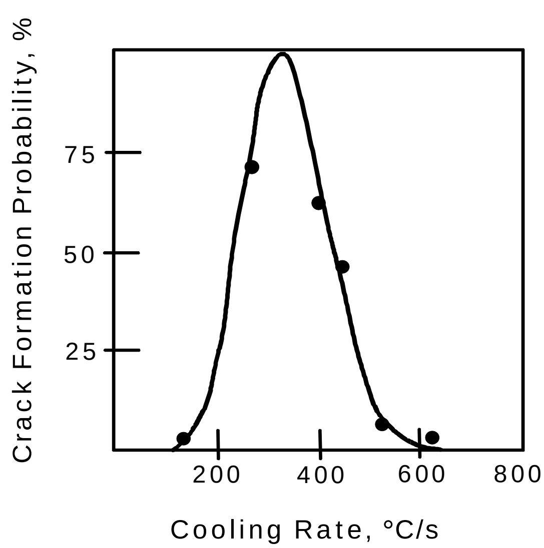

Figure 1 Effect of Cooling Rate on Probability of Part Cracking

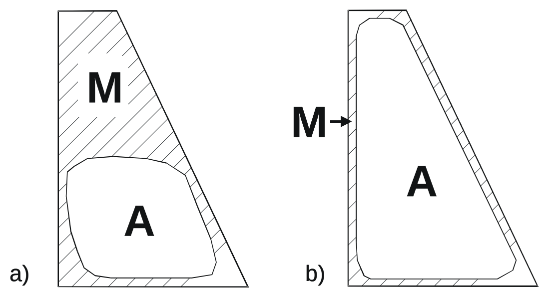

Figure 2 Martensite Formation During Drenching
a) Conventional quenching, b) Intensive quenching

rest of the ring continues shrinking due to the thermal contraction. This results in the ring distortion or may even cause part cracking.

In contrast to conventional quenching, during the IQ process due to a very high heat extraction rate, the martensitic structure forms uniformly throughout the entire part surface area creating a uniform martensitic layer. The martensitic surface layer increases in volume resulting in the formation of the very high surface compressive stresses (Figure 3). The surface compressive stresses are further induced by the thermal contraction of the part austenitic core. Note that the surface compressive stresses hold the part together like a die minimizing the part distortion and preventing part cracking. The IQ process is interrupted at the moment of time when the surface compressive stresses are at their maximum value (see Figure 3) and the part hardened layer is at an optimum depth. The part then is removed from the quench,

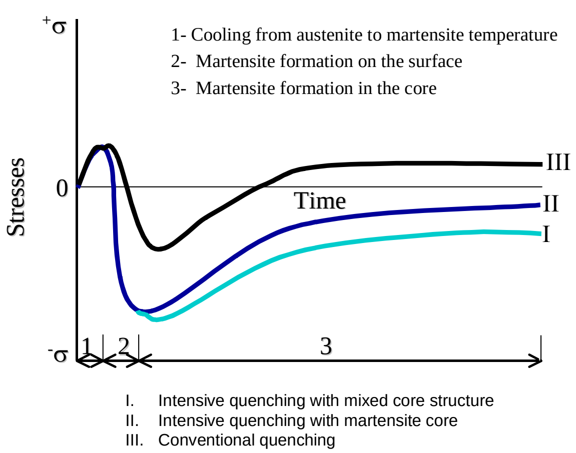

Figure 3 Surface Stresses vs. Time

and cooling continues in the air. At this period of time, the phase transformations in the part core continue resulting usually in a mixed structure and a partial cancellation of the surface compressive stresses. This is in contrast to conventional quenching when the quench is not interrupted, and the residual surface stresses are usually neutral or tensile at the end of quenching. A detail mechanism of the development of the residual surface compressive stresses and dynamics of the phase transformations in the part during the IQ process is described in Reference 2.

To develop intensive quenching process cooling recipes, we are using a proprietary computer program (Reference 2). The computer model describes the part time/temperature, strain/stress and structural conditions during quenching. The computer program uses a finite element approach and material property database developed over the years.

2. IQ Process Equipment

When applying the IntensiQuench® method, the parts being quenched can be processed in batches or in one-by-one manner (single part quenching). Reference 3 describes in details different designs of the IQ equipment. For batch intensive quenching, we are using IQ water tanks that provide uniform cooling and cooling rates required by the IQ process. The IQ tank can be a part of an integral quench furnace, or can be a stand-alone unit. For example, Euclid Heat Treating Co. of Cleveland, Ohio, USA has an integral quench atmosphere furnace of 91x91x183 cm equipped with 45.4 m^3 (12,000-gallon) water tank built by AFC-Holcroft Co. of Wixom, Michigan, USA. Akron Steel Treating Co. of Akron, Ohio, USA has two stand-alone IQ water tanks. The first one is of 22.7 m^3 (6,000-gallon) and is equipped with a 91x91x122 cm atmosphere furnace located across the aisle from the tank. The second IQ tank is of 7.2 m^3 and is a part of the fully automated IQ system that includes in addition to the IQ tank a ∅61x61 cm pit type atmosphere furnace and a load transfer mechanism. Hightemp Furnaces Limited of Bangalore, India is building a similar fully automated IQ system at its facilities in Bangalore. The IQ system will be able to quench intensively the load of ∅61x91 cm. For single part quenching, we are using either a high-velocity IQ system installed at the above Akron Steel Treating Co., or IQ tanks (for large parts with the cross section exceeding 75 mm).

3. IQ Process Value Propositions

The IQ process offers three major value propositions: the part performance improvement, the part cost reduction and environmental benefits (Figure 4). The following proven IQ technique benefits (References 3-5) provide these value propositions:

- ⇒ Improved part mechanical properties (tensile strength, yield strength, impact strength)
- ⇒ Beneficial residual surface compressive stresses
- ⇒ Use of less expensive less alloy steels
- ⇒ Less part distortion
- ⇒ Elimination of quench oil and associated expenses
- ⇒ Reduction or full elimination of the carburization cycle

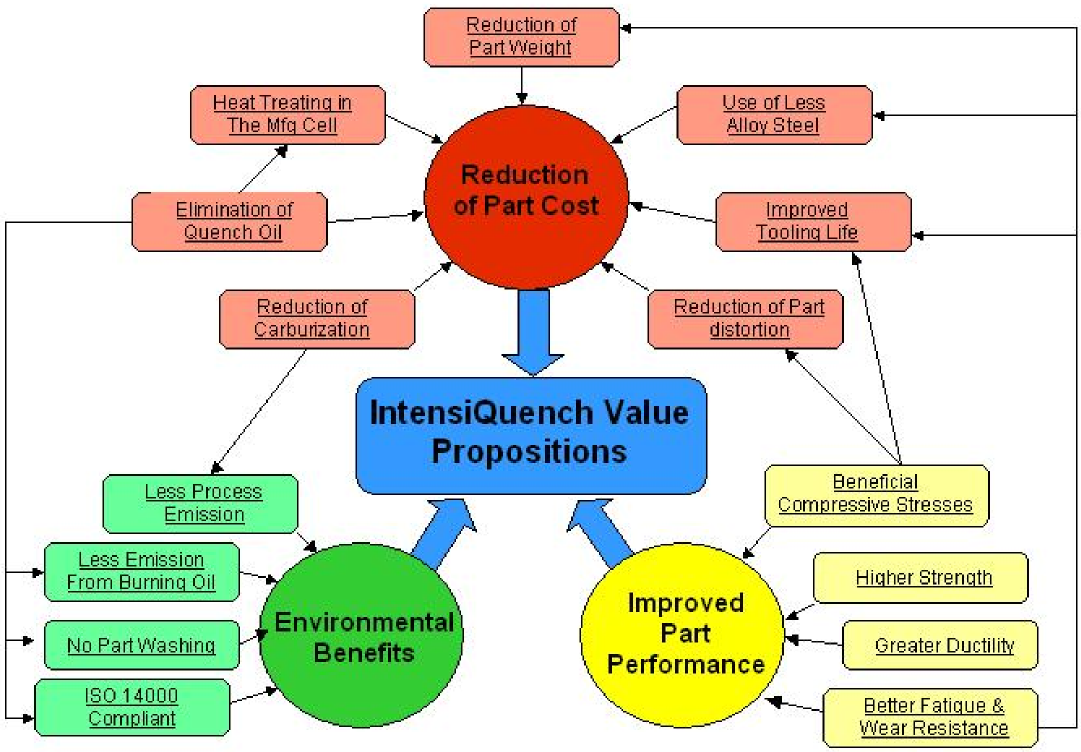

Figure 4 Intensive Quenching Process Value Propositions

4. Elimination/Reduction of Carburization Cycle

This section of the paper illustrates an application of the IntensiQuench® process for carburized parts. As an example, we consider a case study conducted in cooperation with Hightemp Furnaces Ltd of Bangalore, India for universal joint crosses made of 8620 steel (Figure 5). Currently, Hightemp Furnaces Ltd processes the universal joint crosses in integral, oil quench furnaces of their own design. A typical effective furnace size is 1230x660x650 mm. The furnace is atmosphere tight, allowing precise control of the furnace atmosphere. A typical universal joint cross load is presented in Figure 6. As seen, the parts are

Figure 5 8620 Universal Joint Cross

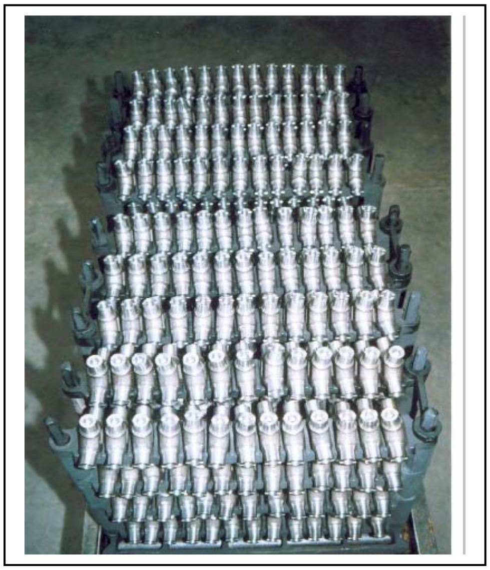

Figure 6   Typical Universal Joint Cross Loads

placed in a special fixture. Hightemp Furnaces carburized four sets of crosses. Two sets were carburized and quenched in oil using a “standard” thermal cycle (Figure 7). An additional two sets were carburized only, using a reduced-time carburization cycle: one set of parts was carburized for 60% of the standard carburization time (“60% carburized”), and the second set of parts was carburized for only 50% of the standard carburization cycle (“50% carburized”).

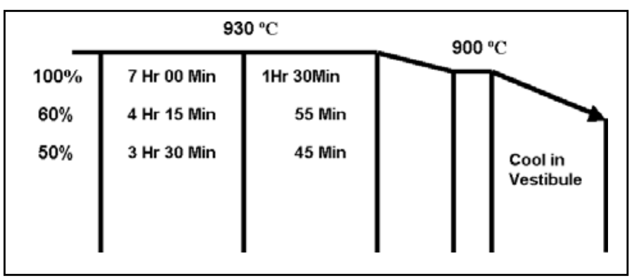

Figure 7   Applied Carburization Cycles

The two sets of parts from the reduced carburization cycles as well as the parts from one set that was fully carburized to the “standard” cycle were reheated in a neutral salt bath furnace and intensively quenched individually in IQT’s experimental 500-gallon IQ system (Reference 3).

The IQ system uses highly agitated water with a low concentration of sodium nitrite (primarily as a rust inhibitor) as the quenchant in this system. Once the part surface has reached the temperature of the bath and has the optimal compressive surface stresses (as determined by the IQT computer models), it is removed from the “intensive” quench and permitted to cool in air. The core cools by uniform conduction through the cold, intensively quenched shell. The entire intensive quench process takes less than a minute on the subject parts. (The quenchant flow velocity in the 500-gallon system is the same as in our 6,000-gallon and 12,000-gallon production batch-type IQ systems. The production systems use the same water quenchant as well.) To evaluate the effect of the IQ process, we measured the following parameters and compared them to the “standard” carburization, oil quenched parts:

- ⇒ Surface hardness
- ⇒ Core hardness
- ⇒ Case depth
- ⇒ Microstructure
- ⇒ Inter granular oxidation
- ⇒ Products of non-martensitic transformation
- ⇒ Part distortion

Figure 8 shows the location on each of the crosses where we took these measurements.

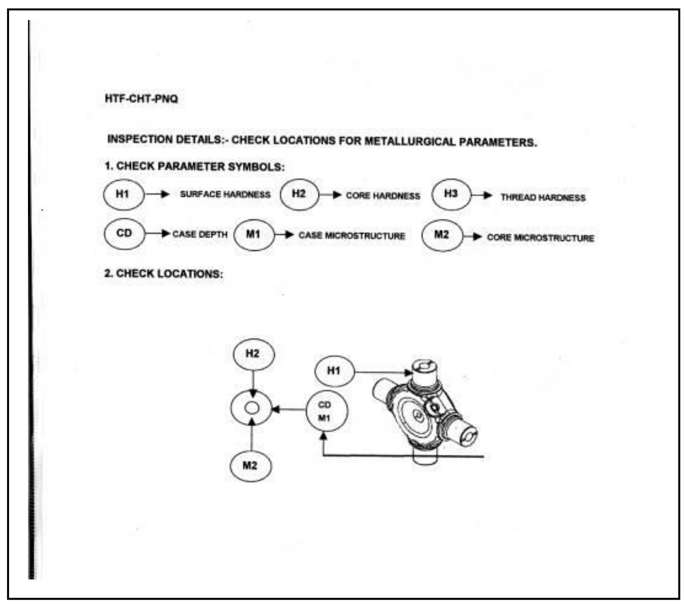

Figure 8   Schematic of Points of Measurements

The results of the metallurgical analysis are the following:

- ⇒ No unacceptable distortion or cracks were observed

⇒ The case depth was uniform throughout the intensively quenched surface of the cross
⇒ The specified mean case depth of 1.5 mm was achieved with 60% of the "standard" process time and intensive water quenching
⇒ The core hardness was greater than the required minimum
⇒ No inter granular oxidation was observed in the intensively quenched crosses

Let's consider the above results in more detail.

Figure 9 presents the hardness distribution in the universal joint crosses for different carburization cycle times. The hardened depth is defined as a depth of the part surface layer with a minimum hardness of 50 HRC (513 HV1). Figure 10 presents the relationship of the part case depth from the carburization time for both the oil quenched parts and intensively water quenched parts. As seen from Figures 9 and 10, the case depth is 1.5 mm for standard oil quenched crosses. Fully carburized crosses that were intensively quenched have a case depth of 1.7 mm or 13% greater than the standard case depth. The crosses that were partially carburized for 60% of the standard carburization time (for 5 hours 10 minutes instead of 8 hours 30 minutes) have the same case depth as the standard cycle carburized and oil quenched parts. Note also that the intensively water quenched crosses have a greater core hardness compared to the standard parts by 50-115 HV1 units.

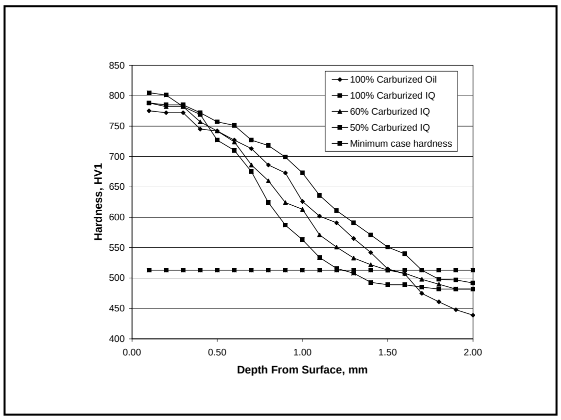

Figure 9 Hardness Distributions for Different Carburization Times

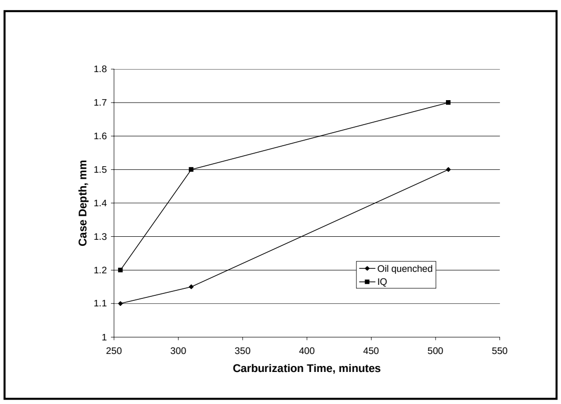

Figure 10 Case Depth vs. Carburization Time

Figure 11 presents the uniformity of hardness distribution in the 60% carburized cross. As seen from the figure, the IQ process provides very uniform hardness distribution throughout the part surface. Samples 1, 2 and 3 were taken from different surface areas (see Figure 8 above). The uniformity of hardness throughout the part surface from intensive water quenching is mainly due to the absence of the sporadic film boiling on the part surface in the "intensively agitated" quench; no film boiling, equals no soft spots.

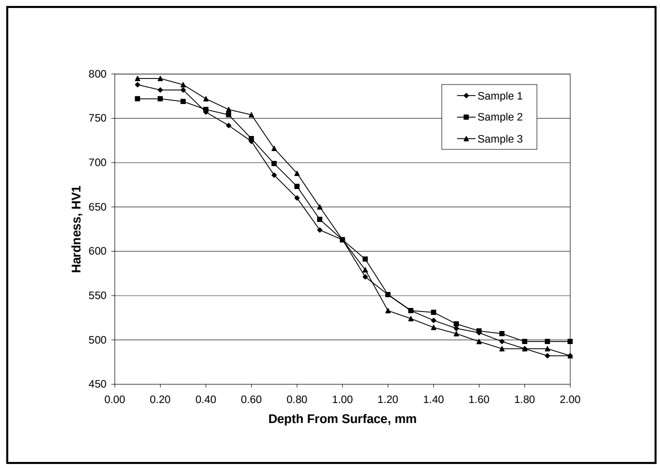

Figure 11 Uniformity of Hardness Distribution in 60% Carburized and Intensively Quenched Cross

Figures 12–15 present the photographs of the part microstructure in the case and in the core for the standard cycle carburized, quenched in oil cross, and for the 60% carburized intensively quenched cross.

For both parts, the case microstructure consists of fine tempered martensite with approximately 5% of retained austenite with no products of non-martensitic transformation and no carbide network. However, as seen from Figures 12 and 13, the

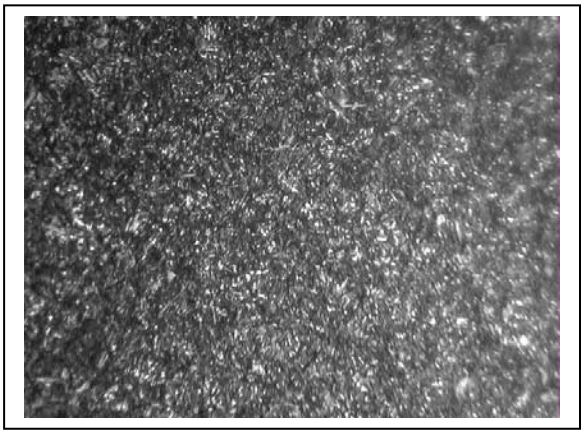

Figure 12 Case Structure of 60% Carburized IQ Cross

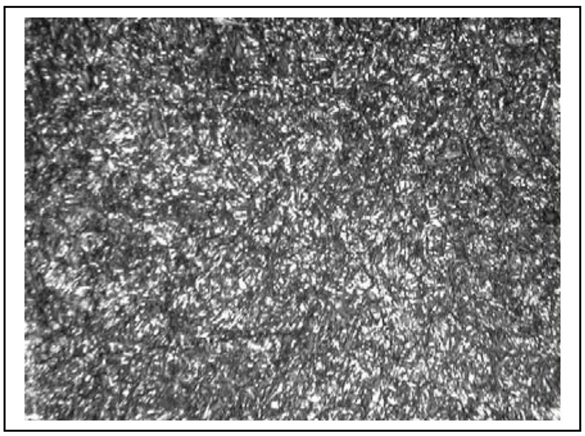

Figure 13 Case Structure of 100% Carburized Oil Quenched Cross

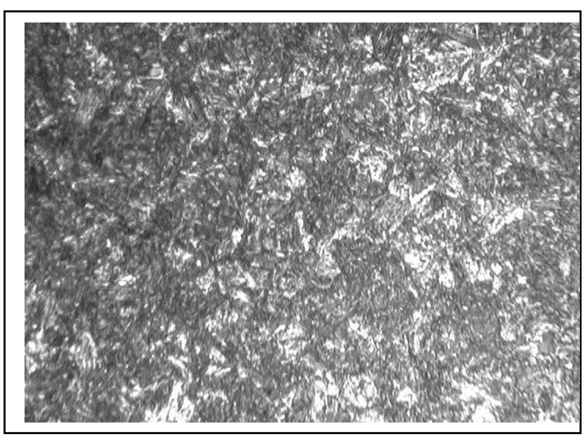

Figure 14 Core Structure of 60% Carburized IQ Cross

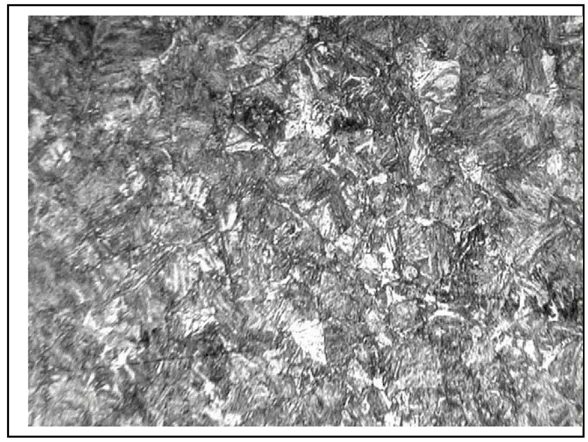

Figure 15 Core Structure of 100% Carburized Oil Quenched Cross

martensitic structure was finer in the intensively quenched part compared to the standard oil quenched part. The intensively quenched cross core consists of low carbon martensite, while the core of the standard cross consists of low carbon martensite and bainite.

Table 1 summarizes the results of previous IQ demonstration studies performed by IQ Technologies Inc for different steel parts. As the data in the table shows, the carburization cycle can be reduced significantly using the IQ process; approximately 40%-50% less furnace carburization time from the standard carburization cycle using conventional oil quenching.

Table 1 Carburization Cycle Reduction for Different Parts

Part	Steel	Case Depth, mm	Cycle Time Reduction
Universal joint cross	8620	1.5	40%
Bearing cage	8617	1.8	50%
Crankshaft	8620	1.5	40%
Railroad part	4130	2.0	50%
Railroad part	4138	2.0	Full elimination

Conclusion

IQ process uses plain water or low concentration solutions of mineral salts in water as quenchants, and, therefore, it is an environmentally friendly method for quenching steel parts in contrast to conventional quenching methods that use oil as a quenchant. IQ process is an effective alternative to conventional quenching techniques that provides the following benefits:

- ⇒ Beneficial residual surface compressive stresses and improved part mechanical properties compared to conventional quenching resulting in improved part performance characteristics (wear and fatigue resistance, service life, etc.).
- ⇒ Use of less expensive less alloy steel
- ⇒ Part weight reduction
- ⇒ Reduction or full elimination of carburization cycles
- ⇒ Significant energy savings
- ⇒ Possibility of conducting heat treatment operations within the manufacturing cell

IQ process requires designing and construction of special quenching equipment or modification of the existing quenching equipment to provide uniform cooling and proper high cooling rates for steel parts.

For more information on the intensive quenching methods, see the IQ Technologies Inc web site www.IntensiveQuench.com.

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