

# Improved production of automotive parts by intensive quench processing

N. I. Kobasko, M. A. Aronov, J. A. Powell, L. C. F. Canale, G. E. Totten

*Intensive quenching offers enormous potential advantages to the automotive component and process designer, including: possible elimination of more environmentally hazardous petroleum oils and aqueous polymer quenchants, elimination of fire hazards associated with the use of petroleum oil quenchants, reduction or elimination of cracking, the possibilities of using less expensive steels in component design, dramatic improvement in properties such as fatigue and impact strength, and reduction or elimination of carburizing times. In this paper, an overview of intensive quench processing is provided.*

*Various case histories illustrating the use of intensive quenching to replace conventional quenching process is also provided.*

**Key words:** heat treatment, quenchant, intensive quench, surface compressive stress

## INTRODUCTION

About 35 years ago, Kobasko first reported the “intensive quenching” phenomenon [1]. Intensive quenching, which is currently practiced commercially under the trade named of “IntensiQuenchSM” is an alternative way of hardening steel parts [2]. Intensive quenching is typically conducted by cooling, usually with pure water quenchant or low concentration water/salt solutions (most often with brine) at a rate several times greater than the rate of “normal” or conventional quenching. In contrast to the conventional heat-treating practices, intensive quenching is conducted at very high cooling rates for parts within the martensite transformation region.

It is important to note that the term “Intensive Quenching” does not simply mean fast quenching or quenching at an arbitrarily fast cooling rate. Instead, various descriptive and specific criteria have been published defining the conditions for intensive quenching [3]. These include:

- Those quenching conditions that yield maximum surface compressive stresses [4].
- Mei has reports that the agitation rate should be sufficient to provide a Grossman Quench Severity value of > 6.0 [5].
- The Biot number criterion for maximum surface compressive stresses:  $Bi \rightarrow \infty$  [6]
- For high surface compressive stresses to occur on a part being quenched, it is sufficient to meet the following condition:  $0.8 < Kn < 1$ . (Kn is the Kondratyev number.) [6].

Research has shown that if steel is cooled sufficiently fast, uniform part cooling will result leading to significantly reduced cracking and distortion, while at the same time improving the surface hardness and durability of steel parts [7-10].

The rapid cooling rate also provides greater hardened depth which improves the mechanical properties of the part. Rapid cooling rates also create high residual compressive stresses

on the part surface permitting the use of lower alloy steels or the use of smaller (lighter) parts which are also stronger which leads to a more cost-effective quenching process. In addition, intensive quenching is a clean and environmentally friendly process since it uses plain water or a low concentration water/salt solutions as a quenchant instead of traditional heat treatment practices that use relatively hazardous and environmentally unfriendly oil.

It should also be noted that intensive quenching is not the same as induction case hardening [11]. These processes are differentiated by:

- Unlike intensive quenching, induction case hardening only provides surface layer hardening. There core does not experiment phase transformations. If core conditioning is required, the part must be heated, quenched and tempered prior to induction case hardening.
- Induction case hardening typically produces a much steeper hardness and residual stress profile than obtained with intensive quenching.
- Intensive quenching is interrupted when residual surface compressive stresses are at their maximum providing the part with optimum hardened depth.

The smoother hardness profile, maximum surface compressive stresses and optimum depth of hardness attainable with intensive quenching yields improved performance characteristics [11].

This paper provides an overview of three of the most commonly used intensive quenching methods which are designated as: IQ-1, IQ-2 and IQ-3. The production of various automotive parts by intensive quench processing is also discussed as well as a brief discussion of the equipment used to perform many of these processes [12,13].

## DISCUSSION

### A. HOW IS INTENSIVE QUENCHING CONDUCTED?

Three of the most common intensive quenching processes are designated as: IQ-1, IQ-2 and IQ-3. Although other IQ processes such as IQ-4 and IQ-5 [14,15] have been reported but will not be discussed further here. They differ by the modes of heat transfer on the part surface during the cooling process.

#### 1. IQ-1 Intensive Quenching Method

The IQ-1 quenching method is a two-step cooling process. It is used for medium-alloy and high-alloy steel parts. During the first stage of quenching, steel parts cool slowly

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from the austenitizing temperature down to the martensite start temperature  $M_s$  (often using hot oil or high-concentration water/polymer solutions). There is an insignificant temperature gradient throughout the cross-section of the part within this slow cooling stage. Therefore, the initial temperature throughout the entire part can be assumed equal to the temperature  $M_s$  at the beginning of the second stage of cooling.

The second stage of quenching is very intensive and it occurs within the temperature range of the martensite transformation. Water jets or directed streams of the quenchant around the steel part provide high cooling rates. Intensive cooling results in the formation of high compressive stresses on the part surface. These compressive surface stresses “fix” the low part distortion obtained in the first, slow cooling stage, and also provide additional strengthening or “super strengthening” of material.

However, a limitation of IQ-1 process is that a) quench oils or high-concentrations of aqueous polymer quenchants are used at the first stage of cooling, and b) the second stage of cooling is conducted in a separate chamber. The use of quench oils or high concentration of aqueous polymer solutions (typically 20% to 24%) considerably reduces the hardening capacity for steel parts. The necessity of a second cooling chamber complicates the hardening process making it difficult to maintain and it is more expensive.

**2. IQ-2 Intensive Quenching Method**

IQ-2 is a three-step procedure: a) fast cooling under nucleate boiling heat transfer conditions on the part surface, b) slow cooling in air, and c) convective cooling in the quenching tank. During IQ-2, the duration of the unstable film-boiling is minimized to avoid part cracking and distortion. This is the primary reason a salt solution (brine) is used.

During the first stage of IQ-2 cooling, martensite forms rapidly on the surface. To avoid surface cracking, 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 “plastic.” The steel part is removed from the quenchant.

After “interruption” of the intensive stage of cooling, the part continues to cool in air. During this second stage of IQ-2, the part surface layer or “shell” is self-tempered by the heat coming from the hot core. The temperature of the part equalizes throughout the cross sectional area. Also, in this second stage, the compressive surface stresses of the part which are developed in the first stage of cooling are fixed. As a result of self-tempering, the martensitic surface layer strengthens eliminating possible cracking during final stage of IQ-2 cooling. In the third phase of IQ-2, the part is returned to the intensive quench tank for further convective cooling to complete the required phase transformations in the surface layer and in the core.

A limitation of IQ-2 is that the water/salt solution boiling temperature does not always coincide with the martensite finish temperature of the alloy. Therefore, the IQ-3 intensive quenching process was developed.

**3. IQ-3 Intensive Quenching Method**

IQ-3 is the most intensive and best hardening method with respect to the creation of high surface compressive stresses, to an optimum depth. IQ-3 yields the highest amount of “super strengthening” of the part for a given material or alloy. IQ-3 involves one-step “intensive” cooling in contrast to the multi-step cooling IQ-1 and IQ-2 processes. When the IQ-3 process is applied, part surface cooling is sufficiently fast that both film boiling and nucleate boiling are completely avoided and the heat transfer mode on the part surface is simply convection. Therefore “direct convective cooling” is the first key element of the IQ-3 process.

In the IQ-3 method, intensive cooling is continuous and uniform over the entire part surface until compressive stresses on the part surface achieve their maximum value and optimal depth depending on part geometry. These maximized compressive surface stresses will be diminished if the core of the part is cooled further, e.g., to the quenchant temperature. Therefore, the second key element of the IQ-3 process is to interrupt intensive cooling at the proper time – when compressive surface stresses are at their maximum value and optimum depth.

There are three major issues related to implementation of the IQ-3 quenching method. The first 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 for a part with complex geometry. The second limitation relates to quenching of relatively thin parts with the thickness of less than about  $\frac{1}{2}$ ". With such thin parts it is very difficult to provide a proper temperature gradient within the part to obtain a 100% martensitic structure in the surface of the part, and to simultaneously obtain an austenitic core that will convert to a hardened intermediate structure in the core of the part. For thin parts, the required high water flow velocity and the short time to “interruption” become, in many cases, impractical.

Finally, the IQ-3 method is not as adaptable to batch quenching of steel parts since it is practically impossible to provide high water flow velocity and uniformity throughout the entire batch. To intensively quench parts of complex shape, thin parts or parts in batches, IQ-2 should be used. However, parts of thick cross-sections (more than  $\frac{1}{2}$ ") and parts of relatively simple geometry are ideal candidates for IQ-3.

**B. MODELING THE INTENSIVE QUENCHING PROCESS**

Designing intensive quenching processes involves the use of computer modeling and simulation which can be adapted to almost any steel part [15]. The process begins by analyzing the thermal and stress profiles within the part during quenching using a finite element approach [7]. 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.

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 [16, 17]. Fig. 1 illustrates the results of the Dante simulation of typical intensive quenching process and the uniform case hardness achieved [4].

**C. EQUIPMENT FOR INTENSIVE QUENCHING**

Currently there are two general types of equipment for intensive quenching. The first type is for the implementation of the IQ-3 quenching technique for a single (part-by-part) quenching method. The second type of the IQ systems is designed for IQ-2 batch quenching of multiple steel parts or for single-part quenching of parts with very complex geometry.

IQ-2 quenching systems are similar to conventional oil quench tank designs used in batch and continuous operations. The differences are: a) IQ-2 quenching technique uses a low concentration (less than 10%) mineral salt/water solution, instead of oil, or polymer/water; b) IQ-2 systems must have a significantly higher quench agitation rate. For example, a full-scale 6,000-gallon IQ-2 quenching system, installed at Summit Heat Treating Co. (Akron, Ohio), is equipped with four 18" diameter props rotated by four 10 horsepower

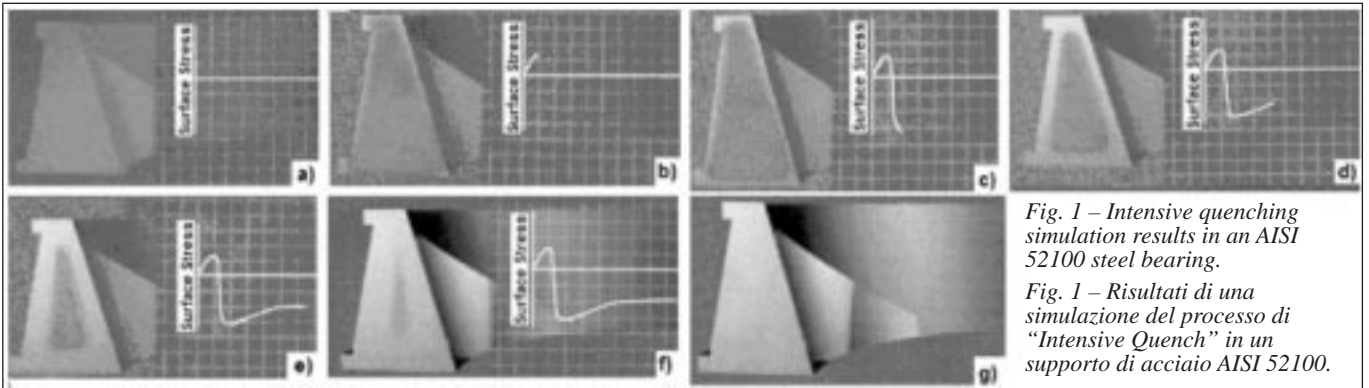


Fig. 1 – Intensive quenching simulation results in an AISI 52100 steel bearing.

Fig. 1 – Risultati di una simulazione del processo di “Intensive Quench” in un supporto di acciaio AISI 52100.

(HP) motors [18]. A similar oil-quench tank in an integral quench batch type furnace would be equipped with only two props rotating by two 5 HP motors [18]; c) IQ-2 quenching systems should be equipped with a very fast elevator mechanism since the duration of different IQ-2 process cooling steps is usually calculated in seconds. Moving from “intensive water quenching” to “still air quenching” of the load should be completed within 2 to 3 seconds; d) IQ-2 quenching system should be automated to control the duration of each the three steps of the IQ-2 cooling recipe - “intensive” to form properly the “shell,” then to “air” cooling, then back to “intensive” cooling.

Existing oil tanks in integral quench furnaces or continuous furnaces can be modified relatively easily to accommodate the IQ-2 quenching 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. They use an intermediate, purge chamber, between the furnace and the quench tank, equipped with a handling mechanism.) In continuous furnace line quench tanks, it is usually necessary to re-design the parts conveyor by fitting it with a variable speed drive to vary the parts’ cooling “time-in” and “time-out” of the IQ-2 quench media.

To implement the IQ-3 quenching method, it is necessary to provide uniform and intensive heat extraction from the part surface, to create a “shell” with maximum compressive stresses to an optimum depth. Once the shell is properly formed the intensive quench is interrupted and the part cools in the air with the core cooling by uniform conduction through the cold shell. IQ-3 can be accomplished in two ways. For parts with relatively simple geometry (for example, cylindrical parts, flat parts, etc.), a high velocity water flow along the part surfaces can provide the required “intensive” cooling (heat transfer coefficients). For parts of more complicated shapes (for examples, shafts with flanges that can block the water stream flowing along the part axis), a water jet impingement approach is a very effective way of uniform, intensive cooling. In both these cases, a pump or pumps provide the necessary “intensive” water flow velocity and uniformity. A typical IQ-3 system includes a water tank, pump(s), valves, piping, water flow, temperature and pressure control devices, automated part handling system, and a water-chilling system.

### 1. Intensive Quenching of Automotive and Truck Axles

In one application, truck half-axles constructed from AISI 4340 steel were heat treated and oil quenched in a continuous process. The half-axles are typically machined to a stock diameter of 40 mm and a length of 1152 mm. The oil quench system was replaced by an intensive spray quen-

ching system using water on an automated close die-forging line at the at the ZIL and GAZ automotive plants. [19, 20] The technology of cold die-forging of axles is shown in Fig. 2a and the intensive quenching process is illustrated in Fig. 2b. In the quenching step of this process fluid flow is enhanced by using compressed air to pressurize the quenchant in the chamber prior to the quench. In this process, the depth of hardening is 2-7 mm. This intensive quenching process permitted the replacement of alloyed steels with cheaper AISI 1040 materials, while attaining significantly increased material ductility.

### 2. Use of Intensive Quenching in Nut and Bolt Production

A special V-Quench tank was developed for the production of small parts such as bolts. [21] The radial flow rate of the quenchant is controlled to promote rapid and uniform quenching of the small parts. Figure 3 illustrates an heat treating line utilizing the V-Quench tank. [21] This system is suitable for the production of shafts, bolts, washers, pins, etc. Intensive quenching provides the following advantages in small-part production:

- Effective and economical prevention of quench cracking,
  - Hardened parts exhibit improved fatigue properties,
  - Lower alloy steels may be used for part production.
- Bolts and washers produced from medium carbon steels are susceptible to quench cracking, up to 90% cracking rates are observed, when quenching in moderately agitated brine or caustic solution after austenitizing. To minimize quench cracking, the hardening temperature is reduced (below the critical range) or oil quenching is used. It has been shown repeatedly that there are numerous advantages to the use of intensive quenching processes using the V-Quench tank. These include:
- Reduce distortion and obtain more uniform hardness,
  - Water vapor contamination of the furnace atmosphere is reduced by 95%,
  - Reduction in electric energy and water consumption.
  - Bolts manufactured from alloy steels may be quenched in the V-tank with improved physical properties compared to oil quenching.

### 3. Bearing Production in a Continuous Intensive Quenching System

Quenching of bearing parts may also be performed in continuous heat treating processes. For example, balls and rollers have been quenched in rotating magnetic fields [22]. The device used for this work consisted of a cylindrical tank with cooling media and an electromagnet which encircled the tank which was used to quench the stator of a synchronous engine. The system used to quench rollers and balls in a rotating magnetic field is shown in Fig. 4 [22].

### 4. Die Production by Intensive Quenching

Intensive quenching of dies constructed from medium and high alloy steels may be facilitated using high concentra-

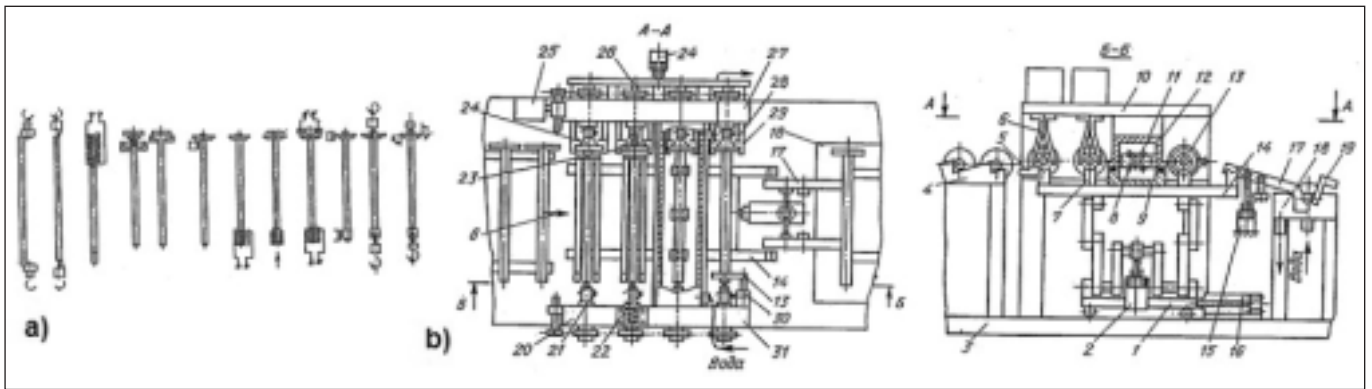


Fig. 2 - a) Illustration of close die-forging of truck half-axes. b) Illustration of intensive quenching process for truck half-axes. 1 - a carriage; 2 - a pneumocylinder for the vertical carriage displacement with the help of levering system; 3 - a support (base); 4 - a storage; 5 - knives for gripping of an coming axle; 6 - a longitudinally-loop inductor; 7 - a prism; 8 - casters; 9 - a lower door of a quenching chamber; 10 - a plate; 11 - casters; 12 - a fixed door of a quenching chamber; 13 - an induction coil of quenching quality control; 14 - a rack; 16 - a pneumocylinder for the horizontal carriage displacement; 17 and 15 - a lever and pneumocylinder of reloading from a prism of a transport vehicle to a quenching tank; 18 - a tank for the final cooling of axles; 19 - an off-loading slide; 20, 27 - blocks; 21 - a casing; 22, 23 - spring-loaded centers; 24 - a cup-shaped friction; 25 - a drive with an electromotor, a speed reducer and a transmission; 26 - a transverse beam; 28 - fixed supports; 29 - a puller; 30 - a pneumatic cylinder.

Fig. 2 - a) Illustrazione di fucinatura a stampo di semiassi di autocarro. b) Illustrazione del processo di "Intensive Quench" per semiassi di autocarro. 1 - un carrello; 2 - un cilindro pneumatico per lo spostamento verticale del carrello con l'aiuto di un sistema di leve; 3 - un supporto (base); 4 - un magazzino; 5 - coltelli per la presa di un assale; 6 - un induttore di circuito longitudinale; 7 - un prisma; 8 - ruote orientabili; 9 - un porta inferiore di una camera di raffreddamento; 10 - una piastra; 11 - ruote orientabili; 12 - un porta fissa di una camera di raffreddamento; 13 - spirale a induzione per il controllo della qualità della tempra; 14 - una griglia; 16 - un cilindro pneumatico per lo spostamento orizzontale del carrello; 17 e 15 - una leva e un cilindro pneumatico di ricarica da un prisma di un mezzo da trasporto a una vasca di tempra; 18 - Una vasca per il raffreddamento finale degli assali; 19 - uno scivolo di scarico; 20, 27 - blocchi; 21 - un involucro; 22, 23 - centronatori caricati a molla; 24 - una frizione; 25 - una trasmissione con motore elettrico, riduttore di velocità e trasmissione; 26 - una trave traversa; 28 - supporti fissi; 29 - un estrattore; 30 - un cilindro pneumatico.

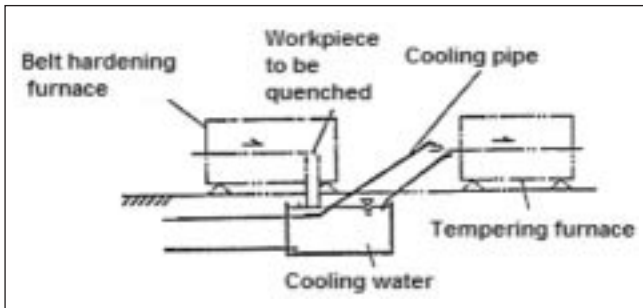


Fig. 3 - Schematic of V(I) - quench tank.

Fig. 3 - Schema di una vasca di tempra a V(I).

tions of aqueous PAG quenchant solutions. Currently, dies are quenched in air-water sprays surrounding the entire surface. However, the working side of the dies are intensively quenched as shown in Fig.5. The quenching process is interrupted when the temperature in the center of the dies is below  $2 \times M_s$  (martensite start) temperature. This technology was developed in the Ukraine.

Similar die quenching technology was developed later in Belarus. [23] The distinctive feature of this controlled quenching technology is that the heat treating of articles of complicated form is localized. This is a characteristic of the die quenching process. In this process, the cooling of the working face of the die and the back side of the die is performed at different rates in order to provide the desired hard-

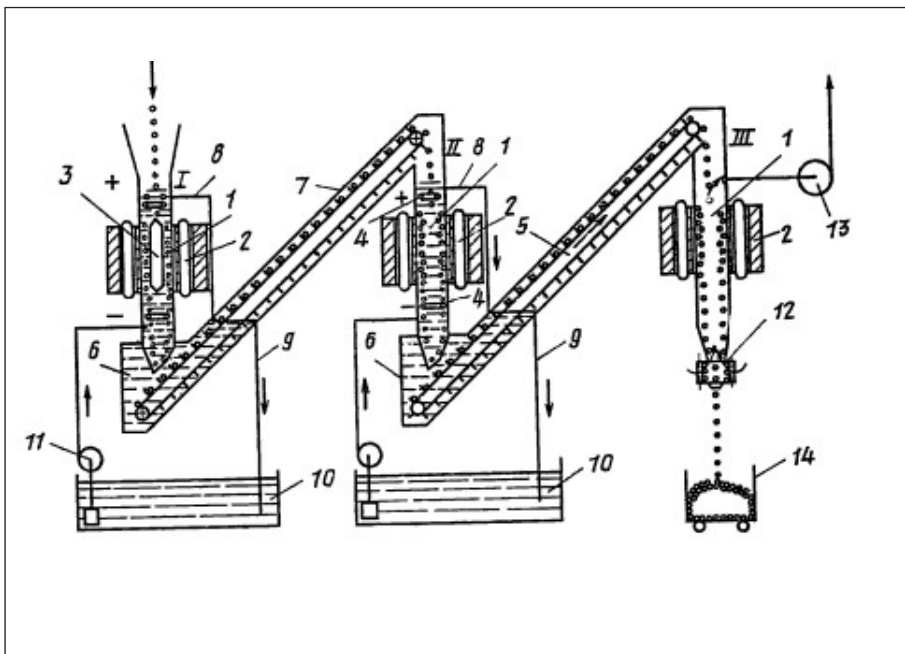


Fig. 4 - System employing a rotating magnetic field used for ball and roller production in a rotating magnetic field: 1 - a cylindrical container; 2 - a source for magnetic field; 3 - a cylinder made of ferromagnetic material; 4 - collar electrodes; 5 - a tilt transporter; 6 - a tank; 7 - a housing; 8, 9 - overflow pipes; 10 - a reservoir; 11 - a pump; 12 - a vortex heat-exchanger; 13 - a ventilation device; 14 - a storage for quenched parts.

Fig. 4 - Sistema che utilizza un campo magnetico rotante per la produzione di sfere e ruote in un campo magnetico rotante: 1 - un contenitore cilindrico; 2 - una fonte di campo magnetico; 3 - un cilindro di materiale ferromagnetico; 4 - elettrodi a collare; 5 - un trasportatore inclinato; 6 - una vasca; 7 - una sede; 8, 9 - tubi di troppopieno; 10 - un bacino; 11 - una pompa; 12 - uno scambiatore di calore a vortice; 13 - un dispositivo di ventilazione; 14 - un deposito per parti temprate.

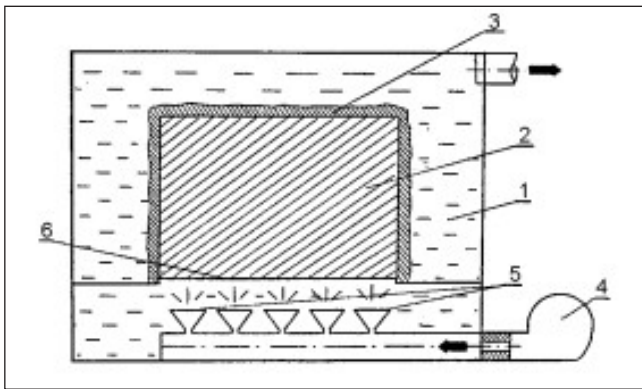


Fig. 5 – Die quenching using an intensive quenching process with air-water sprays.

Fig. 5 – Tempra di uno stampo mediante l'impiego di un processo di "Intensive Quench" con spruzzatori di aria-acqua.

ness in these two different areas.

The Belarus system is composed of [23]:

- Size of the unit: 6200 X 2000 X 3500mm
- Size of the working area: 2500 X 2000 X 2500mm
- Number of jets: 8
- Water consumption and Air consumption: 0.86 m<sup>3</sup>/h and 92 m<sup>3</sup>/h (respectively)
- Water Pressure and Air Pressure : 0.4 Mpa (both)
- Weight of die: up to 8 metric tons.

It has been shown that as a result of testing a pilot lot of dies under manufacturing use conditions, the life-time was increased 4-6 times relative to oil quenching. Additional advantages of this method include: savings of energy and resources, replacement of oil with a more fire-safe air-water spray, a more ecologically friendly and novel improvement in quench processing.

However, experience has shown that many problems accompany air-water spray quenching technology in this process. For example, equipment construction is difficult and expensive and proper flow control of the air-water streams is difficult to achieve. The work reported here suggests that significant technological improvements may be achieved with the use of 20-35% aqueous solutions of a PAG polymer in conjunction with intensive quenching technology. (The proposed intensive quenching process is described in Fig. 6. [24])

D. EXAMPLES OF INTENSIVE QUENCH PROCESSING

The patented IntensiQuenchSM intensive quenching process [2] has been validated by hundreds of laboratory and field experiments. Selected examples are summarized below.

1. Hardening and Mechanical Property Improvement

Intensive quenching has been evaluated and compared to conventional oil quenching processes for through-hardening

Quench	Hardness, HRC		
	40Cr (4140) M10 Bolt	4037 M18 Bolt	5160H Bar Ø1.4 inch
Oil	42.7	51-47	60.4
IQ	54.8	58-60	63.4

Table 1 – As-quenched Hardness for Different Materials (Parts were through-quenched).

Tab. 1 – Durezza di diversi materiali allo stato temprato (tempra profonda),

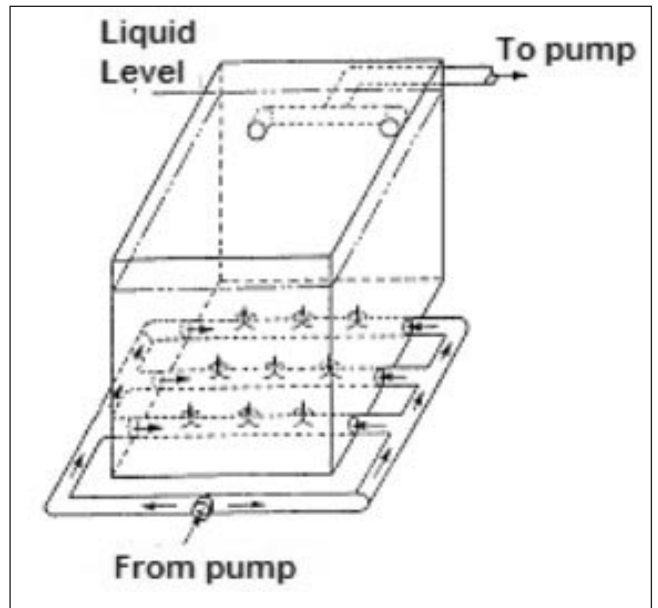


Fig. 6 – Proposed intensive quenching process for use with high concentration of aqueous PAG polymer solutions.

Fig. 6 – Utilizzo del processo di "Intensive Quench" finalizzato all'impiego con una soluzione acquosa di polimero PAG ad alta concentrazione.

various types of parts and different steel alloys. As expected, the as-quenched hardness was improved relative to conventional quench oil for AISI 4140, and M18 bolts and an AISI 5160H steel bar as shown in Table 1 and no quench cracks were observed [12, 25].

The results of a more extensive study comparing the core hardness after quenching and tempering for intensive and conventional quenching processes with a broader range of steel alloys is shown in Table 2 for steel alloys such as: carbon, medium alloy, boron and bearing steels [25]. Once again, significant improvement in core hardness no cracking was observed with parts produced from an optimized intensive quenching process was observed. Another example illustrating the substantial improvement in through hardening capability relative to conventional oil is provided in Table 3 with the results for a five-tooth sprocket constructed from

Part	Core Hardness*, HRC	
	Oil	IQ
86B30 steel 25x25 mm sprocket tooth**	36	50
52100 steel 19 mm wall thickness bearing ring**	56	61
4140 steel Ø45x264 mm kingpin**	30	48
1045 steel Ø25.4x254 mm keyway shaft***	31	50
4137 steel 110x116 mm forged shoe	42	47
4130 steel 129x137 mm forged wedge	29	38

\*) Parts were tempered at the same temperature after intensive quenching and oil quenching.  
 \*\*) Reference 13;  
 \*\*\*) Reference 26

Table 2 – As-Tempered Core Hardness Improvement.

Tab. 2 – Incremento di durezza in profondità dopo rinvenimento.

Quench	Hardness, HRC		Hardened Depth, inch
	Surface	Core	
IQ	52.0	50.2	Hardened through 1/8"
Oil	50.0	36.5	

Table 3 – 86B30 Five-Tooth Sprocket Hardness and Hardened Depth (Reference 13).

Tab. 3 – Durezza di un rullo dentato in 86B30 e penetrazione di tempra.

86B30 steel. The enhanced hardenability provided by the intensive quenching process means part designers can reduce alloy content and lower finished part costs.

Fig.7a shows that the hardness of a 73 mm diameter, 1547 steel cylinder that was intensively quenched exhibited a depth of hardness that is more than 7 times greater than that of the oil quenched sample when measured at the 50 HRC level. Fig.7b shows the hardness advantage is maintained after tempering [8].

Coil springs (coil OD 152 mm, length 547 mm and spring wire diameter of 21 mm) made from AISI 9259 were intensively quenched and the results were compared to coil springs made from the same lot of steel and quenched in a conventional oil [27]. Two springs of each group were de-

structurally tested for residual stress and other metallurgical analysis. Six intensively quenched springs and six oil quenched springs were tempered and then shot peened by Arvin-Meritor who then conducted standardized fatigue tests on the two sets of springs. The as-quenched microstructure for the intensively quenched spring was superior to that of the oil quenched spring as shown in Table 4. The amount of bainite in the intensively quenched spring ranged from 0% at the surface to 5% in the core which was substantially less than that observed for the oil quenched sample. The intensively quenched hardness was 1-3 RC units harder as well. However, the as-tempered hardness of both the intensively quenched sample and the oil quenched samples were essentially the same.

Figures 8a and 8b show the comparison of the surface residual stresses in the intensively quenched and oil quenched spring in both the as-quenched and as-quenched and tempered condition. The same comparison is provided after shot peening in Fig.8c. Compressive residual stresses on the surface of the spring are desired since most of the work of the spring is done at the surface.

Figure 8a shows that the surface compressive stresses are typically tensile for the oil-quenched springs whereas the intensively quenched springs exhibit the desired surface compressive stresses. Which increase from -18 MPa at the very

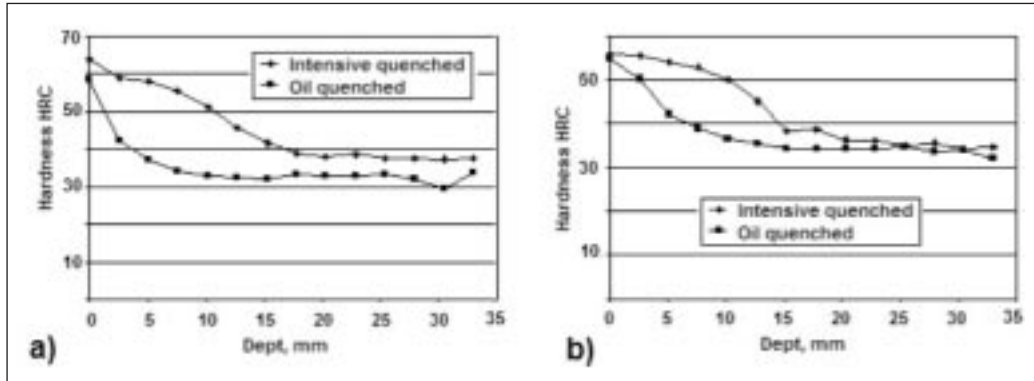


Fig. 7 – a) As-Quenched Hardness Distribution for Ø 73 mm 1547 Steel Cylinder. b) Tempered Hardness Distribution for Ø 73 mm 1547 Steel Cylinder.

Fig. 7 – a) Distribuzione della durezza in un cilindro di acciaio 1547 Ø 73 mm allo stato di tempra. b) Distribuzione della durezza in un cilindro di acciaio 1547 Ø 73 mm allo stato temprato e rinvenuto.

Test Parameter		Oil Quench	Intensive Quench
% Bainite	Surface Core	5-10% 15-20%	0% 2-5%
Microstructure		Tempered martensite and bainite	Tempered martensite with traces of bainite in the core
Grain Size		ASTM 8	ASTM 9

Table 4 – Metallurgical Analysis Results.

Tab. 4 – Risultanze dell'analisi metallografica.

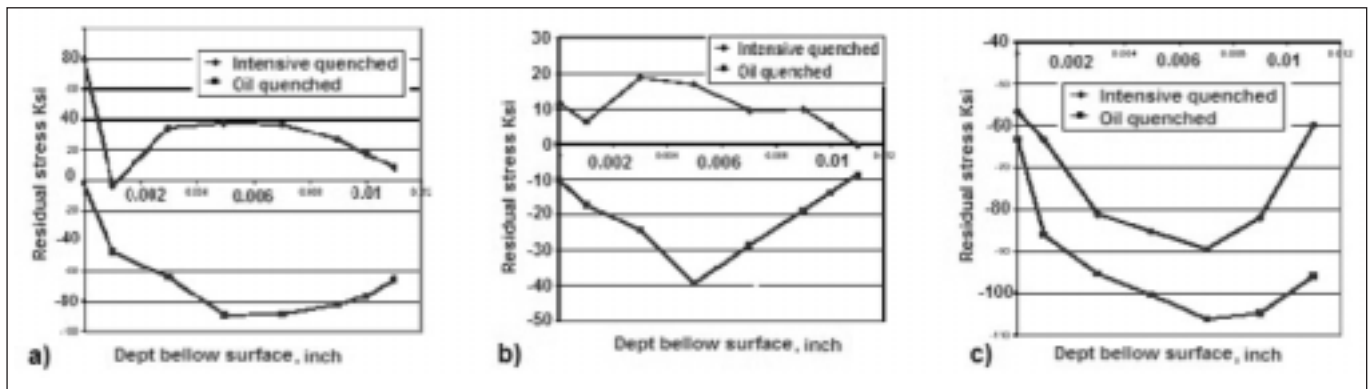


Fig. 8 – a) Surface residual stress for AISI 9259 coil spring in as-quenched condition. b) Surface residual stress for AISI 9259 coil spring in as-quenched and tempered condition. c) Surface residual stress for AISI 9259 coil spring after shot peening.

Fig. 8 – a) Tensioni residue superficiali in un coil di AISI 9259 allo stato di tempra. b) Tensioni residue superficiali in un coil di AISI 9259 allo stato temprato e rinvenuto. c) Tensioni residue superficiali in un coil di AISI 9259 dopo pallinatura.

Table 5 – Mechanical property comparison of 15B35H forks quenched in oil and by intensive quenching.

Property	Oil Quench	Intensive Quench	Improvement(%)
Yield Strength (MPa)	830-1050	1400	33.3
Tensile Strength (MPa)	950-1125	1500	33.3
Impact Strength 20°C (J)	30-60	100-130	66.7-116.7
Elongation (%)	12-18	15	---
Reduction in Area (%)	50-65	63	---

Tab. 5 – Confronto delle caratteristiche meccaniche di forcelle in 15B35H, temprate in olio o con processo IQ.

Table 6 – Comparison of lifetime improvement achievable with the use of intensive quenching relative to oil quenching.

Steel Part	Type of Steel	Lifetime Improvement %	Ref.
Truck half-axles	4340 (oil quench)1045 (intensive quench)	760	24
Shafts	81B40 (oil quench)1045 (intensive quench)	800	25
Punches	Shock-resisting S5	100	-
Punches	High-speed steel (equivalent to M2)	50-100	26
Dies	52100	50-100	27
Forklift forks	15B35H	20	-
Automotive coil springs	9259	30	-
Automotive leaf springs	5160	85	-
Pulverize coil springs	8660	300	-

Note: \*) Based on actual cycle test data

Tab. 6 – Confronto dell'aumento di vita ottenibile con processo IQ rispetto alla temprata in olio.

Table 7 – Thermal Fatigue Improvement of 2"x 2"x5" H-13, Aluminum Die Casting Test Block (Reference 13).

Number Thermal of Cycles	Maximum Crack Length, x100µm		Total crack Area, x106µm <sup>2</sup>	
	Oil	Intensive	Oil	Intensive
5,000	1.0	0	0	0
10,000	4.4	5.4	13.8	22.4
15,000	17.1	12.4	163.8	94.4

Tab. 7 – Aumento della resistenza alla fatica termica in un blocco 2"x 2"x 5", in alluminio H13 pressofuso.

surface to -613 MPa at a depth of 0.13 mm from the surface. (The lower values at the surface are due to the occurrence of slight decarburization.)

The surface stresses are still compressive (up to -276 MPa) after tempering for the intensively quenched spring as shown in Figure 8b. Although Figure 8c shows that shot peening provides surface compressive stresses in the oil quenched spring, the magnitude of these stresses is less than those obtained for the intensively quench spring by about 138 – 276 MPa when measured at a depth of 0.28 mm.

Similar results were obtained for AISI 5160H automotive leaf springs (76 mm wide, 16 mm thick leaves formed with 44 mm eyes at each end of 838 mm long). In this case the B10 fatigue life for the intensively quench leaves was about 45% greater than the oil quenched leaves [28].

Fatigue tests showed that, on average, the intensively quenched coil springs completed approximately 33% more cycles than the oil quenched springs. Weibull analysis showed that the B10 and B50 life was about 27% greater for the intensively quenched springs.

In another application, 15B35H forged steel forks (blade length 102 cm, back length 55 cm and cross sectional area 130 x 38 mm) for a forklift fork manufacturer were intensively quenched in a 6000 gallon batch furnace system [25]. Metallurgical analysis showed that the intensively quenched forks were through-hardened with a very fine martensitic microstructure. The mechanical property comparison provided in Table 5 shows that the intensively quenched forks exhibited approximately 40% greater tensile and yield strength and the impact strength was improved by 200-300%. Fatigue life, as measured in a standard test, improved by more than 25%.

Intensive quenching provides significant part service life

improvement due to improved mechanical properties and the presence of compressive surface stresses. Table 6 provides a summary of the improvement of the service life of the intensively quenched parts relative to oil quenching. Particularly noteworthy is the average improvements achievable using parts made of plain carbon steel which is 7.6-8.0 times longer that of the same configuration parts made of alloy steel and quenched in oil. This means that by using an intensive quenching process that better performing parts can be made with lower cost steels and a lower cost quenching process.

Intensive quenching of traditionally air-hardenable H-13 die-casting steel will provide greater resistance to heat checking (as measured by shorter average heat cycle crack length and less total crack area) resulting in longer die service life as shown in Table 7.

## 2. Reduction of Part Distortion

The effect of intensive quenching on hardness and distortion was studied using a set of 25.4 mm diameter x 254 mm AISI 1045 steel shafts with a keyway (6.4 x 6.4 mm) milled the entire length of the shaft [26]. These shafts were ground and polished to ± 0.025 mm. The shafts were heated in a salt bath furnace under one of two conditions. The first condition was to quench four shafts in a conventional oil with "normal" agitation at 26.7°C. Eight shafts were also quenched in a sealed quench furnace with a conventional oil at 65.6°C with "moderately" greater agitation than used for the salt bath heated/oil quenched shafts. The second condition was to intensively quench four shafts in water at 23.9°C.

As-quenched shaft distortion was determined by placing the shafts on a block with a certified flat granite surface. The amount (height) of "bowing" of the shaft was measured

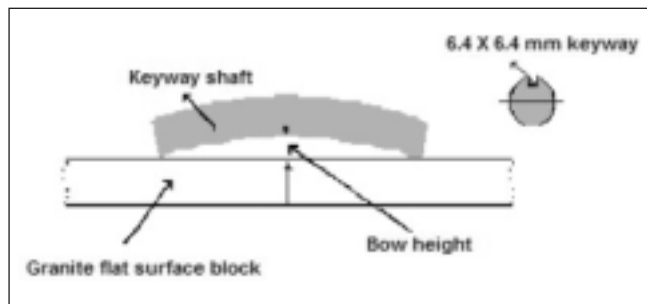


Fig. 9 – Measurement of keyway shaft distortion.

Fig. 9 – Misura della distorsione di un albero con intaglio.

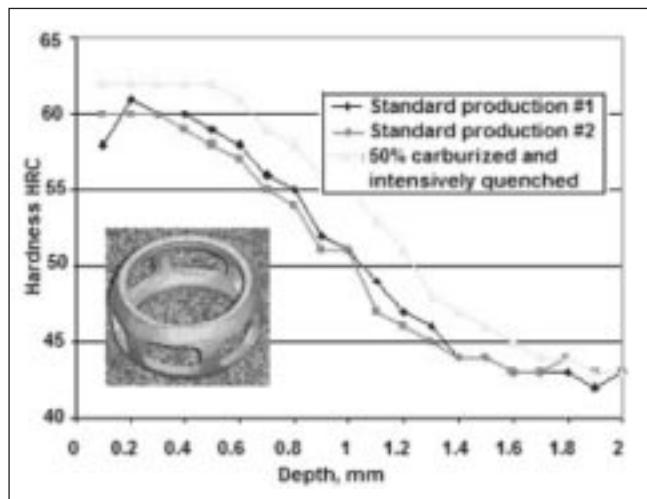


Fig. 10 – Hardness distribution throughout 8617 bearing cage with wall thickness of 4 mm and case depth of 1.2-1.5 mm. Detail of steel bearing cage.

Fig. 10 – Distribuzione della durezza attraverso una gabbia di supporto di acciaio 8617 con pareti dello spessore di 4 mm e profondità di 1.2-1,5 mm. Dettaglio della gabbia di supporto di acciaio.

using feeler gauges as shown in Fig. 9. The accuracy of these measurements was  $\pm 0.025$  mm.

The results of this study are summarized in Table 8. The data shows that the intensively quenched shafts exhibited the greatest surface and core hardness. Also, the intensively quenched shafts exhibited substantially less distortion than either form of oil quenching evaluated.

### 3. Intensive Quenching of Carburized Parts

The potential use of intensive quenching with carburized AISI 8617 steel bearing cages used for automotive CV joints [27]. The objective of the study was to determine if acceptable distortion at the desired hardness profile could be achieved by intensively quenching the bearing cages after a reduced carburizing cycle. A reduced-time carburizing cycle to yield 50% of the standard case depth followed austenitizing and intensive quenching was evaluated.

The resulting microhardness distribution of two standard production bearing cages and a 50% reduced-time/intensi-

vely quenched cage are summarized in Fig. 10 [27]. The surface hardness of the intensively quenched bearing cage was 2-5 HRC greater than shown for the standard production cages. At the HRC = 50 point, the intensively quenched, shallow-case hardened part exhibited a significantly better hardness profile while still exhibiting acceptable distortion [27].

In another study, the use of intensive quenching for AISI 8620 carburized universal crosses was evaluated [29]. Four sets of crosses were evaluated. Two were carburized and oil quenched following the thermal cycle. Two sets were carburized using 60% of the normal cycle (60% carburized) and another two sets were carburized for 50% of the normal cycle (50% carburized). The crosses were then reheated in a neutral salt bath furnace and intensively quenched in a 500 gallon system described in Reference [18]. The results of a thorough metallurgical evaluation showed [29]:

- No unacceptable distortion or cracks were observed.
- The case microstructure for both standard carburized and oil quenched and reduced carburization cycle/intensively quenched crosses consisted of fine tempered martensite with approximately 5% retained austenite with no non-martensitic products and no network carbides observed. The core microstructure was low-carbon martensite for the intensively quenched crosses while the standard oil quench core structure was a mixture of low-carbon martensite and bainite. The intensively quenched crosses exhibited a finer core martensitic structure than standard oil quenched crosses.
- The case depth was uniform throughout the intensively quenched surface of the cross.
- Both the 50% carburized and 60% carburized crosses exhibited a RC =50 at a greater case depth compared to standard carburized and oil quenched crosses by 10% and 32% respectively.
- The specified mean case depth of 1.5 mm was achieved with the intensively quenched 60% carburized crosses.
- The core hardness exceeded the required minimum.
- No intergranular oxidation was observed in intensively quenched crosses.

In some cases, intensive quenching provides a hardness profile that is sufficient to permit the complete elimination of a carburizing cycle. This was the shown for a 4137 Forged “Shoe” which was intensively quenched. Fig. 11 shows that after intensive quenching, the hardness distribution in the “shoe” (below the carburized case) shows that there is no need to carburize this part. Intensive quenching without carburization yields sufficient hardness depth with the same alloy. Table 9 provides a summary of the results of intensive quenching of various carburized steel parts obtained to date. These results have shown that typically carburization cycles can be reduced 40-50% relative to standard carburization cycles with conventional oil quenching.

### CONCLUSIONS

In summary, intensive 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

	Salt Bath Heated/ Cold Oil Quenched	Sealed Quench Furnace Heated/ Hot Oil Quenched	Sealed Quench Furnace Heated/ Intensively Quenched
HRC Surface	43.2	51.4	57.4
HRC Core	32.1	31.0	50.0
Distortion (mm)	0.20-0.36	0.25-0.51	0.08-0.12

Table 8 – Measurement of Shaft Hardness and Distortion (1045 Material,  $\varnothing$  25.4 mm Shaft with 6.4 mm X 6.4 mm Keyway).

Tab. 8 – Misura della durezza e della distorsione di un albero (lega 1045,  $\varnothing$  25.4 mm, intaglio 6.4 X 6.4 mm).



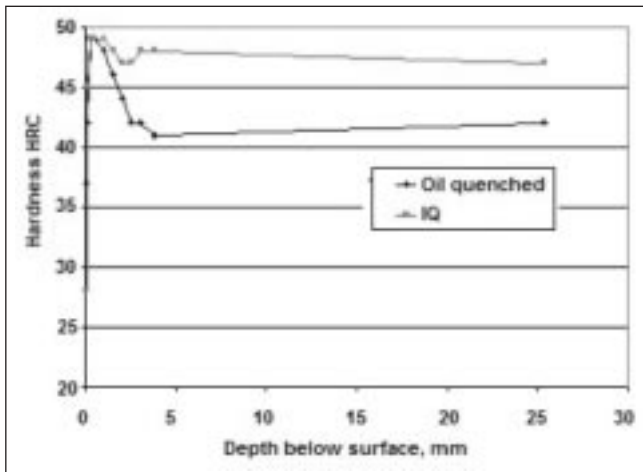


Fig. 11 – Hardness distribution throughout 4137 forged “Shoe” Cross section of 110x116 mm and case depth of 1.5-2.0 mm.

Fig. 11 – Distribuzione della durezza entro un forgiato di 4137 con sezione trasversale di 110x116 mm e profondità di 1.5-2.0 mm.

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	Comp. elimin.

Table 9 – Carburization cycle reduction for different parts.

Tab. 9 – Riduzione dei tempi del ciclo di cementazione per diverse tipologie di pezzi.

steel types. Computer process modelling may be used to facilitate the design of intensive quenching processes. Some of the 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 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; and better integration of the heat-treating process into the production process flow.

It is anticipated that as intensive quench processing becomes even better understood, additional advantages will be identified.

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A B S T R A C T

**MIGLIORAMENTO NELLA PRODUZIONE  
DI PARTI AUTOMOBILISTICHE  
MEDIANTE IL PROCESSO DI "INTENSIVE QUENCH"**

**Parole chiave: trattamenti termici, processi**

*Il processo di "Intensive Quench - IQ" offre enormi vantag-  
gi potenziali nel campo automobilistico sia per la qualità  
dei componenti che per i progettisti di processi.  
In particolare fra questi vantaggi vi sono: l'eliminazione di  
mezzi refrigeranti per tempra pericolosi per l'ambiente (es.*

*oli minerali e polimeri), l'eliminazione dei rischi d'incendio  
associati all'uso di oli derivati dal petrolio, la riduzione o  
l'eliminazione del rischio di cricche, la possibilità di utiliz-  
zare acciai meno costosi nella progettazione di componenti,  
un consistente miglioramento di proprietà quali la resisten-  
za alla fatica e all'urto e la riduzione o eliminazione dei  
tempi di cementazione.*

*In questo studio, viene fornita una descrizione del processo  
di "Intensive Quench". Inoltre sono riportati diversi casi  
pratici che illustrano l'impiego di questo processo in sostit-  
uzione del processo della tempra convenzionale.*