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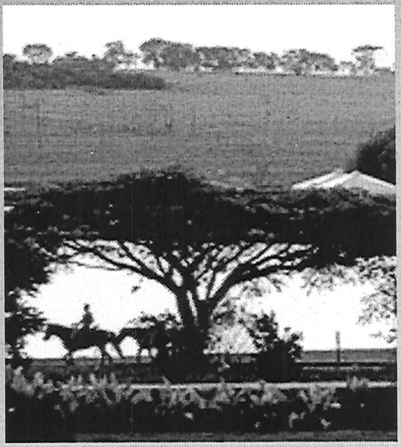

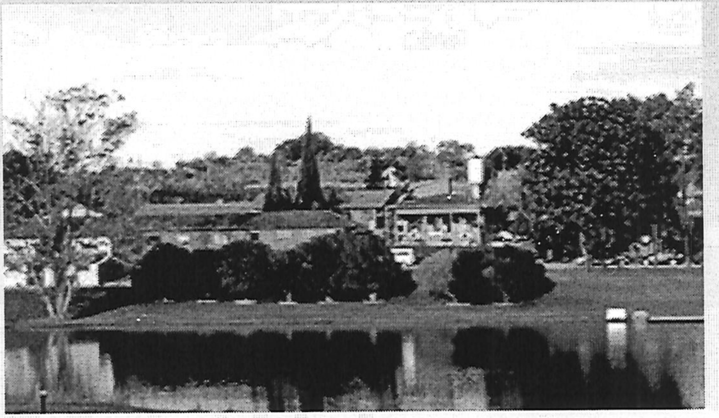

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Immersion Time Quenching System (ITQS) Technology to Facilitate Aqueous-Polymer Quenchant Replacement of Quench Oils.

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ABSTRACT

Due to inherent biodegradability, toxicity and fire safety issues with quench oils, there has been a continuing interest in their replacement by aqueous polymer solutions. However, direct replacement of quench oils by aqueous polymer without appropriate quench system modifications is ill-advised. One method that is recently developed by S. W. Han of Sam Won Industrial Company in Korea is ITQS technology which is currently available from Micro-quimica and G. E. Totten Associates, LLC. In this paper, results of the use of ITQS in conjunction with aqueous polymer quenchants to replace quench oils will be discussed in detail.

Key-words: replacement of quench oil, agitation, ITQS.

INTRODUCTION

Until recently, oil has traditionally been the most commonly used quenchant media, particulary for crack-sensitive steels (1). However this situation is rapidly changing and in view of the improved process flexibility and more uniform properties coupled with their fire safely, environmental and toxicological advantages, polymer quenchants are being used increasingly as replacements for oil. Perhaps the most significant reason for the increased use of polymer quenchants is there relatively more uniform heat removal during quenching causing reduced thermal gradients resulting in a lower propensity for distortion and cracking than attainable with oil (1,2).

A steel part encounters three distinct mechanistic cooling regions upon immersion into a vaporizable liquid medium. The cooling mechanisms of oil and polymer quenchants is compared in Figure 1A and 1B [2]. When hot metal is first immersed in oil, the hot metal is surrounded by a "vapor blanket" resulting in a slow, film boiling mechanism (A phase) When the temperature drops to the Leidenfrost temperature, the vapor blanket ruptures and cooling occurs by a relatively fast nucleate boiling mechanism (B phase). When the surface temperature is less than the boiling point of the fluid, cooling occurs by convection and conduction (C phase). When viewing Figure 1, it is important to note that it is likely that all three all three cooling mechanisms occur on the metal surfaces creating significant thermal gradients during quenching. [2] The presence of these thermal gradients is often sufficient to produce unacceptable distortion or even cracking.

Polymer quenchants operate by a fundamentally different cooling mechanism as illustrated in Figure 1B. Upon initial immersion into the aqueous polymer quenching media, a slow-cooling polymer encapsulated vapor blanket surrounds the hot metal part (A phase). At the Leidenfrost temperature, the polymer film suddenly ruptures resulting in a faster-cooling and relatively uniform nucleate boiling process (B phase). When the surface temperature is less than the boiling point of the water, cooling occurs by convection and conduction (C phase). It is important to note that aqueous polymer quenching produces substantially reduced thermal gradients resulting in a lower propensity for distortion and cracking than attainable with oil (1).

Three of the most critical quenching process variables that affect the performance of a polymer quenchant are: concentration, bath temperature and agitation (1,2-5).

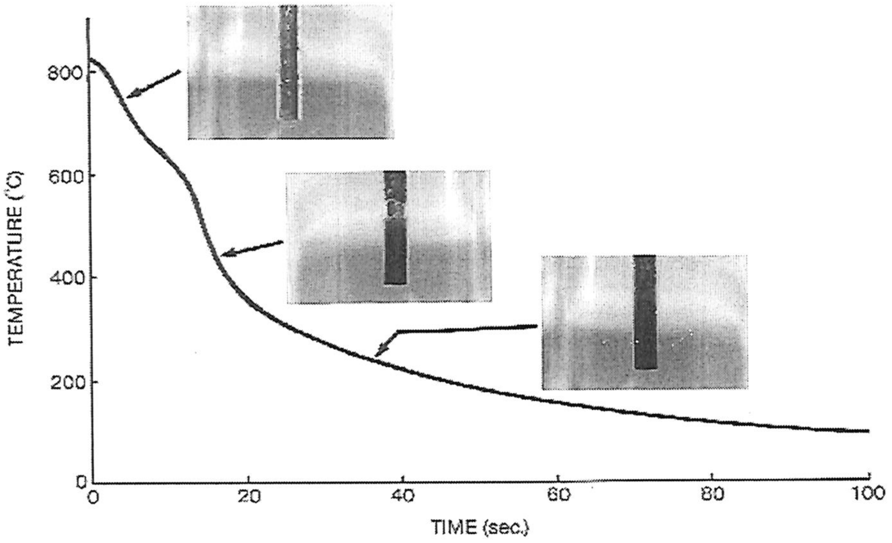

Figure 1 A. - Typical cooling mechanism obtained with a quenching oil.

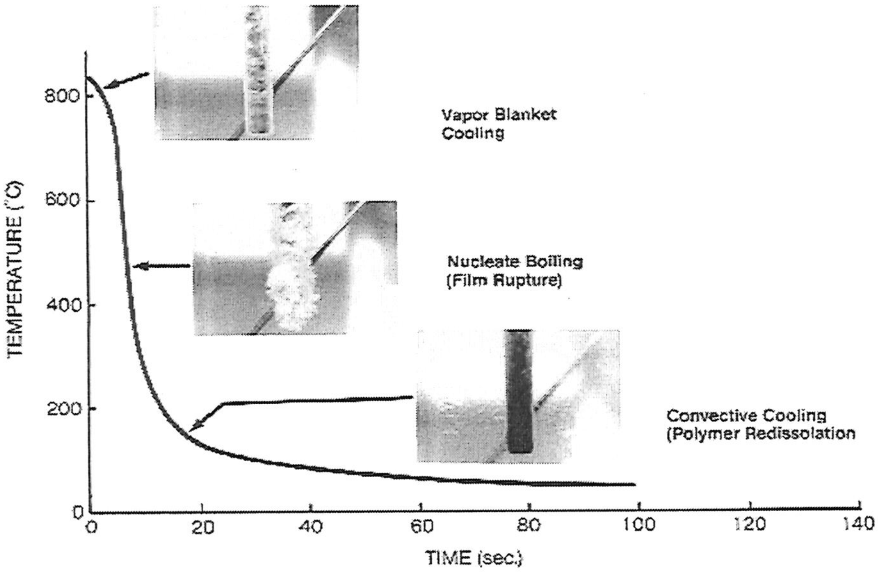

Figure 1 B. Typical cooling mechanism obtained with an aqueous polymer quenchant.

Stability, uniformity and thickness of the polymer film surrounding the part in this region are dependent on the specific polymer and its concentration. Cooling rates decrease with increasing film thickness (increasing concentration). Increasing agitation rates will cause mechanical rupture of this barrier, thus accelerating cooling rates in this region (6). Subsequent stages can their cooling rate increased as well, facilitating nucleate boiling and bulk heat transfer by moving the hot liquid from the heat transfer surface.

When used with crack-sensitive steels, it may be necessary to facilitate even slower cooling in the martensitic transformation temperature (Ms) region in order to optimally reduce both thermal and transformational stresses during quenching. For polymer quenchants, this can be accomplished by increasing the concentration of the polymer quenchant and/or by increasing the quenchant bath temperature. Alternatively, quench severity can be reduced by decreasing the agitation rate. Of these variables, only agitation rate can be controlled during the time cycle of the quenchant process.

In order to obtain both optimal hardness and reduced cracking and distortion, it would be desirable to obtain fast A and B- phase cooling and slow C-phase cooling using agitation rate control. This would be accomplished by maximizing the agitation rate during the initial stages of the quench followed by minimizing the agitation rate as the Ms temperature is approached.

Although time-quenching is a well-known and traditional heat treating process, the ability to continuously control agitation during the quench process is a relatively more recent development (7). Recently, commercial examples of continuous agitation control using an "immersion time quenching system" - ITQS have been reported for both batch and continuous heat treating systems (6-9). In this paper, the use of batch and continuous ITQS system in the production of some parts are discussed.

DISCUSSION

Immersion Time Quench System (ITQS)

Both batch and continuous immersion time quench system are in use today (7,10). Both systems permit the continuous variation of agitation throughout the quenching process. Agitation is provide for the batch ITQS process as shown in Figure 2 with two continuously variable impeller stirrers encased in directional draft-tubes. (Pump agitation can also be utilized).The linear flow rates for the batch systems in commercial use are calibrated at various motor frequencies using Mead velocimeter. Computer controls permit reproducible application of agitation control.

Continuous ITQS is shown in Figure4. This system has an upper conveyor that is used during film boiling and during nucleate boiling processes. In this step the cooling rates are controlled on the upper conveyor by both, agitation and conveyor speed (which controls the quench time). The lower conveyor is used for convective and conductive cooling.

An impeller stirrer is typically placed in the exit region of the conveyor to facilitate fluid movement which will assist in removal of any undissolved polymer on the part, minimizing drag-out.

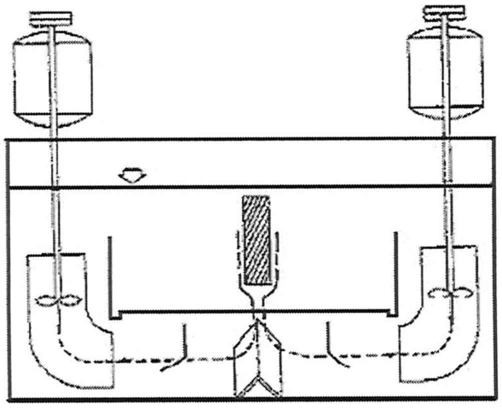

Figure 2-Illustration of a batch immersion time quench system.

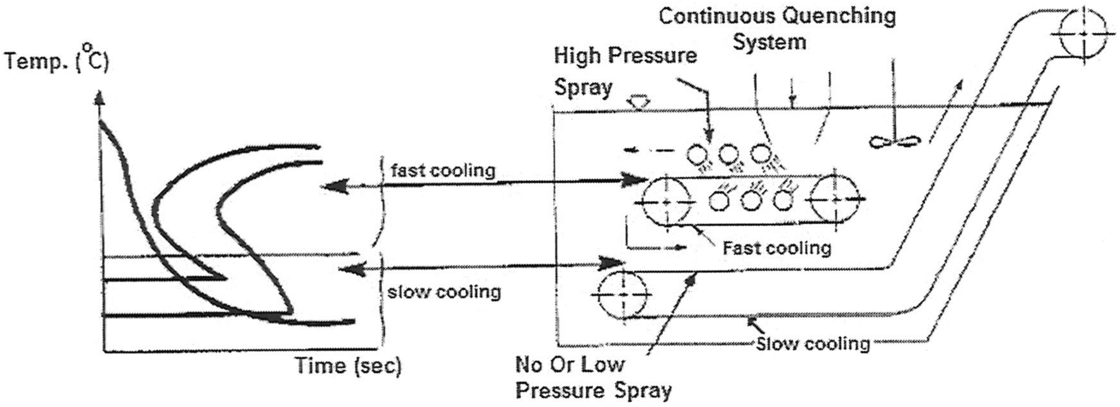

Figure 3- Illustration of a continuous immersion time quench system

Critical Cooling Rate Determination

Accurate determination of the cooling time for the initial cooling stage (AR I) is critical to assure the success of the ITQS quenching process. This should be contrasted with the trial and error methods traditionally employed with "time quenching", the success of which was operator dependent and often difficult to reproduce.

Various methods may be used to calculate the required agitation rates for AR I and AR II, the second stage of the ITQS process. Preferably, all of these methods will employ cooling curve analysis to model the quench severity achieved with a particular set of agitation conditions. Two methods that have been successfully used to ITQS design:

1) Grossman Quench Severity Factor (H-Factor) Correlation
2) Calculation of AR I from CCT Diagrams

In the first method the required H-factor is calculated to obtain the desired amount of through-hardening (7). H-factor can be also obtained experimentally from cooling curves analysis using an instrumented probe with the desired cross section size (10). Once gotten the H-factor, Table1 can be consulted to determine the required amount of time for AR 1. Experience has shown that 1.5m/s is often a suitable flow rate to AR I, there the data in Table 1 was generated using this flow rate.

Table 1

AR I Cooling Time Correlation With Cross- Section Size (Assuming Flow Rate of 1.5 m/s)				
	AR I Cooling Times (s) H-Factor (in^{1})			
(mm)	0.8	1.0	1.5	2.0
15	5 +/− 1	4 +/− 1	--	--
20	9 +/− 2	7 +/− 1	--	--
25	14 +/− 3	10 +/− 2	8 +/− 2	--
30	17 +/− 3	13 +/− 2	10 +/− 2	--
35	--	16 +/− 3	12 +/− 3	10 +/− 3
40	--	18 +/− 3	15 +/− 3	12 +/− 3
45	--	22 +/− 4	19 +/− 4	17 +/− 4
50	--	26 +/− 5	23 +/− 5	20 +/− 5

In the second method is used the CCT diagram for the steel alloy of interest to calculate CR, the critical cooling rate (the rate at the nose of the pearlite transformation curve) and the temperature Where this occurs (T_{CR}) required to avoid undesirable transformation products. In addition to CR, T_{CR} and T_A may be used along with the following equation to calculate AR 1:

$$AR\ I = (T_A - T_{CR})/\ CR$$

Once the CR is known, it is then necessary to obtain the appropriate cooling curves with a probe with the cross-section and quench media of interest. The maximum cooling rate must be equal to, or faster than, the CR determined from the CCT curve. Also, the temperature where this occurs must be sufficient to avoid the formation of undesirable phase transformation products.

Case Histories

Batch ITQS Examples

AISI H13 Tool Steel Die Construction and Use

Engine valves are produced by a forging process using the die shown in Figure 4 This 1.7 kg. die is constructed from an AISI H13 tool steel of 70 mm (dia) x 60 mm (height) as shown in Figure 5.

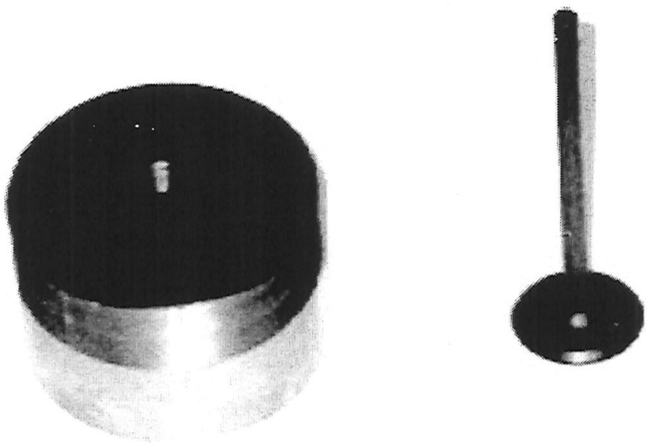

Figure 4 - Illustration of the automotive valve and forging die.

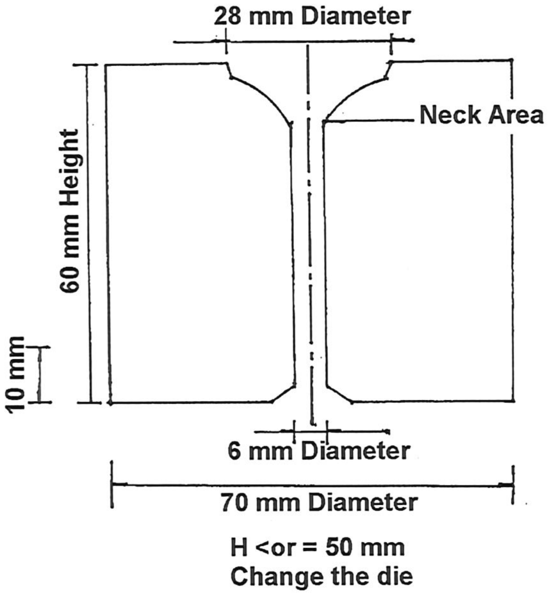

Figure 5 - Dimensions of the AISI H13 forging die.

Currently, the die is austenitized at 1025°C (1877°F) in a neutral atmosphere (see Figure 4) then time- quenched in a conventional mineral oil for 180 s followed by air cooling. After quenching, the die is tempered at 550°C (1022°F) to a hardness of HRC of 53-55. A reduction of hole diameter of 0.05-0.07 mm occurs which is machined to the desired diameter after heat treatment.

The problem is that after forging approximately 1000 valves, the neck of the die is badly damaged (wrinkling) and must be repaired. The die is repaired by removal of 0.6-0.7 mm of the die-neck and die then is reused. Currently, the die can only be reused 15-16 times before it must be discarded. With 5 hot-forging presses operating 24 hours/day this is a very costly and wasteful process.

Mineral oil was replaced by an aqueous PAG polymer quenchant (concentration of 23.5%) at a bath temperature of 33 C.

The results obtained from this trial showed that no cracking was observed with either oil or the aqueous PAG polymer quenchant. Although, as discussed above, the oil-quenched dies had undergone a 0.05-0.07 mm inner-hole diameter reduction, no reduction of the inner-hole diameter was observed for the polymer-quenched dies. The HRC hardness obtained for the aqueous polymer quenchant was more uniform at 55-56 versus 53-55 obtained for the quench oil. Microstructure for the polymer-quenched die is much finer and the surface condition is better than obtained for the oil-quenched die.

The data obtained for this trial shows that although "wrinkles" were observed on the oil-quenched dies after only 1000 forgings, no wrinkles were observed on the polymer-quenched dies. In one case a scratch was observed in the neck area due to relatively high hardness.

With the oil-quenched dies, the overall height of the die decreased by approximately 10 mm after approximately 15 remachinings (0.6-0.7 mm/machining cycle). Therefore the die had to be discarded after the production of approximately 15,000 valves. But with the polymer-quenched dies, only approximately 0.1 mm of the die had to be removed per machining cycle permitting the die to be reused more than 100 times for the forging of 150,000 valves. This represents at least a 10-fold improvement and a substantial process cost savings (11).

Rolling Bearing Production By ITQS Procedure

A polymer quenchant has been used to successfully replace a brine quench for the production of carburized (AISI P2) roller bearings with the following dimensions: 44 mm OD, 35 mm ID, and 35 mm long. Each bearing weighed 454 grams. The total load was 130 kg which includes the weight of the 70 kg fixture.

Traditionally, the bearings were pack-carburized in a compound of charcoal and barium carbonate at 950-980°C for 24 hours in a pit furnace. The case depth was 2.5 mm. The load was reheated in a 5-10% sodium cyanide salt bath at 830°C for 25 minutes at which time they were brine (3-4% aqueous sodium chloride solution) quenched at ambient temperature.

For the batch ITQS procedure, the same carburizing process was used. However, the reheating process was conducted at 900°C for 60 minutes in a neutral benzene/methanol (20/1.5 liters respectively) atmosphere. The load was then quenched in an 8% aqueous solution of PAG at 27-30°C for 10 seconds at 1.2 m/s followed by a slower quenching step at 0.2 m/s. The quench tank contained a total of 4700 liters of quenchant which was agitated by a single 540 mm impeller stirrer driven by a 10 hp motor (12).

A comparison of the two metallurgical results in Table 2 showed that quenching in the ITQS system will: 1.) provide a substantial reduction in gear distortion, 2.) reduce grinding depth and finishing time, 3.) eliminate sodium cyanide effluent problem and 4.) reduce heat treating cost, including energy, processing chemicals, water contamination, etc (12).

Table 2

Comparison of the Brine and Batch ITQS Polymer Quench Process for Roller Bearing Production

Result	Brine Quench	Batch ITQS Polymer Quench
Hardness (Rc)	>60	>60
Case Depth (mm)	2.5	2.5
Distortion (mm)	0.25	0.067
Grinding Depth (mm)	0.5	0.2

Continuous ITQS Examples

AISI 13B37 Track Links

Track links (5.8 kg, 60 mm dia.x220mm long) manufactured from 13B37 steel were inductively heated (1250-1280 C and forged using a 3,000 ton press and trimming with a 350 ton press. The track links were quenched directly into a 11-13% aqueous solution of a PAG quenchant at a bath temperature of 35-40 C and then tempered to HRC 38-41. The AR I time was 10-15 seconds. When quenched, the track links were approximately 850 C in the thin cross-section and 950 C in the thick cross-section.

The ITQS was a single-conveyor system equipped with spray agitation with a pump capacity of 75HP. A schematic for a system used for this work is shown is Figure 6. The AR I and AR II cooling rates are controlled by the spray pressure and conveyor speed.

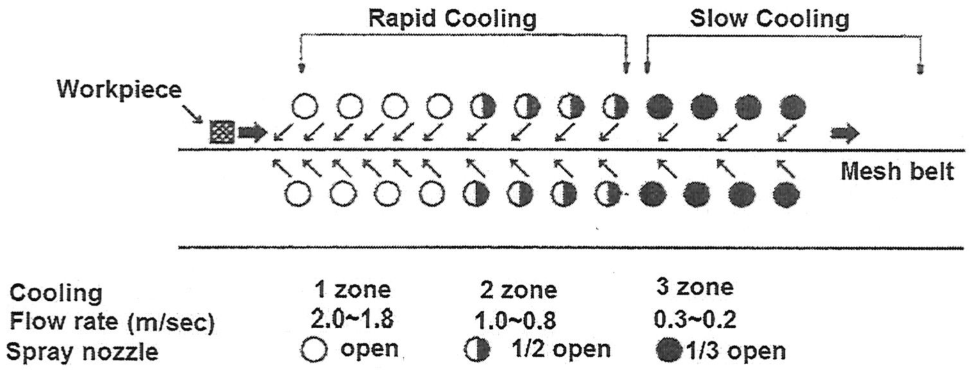

Figure 6- Single conveyor ITQS used for track link production

The results of this work showed that proper design of the ITQS and tight control of AR I were vital to reduce quench cracking and to obtain the desired quench properties. Additional significant factors were: control of the quenchant temperature, AR I holding time and periodic quenchant maintenance (13).

AISI 1043 and 1045 Front Hubs

Front hubs, Figure 7, manufactured from AISI 1043 (2.6 kg) and AISI 1045 (2.3 kg) were manufactured by direct forge quenching following the production cycles summarized in Table 3. The parts were inductively heated to 1200 C and then quenched into an aqueous PAG quenchant solution and tempered. A dual conveyor continuous ITQS similar to Figure 3 was used. Fast cooling (AR I) occurred on upper conveyor and slow cooling occurred on the lower conveyor. ITQS was not used for any of the oil quenching samples. Results confirm the best quench performance of the ITQS system, promoting more uniform and higher hardness than oil quenching.

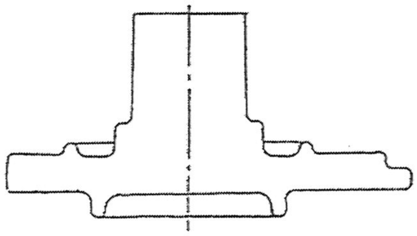

Figure 7- Front hubs used for quenching trials

Table 3

Heat Treatment Condition for Front Hub Production

Material and Quenchant	AISI 1043 Polymer Quench	AISI 1043 Oil Quench	AISI 1045 Polymer Quench
Forging Press	2500 ton	2500 ton	1600 ton
Trimming Press	150 ton	150 ton	250 ton
Holding Time	15-17 sec	-	5-7 sec.
Quenching Temp.	Shaft 880-900 C	850 C	Flange 950-990 C Shaft 880-900 C
Tempering Temperature	640 C (140 min)	580 C (140 min)	640 C (140 min)
Concentration	15-17%	-	16-18%
Quenchant Temp.	40±5 C	70 C	40±5 C
Rapid Cooling Time	12±3 sec.	-	25±3 sec.

CONCLUSIONS

The results reported here show that continuous control of quench severity throughout the quench cycle by agitation rate control can be used to produce parts from various heat treating practices with substantially improved hardness uniformity while at the same time achieving reduction in cracking and distortion relative to oil. Agitation rate process control is achievable with either batch or continuous quenching production cycles. Through the use of this technology, the replacement of oil, and in some cases brine, quenchants with aqueous polymers is facilitated. These conversions have produced cleaner processes with improved safety and substantially reduced production costs. Selection of the appropriate aqueous polymer quenchant, heat treating process and the use of ITQS technology permits the use of polymer quenchants for crack-sensitive steel production.

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