Intensive Quenching of Tools in Water Salt Solutions

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Abstract: - In the paper intensive quenching, named IQ-2 process, is widely discussed. It is shown that this process can be fulfilled by use of water salt solutions of optimal concentration (CaCl\textsubscript{2}) with additives of Ca(OH)\textsubscript{2} and creation of protective anticorrosion layers on the surface of steel parts during their heating. The proposed technology can compete with the expensive technologies which use furnaces with the protective atmosphere and automated tanks filled with the intensively agitated anticorrosion salt solutions. The technology is less costly and provide in many cases the same end result in terms of increasing service life of tools. It is shown that intensive quenching of tools by water salt solutions of optimal concentration increases service life of tools by 1.5 - 2 times as compared with the oil quenching.

Key - Words: - Intensive quenching, Salt solution, Optimal concentration, Prevention from corrosion, Tools, Service life

1 Introduction

Water salt solutions of optimal concentration, especially those which prevent corrosion, are widely used for quenching of tools. As known, water salts solutions of chlorides are used as a quenchant to intensify cooling rate and achieve high mechanical properties of materials [1, 2]. In Ukraine, as a quenchant is widely used 8 -12% water solution of CaCl\textsubscript{2} at 20 - 40\degree C. To prevent corrosion, a small amount of Ca(OH)\textsubscript{2} is added to the solution to keep pH within 8 -12 [1]. Even with the additives of Ca(OH)\textsubscript{2}, corrosion cannot be completely eliminated. That is why, it is proposed a method to cover tools before quenching by nano-layers of Cr\textsubscript{2}O\textsubscript{3}, Al\textsubscript{2}O\textsubscript{3} [3] which prevent decarburization of tools during heating and corrosion after quenching of tools in water salt solutions of CaCl\textsubscript{2}. To interrupt intensive quenching at the end of nucleate boiling process, a noise control system was used [4]. This system measures duration of nucleate boiling process very accurately [4]. After interruption of intensive quenching and equalizing of temperature to provide self-tempering of tools, they were intensively washed. Washing and the second step of quenching are combined to provide superstrengthening of a material [5, 6, 7]. A detail description of procedures for two step quenching of tools in water salt solutions of CaCl\textsubscript{2} is provided in this paper. The technology can be easily realized without use of expensive equipment to produce intensive quenching and complicated calculations to develop recipes. Instead of that, end results are the same in terms of mechanical properties and quality of the surface and increase service life of tools. It is better to use water salt solutions of optimal concentration which prevent corrosion.
completely [8]. However in many cases these solutions cannot provide appropriate critical heat flux density (q_{cr1}) that is why they should be intensively agitated to get high q_{cr1}.

2 What is optimal concentration and method of quenching?

There is an optimal concentration of electrolytes [5, 9] when the first critical heat flux density has an optimal value which is maximal (see Fig. 1). We need this maximal value to prevent film boiling during quenching. When film boiling is absent, heat transfer coefficients during immersion of tools into cold water salt solutions reach 200,000 W/m²K and higher since intensive process of nucleate boiling takes place from the very beginning of quenching. It means that surface temperature drops immediately almost to saturation temperature T_S and during nucleate boiling maintains almost at the same level [10]. The duration of this process can be calculated by equation [11, 12]:

\[ \tau_{nb} = \left[ \Omega + b \ln \left( \frac{\vartheta_1}{\vartheta_{II}} \right) \right] \frac{K}{a}, \]  

where \( \tau_{nb} \) is duration of nucleate boiling (NB) process; \( \Omega \) and b are constants; \( \vartheta_1 = T_I - T_S \); \( \vartheta_{II} = T_{II} - T_S \); \( T_I \) is wall temperature at the beginning of boiling;

\( T_{II} \) is wall temperature at the end of nucleate boiling; \( T_S \) is saturation temperature; \( K \) is Kondratjev form factor; \( a \) is thermal diffusivity.

This equation was used to calculate duration of nucleate boiling process and speed of conveyors. The speed of conveyors should provide interruption of intensive quenching write at the end of boiling process. Then steel parts are delivered after temperature equalizing to the washing and the second step of quenching. The principal scheme of the furnace with the conveyor is shown in Fig. 2. It should be noted that during calculation of speed of

\[ W = \frac{aL}{\left[ \Omega + b \ln \left( \frac{\vartheta_1}{\vartheta_{II}} \right) \right] K} \]

\( q_{cr1}, \) MW/m²

![Fig.1 First critical heat flux density q_{cr1} versus the concentration of NaCl and LiCl in water [5]](image)

The optimal concentration of water salt solutions provides maximum critical heat flux density and maximal effective heat transfer coefficients during nucleate boiling and effectively eliminates film boiling [14]. Ref. [5] present average (effective) values of heat transfer coefficients for water and water salt solutions.

![Fig. 2 The principal scheme of the furnace with the conveyor](image)
Fig. 3 The second version of laboratory equipment which includes personal computer and small acoustical system [4]

Fig. 4 Core Cooling rate and noise intensity in mV during quenching of cylindrical 10 × 50 mm specimen (AISI 304 steel) in 12% water CaCl$_2$ solution at 20°C (frequencies 2 - 3 kHz)

Fig. 5 Core cooling rate and noise intensity in mV during quenching of cylindrical 10 × 50 mm specimen (AISI 304 steel) in 8% water CaCl$_2$ solution at 20°C (frequencies 2 - 3 kHz)

As we can see from Fig. 4, Fig. 5, and Fig. 6, in all three experiments film boiling was absent. Duration of transient nucleate boiling was almost 3 - 4 seconds which agrees with results presented in Table 1. It means that water salt solution (NaCl, Na$_2$CO$_3$, CaCl$_2$) of optimal concentration eliminate film boiling during quenching.

Fig. 6 Core cooling rate of cylindrical 10 × 50 mm specimen made of AISI 304 steel and noise intensity during quenching in 6% water Na$_2$CO$_3$ solution at 20°C (1 are frequencies 100 - 1000 Hz; 2 are frequencies 1.0 - 2.0 kHz)

Fig. 7 Temperature, core cooling rate of AISI 1030 steel (cube 100×100×100 mm) and noise effect during quenching in 12% water NaCl solution at 20°C
Fig. 8  Temperature and noise effect during quenching of cylinder (50×100 mm) in 12% water NaCl solution at 20°C versus time: 1 is temperature at the core; 2 is temperature 5 mm below surface.

All data presented in Fig. 4 - Fig. 8 which were measured by noise control system (see Fig. 4) coincide very well with the data calculated by Eq. (1).

Table 1  Comparison of the measured time of the nucleate boiling process with the calculated data during quenching of pins in 30% water salt solution of CaCl₂ [1,2, 5]

<table>
<thead>
<tr>
<th>Diameter of pin in mm</th>
<th>Steel</th>
<th>Measured time of nucleate boiling in sec</th>
<th>Calculation by Eq. (1), sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>AISI E9310</td>
<td>4.3</td>
<td>4.0</td>
</tr>
<tr>
<td>12</td>
<td>SAE 4130</td>
<td>6.2</td>
<td>6.0</td>
</tr>
<tr>
<td>20</td>
<td>SAE 4130</td>
<td>15.0</td>
<td>15.0</td>
</tr>
<tr>
<td>24</td>
<td>AISI 5140</td>
<td>20.9</td>
<td>21</td>
</tr>
<tr>
<td>27</td>
<td>AISI 5136</td>
<td>28.3</td>
<td>28.0</td>
</tr>
<tr>
<td>30</td>
<td>SAE 4130</td>
<td>32.8</td>
<td>32</td>
</tr>
</tbody>
</table>

Table 2  Results of testing punches on automatic line "National - 164" with performance of 175 strikes per minute[5]

<table>
<thead>
<tr>
<th>Number of strikes until the wearing of punches</th>
<th>Increase, n times</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>IQ in water solution of CaCl₂</td>
</tr>
<tr>
<td>6460</td>
<td>15600</td>
</tr>
<tr>
<td>6670</td>
<td>16500</td>
</tr>
<tr>
<td>4000</td>
<td>12075</td>
</tr>
<tr>
<td>2890</td>
<td>10500</td>
</tr>
</tbody>
</table>

3  Developments in preventing decarburization and corrosion

Authors [3, 13] (National Academy of Sciences of Ukraine, Kyiv) have developed special metallo-organic chemical compositions containing alloying elements such as chromium (Cr), aluminum (Al) and others which during heating transform into a vapor. This vapor creates nano-layer on the surface of steel parts consisting of chromium oxides Cr₂O₃ or aluminum oxides Al₂O₃ which prevent decarburization during heating and corrosion after quenching in water salt solutions of chlorides (see Table 3)

Table 3  Depth of oxidation of different steels depending on temperature and soak time, and existing of protective nano-layer Cr₂O₃ [3, 13]

<table>
<thead>
<tr>
<th>Steel,</th>
<th>T₀, °C</th>
<th>Soak time, sec</th>
<th>No layer</th>
<th>Cr₂O₃ layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1045</td>
<td>850</td>
<td>30</td>
<td>0.02</td>
<td>0.005</td>
</tr>
<tr>
<td>50XФI</td>
<td>850</td>
<td>60</td>
<td>0.01</td>
<td>Absent</td>
</tr>
<tr>
<td>4X13</td>
<td>1050</td>
<td>60</td>
<td>0.02</td>
<td>0.003</td>
</tr>
<tr>
<td>ХВГ</td>
<td>830</td>
<td>40</td>
<td>0.02</td>
<td>Absent</td>
</tr>
<tr>
<td>Cast iron</td>
<td>960</td>
<td>600</td>
<td>0.2</td>
<td>0.03</td>
</tr>
</tbody>
</table>
The optimal interval of temperatures for nano-layer formation of \( \text{Cr}_2\text{O}_3 \) is 600\(^\circ\)C - 950\(^\circ\)C with concentration of 5 - 200 g/m\(^3\) for organometallic containing chromium and 750\(^\circ\)C - 1000\(^\circ\)C with concentration 2.5 - 15 g/m\(^3\) for organometallic containing aluminum which creates \( \text{Al}_2\text{O}_3 \).

Implementation of these developments into industry results in the next benefits:
- A sharp decrease in the depth of the oxidized surface layer;
- A sharp decrease in the thickness of decarburization;
- Reduction of loss of alloying components (W, Mo, V, Ti, Cr, Ni, etc);
- Saving the geometry and dimensional accuracy of parts;
- Saving of natural gas up to 40%;
- Increasing the service life of electric heaters furnaces at approximately 1.5 times.

Authors have published several technical papers and applied their method to prevent decarburization and corrosion in 10 (ten) big Co of Ukraine and other countries [3]. The organometallic compounds are available for selling.

The first work which discussed application of noise control system for quenching steel parts in water salt solutions was published in 1990 [15]. At present time steel parts are intensively quenched in water and water salts solutions which prevent corrosion [16].

### 4 Discussion

Water salt solutions as the quenchants are widely used in Ukraine, Russia, China and others countries. They can be used for intensive quenching to improve significantly mechanical properties of steels and eliminate oil as a quenchant. Water salt solutions of chlorides have high critical heat flux densities which completely eliminate film boiling during quenching. As a result, distortion decreases, mechanical properties increases, the environment improves. Disadvantage of chlorides is corrosion. Combining intensive quenching in chlorides with the protective \( \text{Cr}_2\text{O}_3 \) or \( \text{Al}_2\text{O}_3 \) layers, it will be possible to make next step in the heat treating industry. We can start international cooperation between countries which are using already water salt solutions as a quenchant. Especially promising are water salt solutions of \( \text{CaCl}_2 \) which can be used for steel superstrengthening effect obtaining [17].

### 5 Summary

1. Two-step quenching in cold water salt solutions of optimal concentration (8-12\%) of \( \text{CaCl}_2 \) is discussed which prevents film boiling during quenching of steel parts.
2. The duration of the first step of quenching is measured by noise control system or calculated by generalized equation.
3. After interruption of quenching and equalizing the temperature, the steel parts are intensively washed and further quenched to room temperature simultaneously.
4. Two-step quenching in cold water salt solutions of optimal concentration (8-12\%) of \( \text{CaCl}_2 \) is intensive quenching since heat transfer coefficient at the beginning of cooling is equal to 200 kW/m\(^2\)K.
5. It is shown that intensive quenching in water salt solutions increases service life of tools by 1.5 - 2 times.
6. To prevent corrosion after quenching a small amount of \( \text{Ca(OH)}_2 \) is added to solution to maintain pH at the level of 8 - 12.
7. To prevent oxidation and corrosion after quenching completely steel parts are heated in special atmosphere which creates nano-protective layer of \( \text{Cr}_2\text{O}_3 \) or \( \text{Al}_2\text{O}_3 \) on their surface.
8. The proposed technology can compete with the existing IQ-2 process where expensive furnaces with the protective atmosphere are used and automated tanks with anticorrosion intensively agitated salt solutions are combined with the furnace.
9. The technology can be used for quenching of tools by different companies which are making tools for himself and need technology to be less costly.

References: