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Influence of Quenching On-line on Properties of X70 Steel for Sour Service Seamless Pipe

Ling Zhongqiu¹, Fang Jian¹, Zhou Yong¹, Yuan Zexi²,*

¹Hengyang Hualing Steel Tube(Group) Co., Ltd., Hengyang, 421001, P. R. China
²School of Materials and Metallurgy, Wuhan University of Science and Technology, Wuhan, 430081, P. R. China
*Corresponding author, email: yuanzexi@sina.com

Abstract

It is always hard to resolve the low strength problem of grade X70 sour service seamless steel pipes with large diameter and heavy thickness using traditional quenching off-line, when low carbon and low alloy steel had been used to produce the pipes. In this paper, the influence of quenching on-line on the property and microstructure of such a product was reported. It was shown that the strength can be improved and good toughness can be obtained. At the same time, production cost may be reduced.

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Keywords: Quenching on-line; Large diameter and heavy thickness; Sour service seamless steel pipes; High strength and toughness

X70 sour service steel pipes have high strength and high resistance to corrosion, and hence are used in transportation of crude oil and natural gas that contain H₂S gas[1,2]. Generally, this type of products are made of low carbon and low alloy steels to guarantee a good weldability and low crack sensitivity coefficient, which however, may lead to poor hardenability for large diameter and heavy thickness pipes when quenched off-line. So most X70 sour service steel pipes are made of steel plates by welding, because controlled rolling and controlled cooling technique were used in steel plates, which replace of quenching and tempering treatment and reduce the cost[3-6]. Using seamless steel pipes for X70 sour service pipeline can improve the security, because of its integrated structure. However controlled rolling and controlled cooling has not yet successfully applied in seamless pipe production at present, because seamless pipe production process and deformation process involved are too complex to control. Therefore quenching and tempering treatment are usually employed in producing higher grade seamless steel pipes such as X70 grade seamless pipes. This process not only increases the cost but also is hard to guarantee the strength especially for large diameter and heavy thickness pipe, and thus reducing the
competitive of the product[7-9]. To resolve this problem, quenching-online process for X70 sour service seamless steel pipes is studied in this paper, which evidently improves the strength and reduces the cost when residual deformation and residual heat had been used.

1. Material and Process

1.1. Material

The material used for test were continuous casting billet named HS485S from one of seamless pipe companies. The chemical composition is shown in table 1.

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>V, Nb, Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>wt %</td>
<td>0.07</td>
<td>0.30</td>
<td>1.15</td>
<td>0.008</td>
<td>0.001</td>
<td>0.02</td>
<td>0.01</td>
<td>0.2</td>
<td>0.01</td>
<td>appropriate content</td>
</tr>
</tbody>
</table>

1.2. Test Process.

The 2000 ton billet was divided into two parts, one part was used for quenching online with tempering offline process and the other part for traditional quenching offline with tempering offline process. After pipes were produced by these two different process, the properties, microstructures and carbonitride precipitation were measured and analysed. Two different processes were shown in Figure 1; the process A was the quenching online process and the process B was the traditional quenching offline process. Before heat treatment, production process of piercing, rolling, reheating and sizing was the same for process A and process B. In for the process A, the pipe straightway was quenched online in a water groove after pipe deformation at 920 °C for sizing, then tempered at 600 °C for 80 minutes. In process B, pipes were reheated to 980 °C for quenching and then tempered at 600 °C for 80 minutes. The pipe temperature before quenching in water was 860 °C for both processes. Dimensions of testing pipe were 406 mm in diameter and 23 mm in wall thickness.
Fig.1 Flow chart of two processes

2. Test Result and Analysis

2.1. Mechanical Property

31 specimens from each of the two different processes were machined to 12.7mm diameter round bar (longitudinal) for tensile test and 10×10×55mm rectangular specimen (transverse) with V notch for impact test (test temperature was 0°C). The results were shown in figure 2 to Figure 4. Figure 2 and Figure 3 show that the yield strength and tensile strength were at range of 560MPa~590MPa and 670MPa~710MPa, respectively, for the process A and were in the range of 470MPa~510MPa and 565MPa~615MPa, respectively, for the process B. Figure 4 shows that the impact values were in the range of 180~205J and 220~240J for both process A and B, respectively. It is clear that the yield and tensile strengths with process A were about 90MPa bigger than those with process B, and the impact values with process A were about 35J less than those with process B. Obviously a higher strength but a little lower toughness can be obtained by process A. According to API 5L [10], the yield strength and tensile strength required for X70 sour service steel pipes were in the range of 485~635MPa and 570~760MPa, respectively, with impact value no less than 50J at 0°C when transverse specimen used for testing. So, the process A can satisfy the API requirement for yield strength, tensile strength and impact value, though the impact value was little lower than that from the process B. Meanwhile the minimum yield and tensile strength of the products by process B cannot satisfy the minimum requirements specified in API, though the impact value was very high. The result shows that the process A can be employed to produce large sized pipes with dimension of φ406×23mm, which can easily satisfy the API requirements for X70 sour service seamless steel pipes.

Fig.2 Yield strength of two processes

![Fig.2 Yield strength of two processes](image1)

Fig.3 Tensile strength of two processes

![Fig.3 Tensile strength of two processes](image2)
2.2. Microstructure Analysis.

Specimens taken from the middle wall were analysed by microscope for pipes quenched by online quenching (process A) and offline quenching (process B) processes. The results were shown in Figure 5 and Figure 6, respectively. With two different processes were quiet different microstructures. In the online quenched specimen, the microstructure mainly consisted of intragranular-ferrite (IGF) with lath bainite, while the offline quenched specimen, it mainly consisted of quasi-polygon ferrite with intragranular-ferrite with pearlite. It is clear that intragranular-ferrite and separated fine lath-bainite have high strength and good toughness, and quasi-polygon ferrite have good toughness and low strength. So the pipes produced by the process A possess a high strength and good toughness, while the pipes produced by the process B have good toughness but low strength.

In order to investigate the effect of quenching on microstructure of the two different processes, cooling rate at the middle wall of the pipe was measured by using a thermocouple inserted in the middle of the pipe wall. The average cooling rate measured at middle pipe wall was $20^\circ C/s$ in the temperature range $860^\circ C$ to $500^\circ C$ when quenched in water. This cooling rate was obviously too low for traditional offline quenching process, especially for low carbon and low alloy steel such as steel HS485S. Because of lower cooling rate at pipe middle wall and low degree of under-cooling, the driving force for the microstructure transformation were not big enough to suppress the formation of proeutectoid quasi-polygon ferrite along or near the grain boundary for quenching offline process. During the proeutectoid quasi-polygon ferrite formation process, surplus carbon was expelled from ferrite to nearby austenite, which enriched the austenite with carbon. When the temperature continued to decrease, those parts of the austenite enriched with carbon transformed to pearlite and other parts of the austenite enriched with carbon transformed to intragranular-ferrite and fine M/A island. However, for the pipes from the quenching online process (process A), much separated fine lath-bainite by proeutectoid quasi-polygon ferrite can be produce at the same cooling rate $20^\circ C/s$. It is due to the deformation, which generated large numbers of deformation bands and dislocation for the precipitation of composite carbonitride and oxide of Ti and Nb. These precipitates at deformation bands and dislocations caused intragranular-ferrite transformation and separated lath-bainite, but restrained quasi-polygon ferrite transformation. During the intragranular-ferrite transformation process, surplus carbon was released to the austenite and the fine M/A island formed.
2.3. TEM Testing.

Precipitates of Ti and Nb composite carbonitride in specimens produced through were analysed by means of transmission electron microscopy(TEM) and energy dispersive spectoscopy(EDS). The results in Figure 7 and 8 show that composite precipitate (Ti,Nb)(C,N) can be observed in specimens produced through both process A and B. Obviously, the precipitates in specimen produced through process A were larger in number and smaller in size than those in specimen through process B. Fine carbonitride precipitates were formed along the dislocations or within the grains in specimen through process A, while few bulky precipitates were mainly distributed at grain boundaries in specimen through process B. It is thus clear that the processes used had a big influence on the precipitation of carbonitrides. When pipes produced through process A deformed at 920°C, a mass of deformation bands and dislocations were generated within the grain, which were the locations at which carbonitride of Ti and Nb subsequently precipitated with a strengthening effect on the material[13-15]. In process B, the pipes were reheated to 980°C for quenching offline. Some of the fine carbonitrides of Ti and Nb precipitated in the rolling process were redissolved during the reheating process, and at the same time some of the carbonitrides grow larger and gathered at the grain boundaries. These is the reason why more fine carbonitrides of Ti and Nb were observed in the specimen produced through the process A and few bulky carbonitrides were formed at grain boundaries in specimen through process B.
3. Conclusions

1. With the quenching online and tempering process, the X70 sour service seamless steel pipes can be produced with high strength and good toughness that can satisfy the API requirement. The production cost of the pipes may also be reduced by utilising the pipe residual heat.

2. Properties of the X70 sour service seamless steel pipes with the quenching online process can be improved. It enables the products with high strength and good toughness, even if the products with large dimension such as 406mm in diameter and 23mm in wall thickness.

3. Large numbers of fine carbonitrides \((\text{Ti,Nb})(\text{N,C})\) precipitated within the grains during the rolling process can effect on strength of the products in quenched online. But some of the carbonitrides were redissolved and some of the fine carbonitrides grow larger and gather at grain boundaries during the reheating process in quenching offline process, and therefore the strengthening effect on the products was lost.
Reference