

# Effects of Different Heat Treatment Process on Mechanical Properties and Microstructure of Q690 Steel Plate

Dashan Dong<sup>1,\*</sup>, Hongpeng Li<sup>1</sup>, Kuankuan Shan<sup>1</sup>, Xiaoshuai Jia<sup>2</sup> and Longfei Li<sup>3</sup>

<sup>1</sup>Logistics Engineering College, Shanghai Maritime University, Shanghai 201306, China

<sup>2</sup>Shanghai Jiao Tong University, School of Materials Science and Engineering, Shanghai 200240, China

<sup>3</sup>Jiang'an locomotive depot of Wuhan railway bureau group co, LTD in China, Wuhan 430000, China

\*Corresponding author e-mail: 348770945@qq.com

**Abstract.** Taking high strength steel Q690 as the research object, the mechanical properties, microstructure and XRD of Q690 steel plate after treated by different processes are studied. The result shows that the mechanical properties of the Q-P-T heat treatment process have been greatly improved, the yield strength is 1112.5MPa, the tensile strength is 1285.9MPa, the elongation is 8.23%, and the surface hardness is about 39HRC. The strengthening and toughening mechanism of Q690 steel after Q-P-T process is discussed. Studies found that the good comprehensive mechanical properties of Q-P-T steel are made up of martensite, retained austenite and dispersed carbide, which are of great significance to improve the strength of the steel.

## 1. Introduction

High strength steel with yield strength of 690MPa has been widely used in energy, transportation, construction and other industries due to its excellent performance and economic benefits. European is well ahead of the rest of the world in research and application of marine steel. At present, Marine steel is widely used in the construction of offshore platforms in S355, S420, S460 and S690 [1]. Germany's Rhine Bridge Dusseldorf-ILverish and France's Millau Viaduct Bridge are all made up with S460 high strength steel. In order to reduce the size of the pier and meet the requirements of appearance, the S690 high strength steel is used in the Nesenbachtalbruke Bridge in Germany [2]. Q690 steel plate, such as high strength low alloy steel has superior strength and toughness than traditional carbon manganese steel [3]. At present, TMPC technology has been widely used in the production of high strength low alloy steel [4]. When the yield strength of high strength steel is higher than 690MPa, TMPC technology has certain limitations [5]. However, the steel plate after processing (quenching+high temperature tempering) has good organization and mechanical properties [6]. Therefore, high strength steel which is processed by the modulation process occupies a large share in the production of high-strength steel in the world.

Quenching is the main method to obtain some special properties of the steel. The purpose is to get martensite as much as possible after the austenitizing workpiece. Tempering temperature will affect the microstructure and mechanical properties of high strength steel [7]. Quenching medium [8] is one



of the important factors that affect the quenching process of steel. Selecting proper quenching medium plays an important role in improving quenching quality and obtaining stable quenched structure. Common heat treatment processes consist of quenching and annealing process [9], isothermal quenching and etc. [10] The Quenching-Partitioning treatment proposed by Peer [11] can improve the overall mechanical properties of steel significantly [12]. The performance of high strength steel can be further improved by adopting "quench-carbon distribution - tempering (q-p-t) process" [13, 14].

In this paper, the effect of different heat treatment processes on the mechanical properties and microstructure of Q690 high strength steel with thickness of 12mm is studied.

## 2. Experimental materials and methods

The experiment takes Q690 steel plate as raw material, and the thickness of steel plate is 12mm. The composition is shown in Table1.

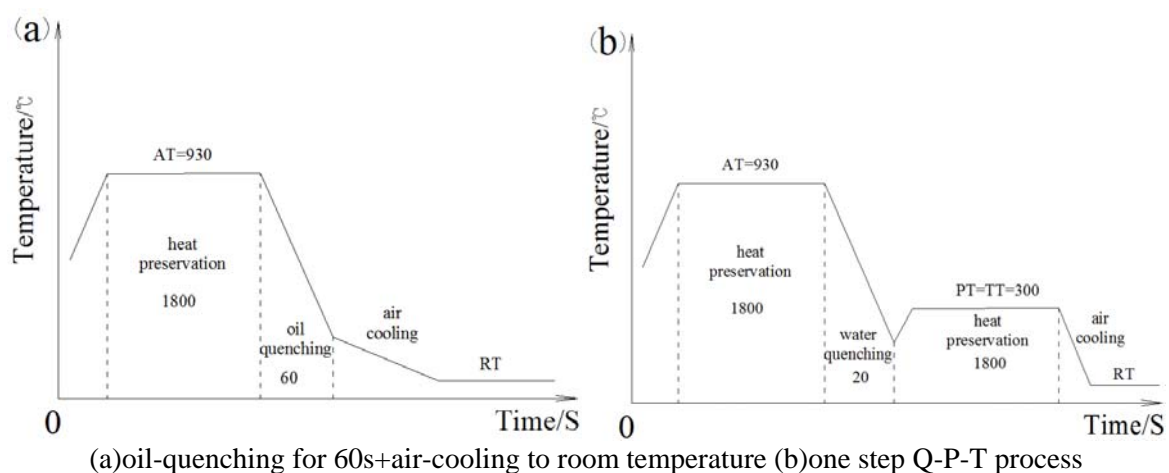
**Table 1.** Chemical composition of Q690 steel (wt%).

C	Si	Mn	P	S	Cr	Al	Mo	Ti	Cu	Nb	Ni	V
0.15	0.35	1.31	0.012	0.002	0.270	0.034	0.160	0.016	0.09	0.01	0.03	0.045

Mechanical properties of Q690 steel plates treated by different heat treatment processes are tested. The tensile sample is processed into a standard sample with a nominal width of 81mm according to the standard, and the tensile strain rate is 0.002mm/s on the Zwick/Roell standard tensile testing machine. Hardness test is 10x10x100 (mm) sample, which is tested by 500RA Rockwell hardness tester. The samples 10x10x55(mm) with the standard impact measurement purpose are taken in the radial direction and conducted the impact test on PTM2200-D1 automatic impact testing machine. The microstructure of the samples is observed by using a Nikon ECLIPSEMA200 optical microscope (OM). The content of the tissue of the samples is measured by a Rigaku/max2550VB/PC X-ray diffraction (XRD).

## 3. Different heat treatment processes

The Q690 steel plate is heated to 930 thermal insulation for 30min to make the austenitizing, then treated by different heat treatment process. The heat treatment process is shown in Fig.1.

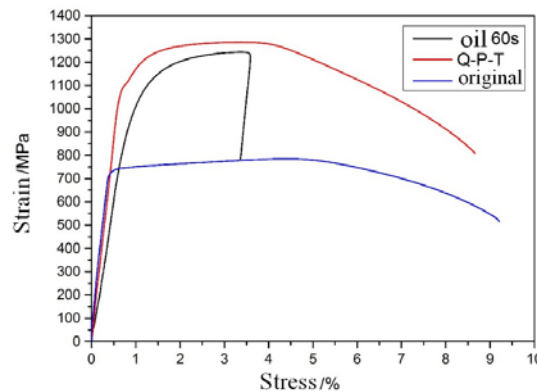


**Figure 1.** Different heat-treatment process of Q690 steel plates.

## 4. Test results and analysis

### 4.1. Mechanics property analysis

The tensile curves of Q690 steel plate after different heat treatment are shown in Fig.2.



**Figure 2.** Stress-strain curves of Q690 steel plates under different heat-treatment process.

Compared with the stretching curves in Fig.2, the strength of the steel plate treated by Q-P-T heat treatment process is higher than the original steel plate. The reason is that there is a certain amount of martensite after the quenching stage of Q-P-T heat treatment process which makes the strength of steel increase.

**Table 2.** Mechanical property under different heat-treatment process.

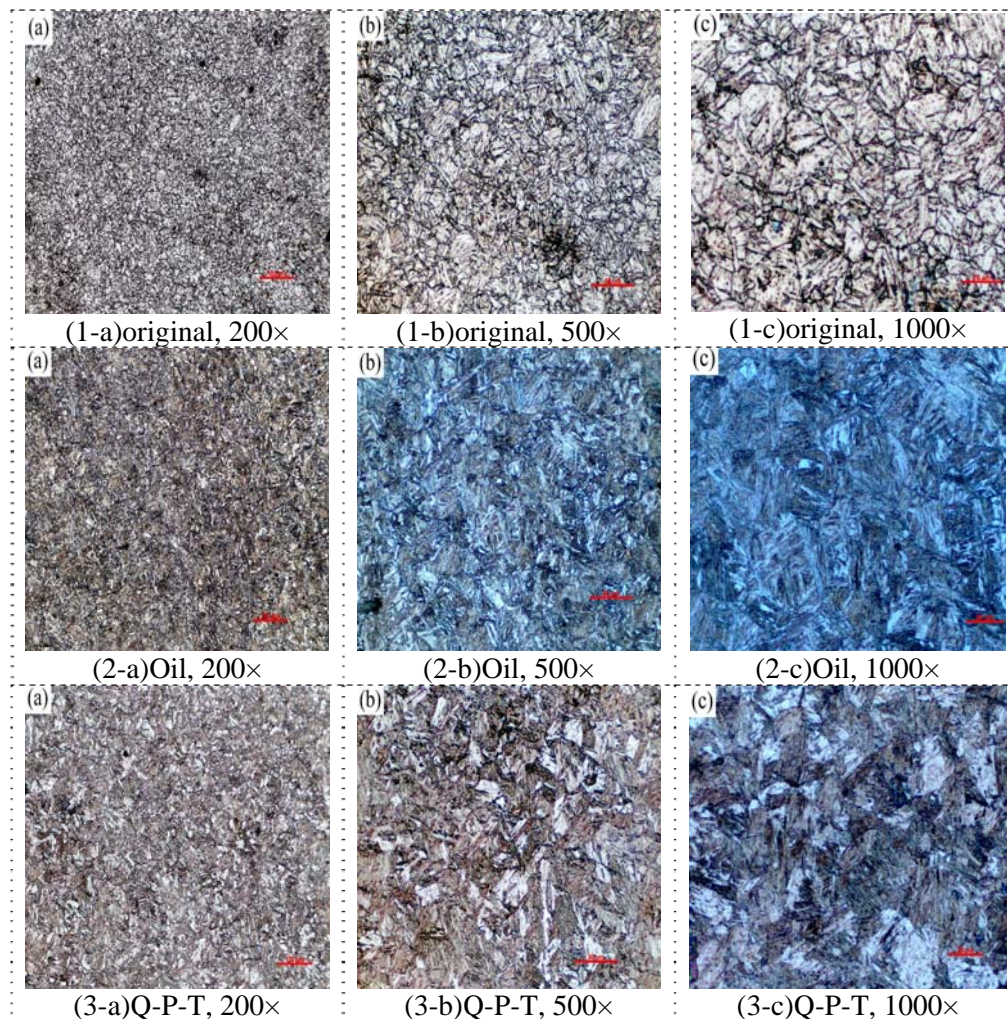
Name	Heat treatment process	Yield strength(MPa)	Tensile strength (MPa)	A%(Elongation)	Hardness(HRC)	Impact toughness(J/cm2)
a	original state	742	785	8.95	25	142.78
b	oil-quenching	1080.8	1243.5	2.65	34.9	78.38
c	Q-P-T	1112.5	1285.9	8.23	38.5	115.67

According to the tensile performance data of different heat treatment process in Table 2, c sample treated by Q-P-T heat treatment process has superior comprehensive mechanical properties.

The yield strength of c sample treated by Q-P-T process is 1112.5MPa, the tensile strength is 1285.9MPa, its strong plastic product is 10582.96MPa%. However, the yield strength of b sample treated by oil quenching is 1080.8MPa, the tensile strength is 1243.5MPa, its strong plastic product is only 3295.23MPa%. It can be concluded that the comprehensive mechanical properties of the samples treated by Q-P-T process are much higher than oil quenching and the original state, which shows the superiority of Q-P-T heat treatment.

From the surface hardness after treated by different heat treatment processes, it can be seen that the surface hardness of the steel plate after oil quenching and Q-P-T heat treatment has been increased, compared to the original plate surface hardness. But the surface hardness after Q-P-T process is the highest which is far higher than the parent metal. The reason why the material has high hardness is that the initial quenching has a higher cooling rate, which leads to higher martensite content in the tissue.

#### 4.2. Microstructure analysis



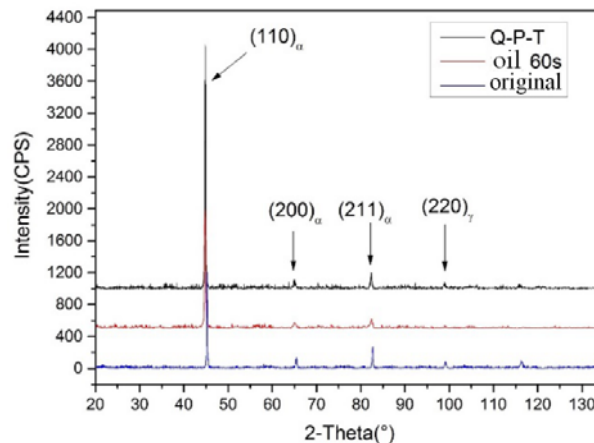
**Figure 3.** Microstructure of steels under different heat treatment process.

The microstructure of the Q690 steel plate before heat treatment includes: normalizing state (or hot rolling state, generally pearlite+equiaxed ferrite), cold rolling state (deformed ferrite+pearlite structure), spheroidized structure (granular carburizing body+ferrite, etc.). The experiment takes Q690 steel plate as raw material and the thickness of steel plate is 12mm. The microstructure is uniform tempered martensite, and there are small carburized particles dispersed in ferritic matrix, as shown in Fig.3 (1-c). From the microstructure of raw material can also be seen that the grain is relatively small, so the material has good toughness.

By comparing the microstructure of the samples treated by the Q-P-T heat treatment process, as shown in Fig.3 (3), there are retained austenite and martensite in Q-P-T samples, the martensite grain boundaries become blurred and carbides are attached to the martensitic crystal interface. In the process of Q-P-T, carbon will diffuse outward from martensite. In this process, the carbon near the martensitic crystal interface diffuses first, which leads to the low carbon content of martensite. In the process of diffusion, part of the carbon precipitates as carbide and adheres to martensite crystal interface. The other part of carbon dissolves in austenite which increases the abundance of carbon in austenite and improve its stability.



### 4.3. XRD diffraction analysis



**Figure 4.** XRD spectra of the samples under different heat treatment processes.

The results of XRD in Fig.4 shows that the content of retained austenite in Q-P-T sample is 4.3%, raw sample is 8.7%, while oil sample is extremely low. It is further revealed that a certain amount of retained austenite is the important reason of good toughness.

It can be seen from the diffraction peaks of martensite after treated by different heat treatment process that the content of martensite in Q-P-T sample is up to 81.6%, oil sample is about 20%. The content of martensite is the main factor to determine the strength of steel. The way of Q-P-T process to improve the strength of materials is revealed by analyzing the content of martensite.

## 5. Conclusion

This paper studies the Q690 steel plate after treated by different heat treatment processes, and the main conclusions are as follows.

(1)Through the comparison and analysis of the mechanical properties of Q690 steel plate treated by different heat treatment processes, the strong plastic product of Q-P-T steel plate is higher than some traditional processes, the yield strength is 1112.5MPa, the tensile strength is 1285.9MPa and the elongation is 8.23%. It shows the superiority of the Q-P-T process in improving the comprehensive mechanical properties of materials.

(2)Through the analysis of microstructure and XRD after treated by different heat treatment processes, it can be seen that the content of austenite in Q-P-T sample is significantly higher than oil sample. The main reason is that the distribution of carbon from martensite to retained austenite in the process of carbon distribution, which increases the carbon content of retained austenite, thus improving the stability of retained austenite. Owing to martensite determines the strength of steel, retained austenite determines the toughness of steel, the microstructure of martensite and retained austenite in Q-P-T steel reveal the mechanism of microstructure on mechanical properties.

## Acknowledgments

This work is supported by Shanghai Science and Technology Commission's innovative action plan project (16DZ1120202, 17DZ1101401, 17DZ1101102). Corresponding author: Xiao-Shuai JIA.

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