Analyzing of Nonuniform Hardness for Anchorage Clamp Plate after Heat Treatment

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Abstract. 20CrMnTi wire rod can be used to manufacture the anchorage clamp plate. In the normal production, the test results show that the hardness of anchorage clamp plate is nonuniform. In this paper, the chemical composition, microstructure, grain size of clamp plate billet and the microstructure, hardness of the finished clamp plate product were studied and analyzed. The results show that improper heat treatment technics causes nonuniform hardness for anchorage clamp plate.

1. Introduction
Prestressed anchor working clamp is one of the most critical parts in the prestressed anchorage system. The structure shape of work clamp is the outline for the cone, the internal structure is non-standard thread. After more than 10 production processes, the part was cutted along longitudinal incision, and finally processed by heat treatment. The specific production process is With 24mm specifications of 20CrMnTi hot rolled wire, annealing, pickling, phosphating, cold forming (clamp blank), blank hole tapping, cut into two piece, carbonitriding, quenching, tempering, and finished product inspection. According to the hardness requirements design of clamp, China's current production control range is HRC58-64 or HRA78-84. The hardness of clamp must be achieved by heat treatment, otherwise it is difficult to anchor. On the other hand, the hardness of clamp can not be too high, otherwise the clamp will crack or even break\cite{1}.
In the process of normal production inspection, it is found that the hardness of the clamp is uneven. In order to find out the cause of uneven hardness of clamp, the chemical composition, microstructure, grain size of clamp blank and the hardness and microstructure of finished product were analyzed. It is useful for the improvement of heat treatment process.
2. Experimental material and methods

The experimental materials are 5 pieces of clamp blank, 5 pieces of qualified clip and more than 20 pieces of clamp with uneven hardness. Firstly, the chemical composition, microstructure and grain size of clamp blank and hardness of the finished product were tested. Then the characteristics of hardness distribution were analyzed. Finally, the microstructure of the samples with different hardness was analyzed in order to determine the causes of uneven hardness. The grain size of the clamp blank is tested according to GB/T 6394. The chemical composition of blank samples need to be heading into an appropriate shape and then testing. The hardness of the finished clip is measured by the automatic hardness tester with AT200DR-TM model. The microstructure was analyzed by means of metallographic microscope and scanning electron microscope.

3. Test result

3.1. Analysis of the clamping piece blank

3.1.1 Analysis of the composition of the blank

The chemical composition of clamp plate were listed in table 1.

| grade  | chemical composition (mass fraction, %) |
|--------|----------------------------------------|
|        | C   | S   | Si  | Mn  | P   | Ni  | Cu  | Cr  | Ti  |
| 20CrMnTi | 0.18 | 0.005 | 0.25 | 1.00 | 0.011 | 0.017 | 0.05 | 1.20 | 0.10 |

According to the results of the component analysis, the content of each alloy element is within the national standard.

3.1.2. Microstructure and grain size of blank

There is fiber zonal texture in the clip blank after cold working(Caused by hot rod itself and cold working). The microstructure and the grain size of clamp blank are shown in figure 1 which are fine and uniform, and the grain size is 9 grade.

![Figure 1. The microstructure (a) and the grain size (b) of clamp plate billet.](image-url)
3.2. Performance and microstructure analysis of the finished clamp

3.2.1 Analysis of the hardness of the finished clamp

The hardness test value of qualified samples and unqualified samples are shown in figure 2. The so-called nonuniform hardness is that the hardness value of some samples is higher or lower than the hardness value of qualified samples.

![Hardness result of clamp plate](image)

Figure 2. The hardness result of clamp plate.

3.2.2. Analysis of microstructure

As you know, the performance is determined by the microstructure. Due to the nonuniform hardness of the surface of unqualified products, the microstructure of the unqualified products surface must be different from the qualified products. So the analysis of the surface microstructure is very important [2,3].

The polished surface of qualified samples and unqualified samples were observed in optical microscope. But there is no difference between them. Moreover, we did not find any empty in the surface microstructure.

1) samples with qualified surface hardness

From figure 3(a) we can know that the macrostructure of cross section of qualified samples can be divided into four regions: external area of carburized layer, fine grain zone and inner tooth of carburized layer.

![Microstructure analysis](image)
The surface Texture Distribution, 10X. (a) The thickness of surface troostite is 15μm. (b)

Figure 3. The macrostructure (a) and microstructure (b) of clamp plate with competent surface hardness.

Figure 3(b) is the surface microstructure of the samples. The surface layer microstructure was martensite and troostite which along the crystal boundary. The microstructure in the core of the sample was lath martensite. No carbides were observed in the carburized layer.

2) samples with lower surface hardness
The macrostructure of cross section of samples with lower surface hardness can be also divided into four regions: external area of carburized layer, coarse grain zone, fine grain zone and inner tooth of carburized layer. Its coarse grain zone is lath martensite.

The surface microstructure of samples with lower surface hardness was observed. The surface microstructure is a large number of troostite and a small quantity of martensite in the surface carburized layer. There is little distribution of carbide particles in the surface carburized layer (figure 4(a)). A large number of ferrite was found in the core of the samples, see figure 4(b).

Figure 4. The microstructure of lower hardness sample (a, b).

The microstructure in the core of the sample is a large number of ferrite, a small quantity of martensite and bainite, which shows that the effect of quenching is not good so that completely martensite structure is not obtained.

3) samples with higher surface hardness
The macrostructure of cross section of samples with higher surface hardness can be also divided into four regions: external area of carburized layer, coarse grain zone, fine grain zone and inner tooth of carburized layer. Its coarse grain zone is lath martensite.

The microstructure of the surface layer and the heart of the samples with higher surface hardness was observed, see figure 5. The surface microstructure is martensite and intergranular troostite. A large number of larger carbides distributed at carburized layer were found in figure 5(b). The center of sample is lath martensite.
4. Test results discussion
The surface hardness of products depends on the surface microstructure. Troostite, martensite and carbonitriding degree in surface layer microstructure determine the surface hardness. The carbonitriding degree can be characterized by the quantity of carbide in carburized layer. Carbonitriding degree is mainly depended on carbonitriding temperature and atmosphere under the premise of chemical composition meet the requirements.

4.1. Analysis of unqualified samples with lower surface hardness
Causes for the lower surface hardness after carbonitriding are low concentration of surface carbon and nitrogen, decarburization, nitrogen removal, too much residual austenite; black organization formed in the surface layer. There is no obvious decarburization and excessive residual austenite but major black organization in the surface layer with microstructure test. Therefore, the main reason for lower surface hardness is too much black organization. According to the different morphology, the black organization can be divided into 3 categories: black, black belt and black net [4,5]. Black organization structure was punctate appeared in the surface of gear member. Black organization structure is the micro morphology of surface holes. There is a very thin oxide on surface of black belt and inside are troostite, bainite, and containing alloy oxide, carbon nitride and a little martensite, residual austenite as well. Black net is mainly trooslite and bainite.

The main reason for lower surface hardness is a large number of Troostite formed in the surface layer. Troostite more, hardness value lower. There are two reasons for the lower hardness. One possibility is low temperature of carbonitriding and poor activity of furnace gas. Austenite is not stable enough because of low surface carbon content and then transform into troostite. May also be decarburization caused by slow cooling after carbonitriding and surface decarburization during quenching heating process. In addition, The content of alloy elements and C, N in the austenite decreased because of Cr, Mn and other alloy elements dissolve in carbon nitride in the surface layer. Then, the stability of austenite decreased when quenching and finally leads to reticular troostite formation. We have observed the troostite at the surface layer in all the samples, and just how many. Moreover, on the
basis of the above factors, more generation of troostite was achieved because of cooling rate of quenching is insufficient[6].

4.2. Analysis of unqualified samples with higher surface hardness
Although the surface layer of unqualified samples with higher surface hardness is martensite and a small amount of troostite. But high surface hardness was achieved eventually because of the high degree of carbonitriding (more carbide in the carburized layer).

5. Conclusion
- Coarse grains both exist in the surface hardness qualified samples and unqualified samples. The coarse grain was formed in the carbonitriding process and subsequent heat treatment process which has nothing to do with raw materials.
- The main reasons for the unqualified products with lower surface hardness are due to a large number of troostite at surface layer generated after heat treatment.
- The main reasons for unqualified products with higher surface hardness are due to over carburizing at the surface after carbonitriding.

6. Reference
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