Effect of Heat Treatment on Microstructure and Properties of Steel

Huang Guiyun[1,a,*], Li Yong[1,b], Xiong Yakun[2,c]

[1]Beijing Polytechnic, Beijing, China

[2]Beijing Union University, Beijing, China

[a]18801281447@163.com, [b]liyong0401@126.com, [c]1487912802@qq.com

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Abstract: The microstructure and properties of metal materials are different when treated with different heat treatment processes. In order to obtain the best performance of use, heat treatment plays an important role in fully exploiting the potential of materials and achieving maximum economic benefits. Conventional heat treatment usually refers to annealing, normalizing, quenching and tempering. Different heat treatment processes were carried out for selected steel 45 steel and T12 steel. The changes in metallographic structure of materials caused by different processing technology were systematically observed and their properties were tested. The hardness is analyzed from the aspects of heating temperature, different cooling methods, tempering after quenching and so on, and the causes of abnormal data are explained.

1. Introduction

Metal heat treatment is a discipline to study the relationship between metal material composition, process and microstructure and properties. The microstructure and properties of metal materials are different when treated with different heat treatment processes. In order to get the best performance, heat treatment plays an important role in fully excavating the potential of materials and achieving the greatest economic benefits.

Conventional heat treatment is usually referred to as annealing, normalizing, quenching and tempering.

In this paper, the selected steel 45 steel and T12 steel were subjected to different heat treatment processes, and the changes in metallographic structure of the materials caused by different treatment processes were systematically observed and tested.

According to the needs of actual organization and performance, the formulation of heat treatment process includes: determination of heating temperature, determination of heating and heat preservation time and selection of cooling medium.

2. Determination of heating temperature

The basis for determining the quenching heating temperature is the critical point corresponding to the composition of the steel. For hypoeutectoid steel, eutectoid steel and hypereutectoid steel, there are different process principles for determining the quenching temperature:

The quenching temperature of the subeutectoid steel is:Ac3+(30~50℃)。If the quenching temperature is too high, the martensite structure after quenching will be significantly thickened, which will deteriorate the mechanical properties of the material.When the quenching temperature is lower than Ac3, the quenched structure will contain undissolved free ferrite, so that the hardness after quenching is lowered.However, according to recent studies, it has been found that the subtemperature quenching (the insertion of one or several times below the Ac3 point temperature between the common quenching and tempering) will improve the toughness of the material, inhibit the reversible temper brittleness of the steel, and reduce the critical embrittlement temperature more expensive, so the subtemperature quenching is a new process of strengthening and toughening.Table 1 lists the critical points of some common steels for reference.

The quenching temperature of eutectoid steel and eutectoid steel is:Ac1+(30~50℃) 。 Controlling the amount of secondary carbides dissolved into the austenite (ie, controlling the quenching heating temperature) can control the morphology of the martensite.When the temperature is too high, if the temperature exceeds the Acm point, the martensite tissue will be thick, and the amount of retained austenite will increase significantly and the mechanical performance will be poor. At the same time, it also increases the quenching stress, which increases the tendency of deformation and cracking.

Table 1 Critical point of common carbon steel

Steel number	Critical point temperature (approximate)			Steel number	Critical point temperature (approximate)		
	Ac1	Ac3	Acm		Ac1	Ac3	Acm
20	735	855		T8	730		
30	732	813		T10	730		800
45	724	780		T12	730		820
60	727	766		40Cr	743		
T7	730	770					

3. Determination of heating and holding time

The theoretical time for quenching and heating is determined according to the following formula:
$\tau=\tau_1+\tau_2+\tau_3$
Among them:
τ——Total heating time
τ_1——The time required to reach the specified temperature after the work of the workpiece is entered.
τ_2——The time when the workpiece is fired (when the surface temperature of the workpiece reaches the center of the body).
τ_3——Time needed for an organization to change
In the production practice, the experience data of box type resistance furnace heating time are listed in Table 2. When calculating, the smallest size direction of workpiece is selected.

Table 2 Time required for different heating temperatures in box-shaped resistance furnace

Heating temperature(℃)	Heating time		
	Round steel (minutes/mm)	Square steel (minutes/mm)	Sheet steel (minutes/mm)
600	2.0	3.0	4.0
700	1.5	2.2	3.0
800	1.0	1.5	2.0
900	0.8	1.2	1.6
1000	0.4	0.6	0.8

4. The selection of quenching medium:

After determining the quenching heating temperature and heating and holding time, it is necessary to select the appropriate cooling medium to achieve the desired technological purpose.The basis is as shown in Figure 1 below.
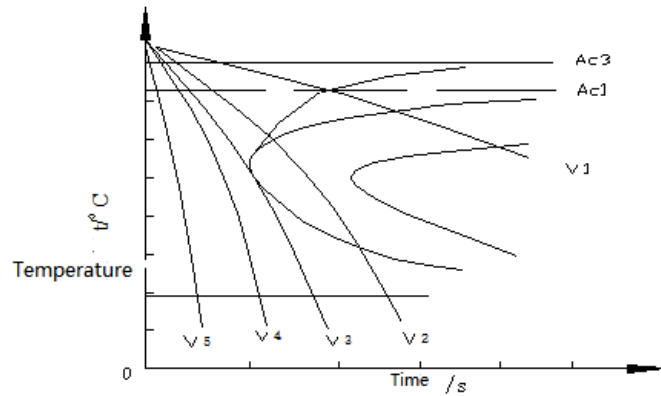
Figure 1 Schematic diagram of the quenching medium cooling curve (the title does not seem right, CCTT diagram)

Figure 1 shows that a single martensite can be obtained by cooling only at a critical cooling rate of V3 at a critical cooling rate (such as V4, V5). (in theory, the retained austenite is also contained in the tissue). When the cooling rate is less than V3 (such as V1 and V2), martensite (V1) or non martensite (V2) may not be obtained after quenching. Therefore, the choice of quenching medium is first to make the cooling speed greater than the critical cooling rate of V3, and then select the smaller deformation and cracking tendency. The ideal quenching medium should be: in the most easily decomposed temperature range of the supercooled austenite (the tip of the nose of the C curve) has a strong cooling capacity to suppress the decomposition of the supercooled austenite. And near Ms, there is a relatively mild cooling rate. Such quenching medium has higher quenching and cooling speed without causing excessive quenching stress. Therefore, the quenching medium should be selected according to the C curve of the specific material. Table 3 shows the cooling capacity of some common cooling media in different temperature zones.

Table 3 Common quenching medium cooling capacity

Quenching medium	Cooling rate (°C/sec)	
	In the interval of 550~650°C	In the range of 200~300°C
Water(18°C)	600	270
Water(26°C)	500	270
Water(50°C)	100	270
Water(74°C)	30	200
10% aqueous caustic soda18°C	1200	300
10% sodium chloride aqueous solution18°C	1100	300
10% soda aqueous solution18°C	800	270
Distilled water	250	200
Oil emulsion	70	200
Soap water	30	200
Mineral oil	100	20
HG	500	130
Copper plate	60	30
iron plate	35	15

The martensite obtained after quenching of steel has high hardness, strength and high quenching stress, and is usually rarely delivered directly. Therefore, quenching parts generally must be tempered in time, otherwise it will often cause deformation, cracking, and even the phenomenon of

part collapse.

According to the different performance of the parts, the quenching parts are classified into low temperature tempering (<250℃), medium temperature tempering (350~500℃) and high temperature tempering (>500℃). As the tempering temperature increases, the hardness and strength indicators gradually decrease, while the plasticity and toughness indicators gradually increase, and most of the quenching stress is reduced or eliminated.

The holding time of tempering is usually set to 0.5~2 hours according to the empirical data, combined with the material and size of the specific workpiece.

In this paper, through the normal quenching and tempering process of 45 steel and T12 steel, and the actual operation, some mechanical properties are determined. Combined with the observation of the microstructure of 45 steel and T12 steel after different heat treatment processes, the properties are determined. The law of its organization and performance changes.

5. Hardness test and analysis

After the sample was cooled, the two planes parallel to each other were smoothed and light with coarse sand paper (No. 200 and 400), and the hardness value was measured by the HR-150A Rockwell hardness tester. As the sample is subjected to heat treatment and has high hardness, the test is carried out in HRC, and the test results are recorded in Table 4.

Table 4 Hardness of the sample after different heat treatment processes

Sample Numbering	Sample heat treatment process	Steel number	average value	Sample Numbering	Sample heat treatment process	Steel number	average value
1	Normal heating, water cooling	45	60.57	5	Normal heating, water cooling, 200℃ tempering	45	50.40
		T12	66.8			T12	64.1
2	Normal heating, oil cooling	45	33.57	6	Normal heating, water cooling, Tempering at 400℃	45	41.40
		T12	40.3			T12	48.5
3	Normal heating, air cooling	45	15.73	7	Normal heating, water cooling, 600℃ tempering	45	31.10
		T12	27			T12	32
4	Unheated state	45	12.53	8	760℃ heating, water cooling	45	46.13
		T12	0.5		970℃ heating, water cooling	T12	64.1

(Note: Water cooling uses 10% sodium chloride aqueous solution; oil cooling uses oil.)

(1) The effect of heating temperature on properties: quenching critical temperature is too high or too low will cause adverse effects on quenched steel. The heating temperature is low, the hardness will be insufficient; the heating temperature is too high, it will cause the overheating of the quenched steel, make the steel crack easily, the brittleness is big, and the toughness is insufficient. Therefore, during quenching, suitable quenching temperature should be selected, not the higher the temperature.

(2) The effect of cooling mode on Performance: the faster the cooling rate, the higher the hardness, the cooling rate, the brine > clean water > Oil > air. When the cooling rate is different, the temperature of the solid state transformation is different, and the structure is very different. In general, the faster the cooling rate is, the lower the temperature of the steel is, the higher the hardness of the microstructure is obtained after the transformation. It is mainly because the lower the transition temperature, the lower the activity of the atom and the thinner the tissue, for example, the interlayer spacing of the pearlite body decreases with the decrease of the formation temperature; if the cooling rate is large enough, martensite can be changed to get martensite, and its hardness will be higher.

(3) The effect of tempering temperature on Performance: high hardness after quenching is because carbon is solid dissolved in the matrix and the atoms are arranged closely. When the

carbides re precipitate, the atoms are not arranged closely and the hardness drops. The higher the temperature of the tempering, the more active carbon atoms, the easier the precipitation is, and the lower the hardness.

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