Heat treatment technology and related research of high carbon wear resistant steel ball

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Abstract: Steel ball with the method of solid carburizing heat treatment, the operation process, process didn't prepare behind often appear uneven carburizing in batch production, uneven hardness, the plaque pitting, thus to make the steel ball after heat treatment hardness is qualified, switch to direct drip type gas carburizing process, to improve the hardness after the heat treatment of steel ball, in the nitrogen-based protective atmosphere heat treatment, the application of oxygen probe automatic control of carbon potential of furnace atmosphere, to heat the bright quenching of GCrl5 steel ball, study the changes of atmosphere carbon potential impact on the quality of heating steel ball surface, through metallographic analysis, obtained the best control parameters, high quality steel ball In this way, the mechanical properties of the bearing steel ball surface are improved, the 45Mn2 steel ball obtained by adding manganese element, and the mechanical properties of steel ball after heat treatment are better than 45 steel and medium manganese cast iron.

Keywords: gas carburizing, carbon potential, mechanical properties, wear resistance.

1. Introduction

Coal pulverizing equipment is one kind of coal mine machinery, and the steel ball is an indispensable part in many colliery crushing equipment, and the steel ball and material are often hit by each other to complete the crushing of the material. The material of steel ball is the most common material of cast iron sphere and 45 steel, but its wear resistance has not been ideal. Therefore, improving the wear resistance of steel balls and taking into account the production cost has become the focus of researchers and enterprise technicians. In this paper, 45Mn2 steel is used to forge steel ball. After industrial test, its wear resistance is superior to 45 steel and manganese cast iron in rare earth, which has produced good economic benefits. One of the reasons for the
short service life of steel balls is that steel balls are not protected during quenching and heating, resulting in oxidation of parts. Then the decarburization layer is formed on the surface, and it can not be completely removed in the subsequent cold processing, resulting in the decrease of the surface hardness and the larger residual tensile stress, so that the wear resistance and contact fatigue life of the steel ball parts are reduced. Heat treatment with nitrogen based protective atmosphere can prevent oxidation of steel balls during heating. Thereby improving product quality and service life of steel balls, at the same time, it can also reduce machining allowance, save a lot of steel and reduce costs. The bearing steel ball is heat-treated with nitrogen based protective atmosphere. Carbon potential control instrument is used to control the carbon potential of the atmosphere in the furnace. The influence of carbon potential on the surface quality and properties of bearing steel ball after heat treatment is studied.

Solid carburizing and carbonitriding technology have become a mature steel surface strengthening process after decades of development, and are widely used in industry [1]. However, the main shortcomings of the traditional carburizing and nitriding process are complex equipment, a few hours of sample penetration, high temperature (800~1100), easy deformation of the workpiece and low production efficiency. The emergence of direct drop gas carburizing and liquid plasma electrolysis carburizing nitriding provides a new way to solve these problems and solves the hard problem of steel ball heat treatment.

## 2. Steel Ball Production Technology and Related Theory

### 2.1 Carburizing Treatment of Manganese Steel Ball

The forging process of 45Mn2 steel ball is adopted. The initial forging temperature is 1200 C, the final forging temperature is not less than 1000 degrees C, the optimum deformation amount is 25% ~ 40%[2], after the deformation is quenched immediately after the deformation, the interval time between the forging end and the quenching is not more than 6 seconds. In order to obtain deeper hardened layer, wear resistance is improved, while spherical objects are not easy to crack. The quenching medium selected the NaCl solution with a more intense cooling rate of 5%. After quenching, the tempering was used at different temperatures. The time of tempering was calculated according to the effective thickness, according to 1.5min / mm.

A barrel type heat treatment furnace is used to carburizing low carbon steel ball. In the process of carburizing, the cheap kerosene is widely used as a carburizing agent and carburizing at 920~940 C. High hardness, wear resistance and corrosion resistance can be obtained in tens of seconds to a few minutes. It is a promising new technology [3]. In the process of carburizing, a large amount of kerosene is used in
order to accelerate carburizing speed, so that the active carbon atoms from the pyrolysis of kerosene can not be absorbed on the surface of the steel ball in time. These activated carbon atoms synthesize carbon form of the molecule, which deposited on the surface of the steel ball, affecting the carburizing and reducing the carburizing speed. After kerosene cracking, a small amount of decarburized gas is contained in addition to carburized gas, and carbon black can be removed or prevented from carbon black by CO2, H2O, H2 and O2. At the same time, the concentration of activated carbon in the carburizing atmosphere is increased, and carburizing is accelerated, which plays a role of catalytic osmosis.

Several catalytic methods to accelerate the carburizing process are described below. With the increase of tempering temperature, the tensile strength decreases and the impact toughness increases with the increase of tempering temperature. The microstructure after quenching is lath martensite. The workpiece is placed in a specific electrolyte and discharged by the film on the surface of the workpiece. High hardness, wear resistance and corrosion resistance can be obtained in a few seconds to a few minutes. The erosion layer is a promising technology.

Annealing is to heat the steel to the temperature of phase change or partial phase change and heat for a period of time, and then make it cool slowly. The purpose of the annealing is to eliminate the defects of the tissue, improve the homogenization of the components and refine the grain, improve the mechanical properties of the steel, reduce the residual stress and improve the cutting performance. Normalizing is a heat treatment method of heating steel to a critical temperature, converting it to uniform austenite, and then cooling it naturally in the air. It can eliminate the hypereutectoid steel network cementite and improve the comprehensive mechanical properties. It is more economical to replace the annealing process with normalizing parts for less demanding parts. Quenching is to heat the steel above the critical temperature, heat the heat for a period of time, and then quickly put into the quench agent, so that the temperature suddenly decreases, and the critical cooling rate is rapidly cooled, and the heat treatment method, [4], with martensite dominated unbalance tissue is obtained. Quenching can increase the strength and hardness of steel and reduce plasticity.

2.2 Carbon Potential Control in Nitrogen Base Protection

Oxygen and rich gas are supplied by a group of nitrogen cylinders and rich gas cylinders. The composition of the gas is 99.5%, the propane gas contains 88.9% C, 8.7% propylene, 1.6% isobutene, and 0.8% methane, and the two gases flow through the pipe filter, drier, throttle valve, flowmeter, and solenoid valve after decompression valve. Reach the mixer. After the gas is mixed, the gas is measured by gas
chromatograph. The internal pressure of the furnace gas is measured by the V pressure gauge, and the carbon potential in the furnace gas is measured by the oxygen probe at the top of the furnace.

When the furnace temperature rises to the normal quenching temperature, a certain proportion of nitrogen and propane gas is put into the furnace, and the air in the furnace is discharged, and a certain carbon potential is generated in the furnace. The oxygen probe transmits the carbon potential in the atmosphere to the electrical signal for two times to the instrument, gives a potential value and compares it with a given potential value. When the signal is higher than the given potential value, the electrical signal produced by the electric signal makes the actuator action, the solenoid valve closed, the propane gas flow decrease, the original nitrogen and propane gas. When the carbon potential of the furnace gas decreases, the electrical signal given by the oxygen probe drops, when the signal is lower than the pre given signal, the signal difference makes the execution action, the solenoid valve opens, and the carbon potential of the furnace gas increases. Repeat the above actions to keep the carbon potential stable in the furnace atmosphere, and accurately control the carbon potential in the furnace gas through the oxygen probe carbon potential automatic controller.

3. Thermal Deformation Effect

A large number of defects exist in the deformed matrix, resulting in distortion, storing a certain amount of distortion energy, and deforming the structure in a thermodynamically unstable state. Under certain conditions, it will transform toward a stable state with less defects, mainly depending on the thermal activation of atoms and vacancies. When recrystallization occurs in the deformed matrix, the migration of grain boundaries is caused, and the free energy of the deformed matrix decreases. In the process of grain boundary migration, the driving force that drives its migration is observed.

Discontinuous precipitation occurs during recrystallization of deformed metals. When the grain boundary slid over a large angle, the dislocation density in the deformed matrix was reduced and a small amount of precipitates were left. The chemical kinetics of the phase transition could also promote the migration of grain boundary and promote the recrystallization process. In addition, other factors can also be the driving force of grain boundary migration. Such as the driving force caused by elastic strain and magnetization induced by magnetization. Comparatively speaking, they are less than deformable storage energy and chemical energy, and have much less influence on recrystallization.

With the increase of deformation, the distortion of the matrix becomes more and more serious and the dislocation density in the matrix increases continuously. When the
dislocation density in the hot metal is up to a certain value, the distortion reaches a certain degree. The dynamic recrystallization will occur when the energy stored in the deformation matrix is large enough. Dislocation density generally increases with the increase of deformation. The study shows that the rheological stress of metal in the process of deformation is proportional to the square root of dislocation density, so the critical rheology stress is used to describe the dynamic recrystallization in theory.

4. The Effect of System Parameters on Response
In order to avoid the low hardness of the steel ball, uneven distribution of hardness and easy cracking, the quality of the final steel ball product can reach the international standard after the comprehensive experiment and research on the production process of the steel ball. The main performance indexes of the exported steel ball products are as follows [5]:
1. Surface hardness of steel ball: HRC≥61
2. Core hardness of steel ball: HRC≥40
3. Impact toughness of steel ball: AK≥8J

![Figure 1. A Decarburization](image)

At present, the steel ball is influenced by its material, its chemical composition fluctuates greatly. In order to ensure the quality and effect of heat treatment, the raw material is classified and the decarburization of the raw material is understood. The 60mm x 60mm billet is heated and the metallographic observation is carried out. In Figure 1, the whole appearance of the surface decarburization layer of the square billet in 1 is adopted. The decarburization layer of the material is measured by a microeyepiece. The thickness of decarburization layer is about 1.2mm, and B is a magnifying photo of the surface of the decarburization layer, and a large number of ferrite structures appear on the surface of the steel ball.

The selection of quenching equipment and quenching medium, according to the actual situation of the production site, quenching and quenching quench are selected in the quenching equipment. By using the blank of the production site, the selected raw
materials are forged at high temperature. After the final forging, the quenching medium is loaded with about 100 kilograms in the quenching barrel. The steel ball after the end of the forging is put into the quenching barrel and quenched in the process of quenching, in order to make the surface of the steel ball surface. With uniform quenching, the operator clamps the ball into the quenching medium to move back and forth in the quenching medium. In order to study the effect of quenching medium and quenching temperature on the final quality of steel balls. Not only the quenching medium is chosen as the solution of NaNO2 with clear water and 5% concentration, but at the same time, different temperatures are set for various media. The quenched steel ball did not undergo immediate tempering, and its hardness was measured. Quenching experiments under different water temperatures were carried out on a steel ball with diameter of 120mm after quenching at high temperature and [6] in water. In quenching process, because the heat dissipation during quenching is not timely, the water temperature is increased naturally. It is disadvantageous to the hardness distribution on the surface of the steel ball.

The steel balls with the same size were quenched in NaNO2 quenching solution at different temperatures, and then quenched under high temperature forged in a concentration of 5% NaNO2 solution. The NaNO2 used in the experiment accords with the GB2367-90 standard. The results are shown in Table 1.

Table 1. Hardness of steel balls quenched with NaNO2 solution at different temperatures

<table>
<thead>
<tr>
<th>number</th>
<th>Quenching medium temperature (°C)</th>
<th>Hardness distribution (HRC) on the surface of steel ball</th>
<th>Mean value of hardness (HRC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28～40</td>
<td>48,46,45,45,43.5,45,52,43,46,49,50</td>
<td>46.6</td>
</tr>
<tr>
<td>2</td>
<td>40～52</td>
<td>42,42.5,47,51,50.5,51,52,49,46,44,48,49</td>
<td>48.5</td>
</tr>
<tr>
<td>3</td>
<td>52～61</td>
<td>43.5,44.4,46,49,50.5,49,46,48,46,39,38</td>
<td>45.4</td>
</tr>
</tbody>
</table>

It is known from table 1 that, under the same conditions, the surface hardness of the steel ball is slightly higher after quenching by the NaNO2 medium with a concentration of 5%, and the hardness distribution on the surface of the steel ball is more uniform. Extract ball 7, cut it open, and test the hardness of the heart. By means of spark wire cutting, a cross section of 10mm * 10mm is cut through the center of the steel ball. It can be seen that after heat treatment quenching, the hardness distribution of the steel ball surface and core is relatively low, and it does not reach the performance index of the exported steel ball.

In solid carburizing process, solid carburizing is essentially a gas carburizing process, which is only produced by solid charcoal. In the process of carburization, oxygen and
charcoal in the air produce CO, that is, 2C+O_2 2CO, and CO is unstable at high temperature. It will decompose the active carbon atoms, 2CO CO_2+C, and CO_2 can produce CO with the effect of charcoal, that is, CO_2+C 2CO, and the osmotic agents used in the process of solid carburizing are mainly barium carbonate, sodium carbonate and grass. Sodium acid and sodium acetate. Increasing the amount of activated carbon has played a role of expedite. Therefore, the agent can be added to the furnace to accelerate the carburizing process.

Under certain heating temperature, the carbon content of austenite in steel can be determined by the upper formula. The saturated carbon content of austenite is 0.5% ~ 0.6% at that temperature when the steel ball is heated to 840 and 5 C to reach the equilibrium state, and the best comprehensive mechanical properties can be obtained by heat treatment only when the average carbon content is 0.5% to 0.6%, and the potential of the oxygen probe corresponding to the carbon potential is 1100 [7].

As the content of martensite carbon increases, the amount of high carbon martensite and the residual austenite increase, and the number of carbides also increases slightly. This is due to the high carbon potential of the furnace gas, and some of the active carbon atoms dissolve in the surface austenite, making the carbon concentration in the austenite of the steel ball surface reach full and supersaturated state. However, the diffusion rate of carbon atoms to the center is low by the lower heating temperature, so the carbon content of the austenite is higher in the surface layer, and some carbon atoms are precipitated in the austenite, forming carburized carbide.

After the deformation and deformation of the matrix, the dislocation density of the metal decreases greatly. In this process, the dislocation density inside the matrix is discontinuously reduced by the growth of the separated grains, and it is also called discontinuous recrystallization. In situ recrystallization can be observed in the process of cold deformation metal heating, also known as continuous recrystallization. The metal with very low cold deformation does not have such a nucleation during heating. The grain boundary movement occurs only in the deformation matrix to form a low dislocation density region, which is called the grain boundary movement induced by strain.

Because the temperature field is the function of the radius and time of the steel ball, the temperature field of the steel ball of different diameter must be different during the quenching process. For the steel ball of different sizes, the temperature distribution can be quickly calculated by input of different time. According to the actual production situation and the relevant theoretical knowledge, it is specially designed. Some key time points are simulated, and the simulation results are shown below:

(1) The temperature distribution of steel ball with 40mm radius after quenching in water is shown in Figure 2;
(2) The temperature distribution of the steel ball with a radius of 60mm after quenching in clear water is shown in Figure 3;

![Figure 2. Temperature field distribution](image1)

![Figure 3. Temperature field distribution of temperature field distribution of B](image2)

After forging, the surface temperature of the steel ball is about 950 ~ 1050 centigrade. If it is quenched immediately after the end of the forging, the deformation strengthening effect formed in the forging process is retained on the one hand and the hardness of the steel ball is improved. On the other hand, due to the high quenching temperature, the thermal stress and the tissue stress are large, which can easily cause the quenching and cracking. When the precooling time is too long, the transformation of austenite structure to the microstructure of pearl will happen, which will adversely affect the hardness of the steel ball. Therefore, it is very necessary to establish suitable quenching time through experiments. During quenching, the quenching medium is clear water, and the water temperature is always maintained at about 40 C. The steel ball was pretreated in water for 10 minutes, and the diameter of steel ball was 80mm. The diameter of 120mm steel ball was 15 minutes [8]. The longer the cooling time of the steel ball in the medium is quenched, the more martensitic transformation is carried out, the higher the hardness, the increase of the microstructure stress in the steel ball and the cracking trend of the steel ball. Because
of the high carbon content in this experiment, it is close to the composition of eutectoid steel. At the same time, the quenching cooling time of the steel ball in the quenching medium should not be too long while the steel ball is hardened, and the steel ball should have a certain residual temperature when the steel ball is water, and it will be tempered in time.

For carbon steel, the common quenching medium is clean water. Because in the process of quenching, the surface of the steel ball is easy to form a layer of steam film, which is not conducive to the heat diffusion, and the quenching cooling speed of the steel ball is reduced. In order to avoid the appearance of this situation, a small amount of salt is added to the water. Quenching uses the salt crystallized on the surface of the hot steel ball to blow the steam film open, thereby improving the quenching cooling rate of the steel ball. The effect of quenching medium and quenching temperature on the hardness of steel balls was studied in the experiment. The quenching medium is water and 5% NaNO2 brine solution. Because NaNO2 brine solution has more cooling capacity than water, and it will not cause serious corrosion to other facilities.

5. Conclusion

On the basis of the above research, the relationship between the cooling rate and the change of the radius and time in the process of steel ball quenching is studied. Through this work, the effect of the cooling rate on the final microstructure of the steel ball in the process of steel ball quenching can be better explained, and the final microstructure of the steel ball can be obtained. It has a good guiding role. If the quenching cooling rate is more than 50 [9] / sec, the martensitic structure will be obtained. If the quenching cooling rate is lower than 50 C / sec, other non martensitic tissues will appear, resulting in the decrease of the hardness of the steel ball and the adverse effect on the steel ball.

Because the carburizing of the rotary furnace is carried out in the gas medium, there is a trace of nitrogen and carbon in the air into the surface of the steel ball, so the steel ball is more wear-resistant than the solid carburizing. Within a certain range, the increase of manganese content can effectively improve the strength and hardness of steel without increasing the economic cost. With the increase of diameter, the surface hardness of the steel ball is basically the same as that of 62HRC after forging, and the hardness of the core decreases gradually. When the quenching temperature is constant, the tensile strength decreases and the impact toughness increases with the increase of tempering temperature. The microstructure of the material after quenching is a strip martensite, and the comparison test of wear resistance shows that the 45Mn2 steel ball has obvious antiwear property compared with the medium manganese cast
iron ball and the common 45 steel forging ball, and the economic benefit is remarkable. The nitrogen base protection atmosphere can prevent the oxidation and decarbonization of the bearing steel ball, but the carbon potential of the furnace gas must be controlled to make it equal or too much carbon content in the austenite at the temperature. The carbon potential automatic control instrument of the oxygen probe can be used to control the carbon potential of the nitrogen based protective atmosphere accurately. After heating the steel ball after quenching by the nitrogen base protection atmosphere, the soft point of surface quenching is eliminated and the surface is formed to form pressure stress. The hardness and wear resistance and contact fatigue life can be improved.

Reference