Research on carburizing technology and developments

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Abstract: Carburizing is a surface chemical heat treatment technology, so that the steels’ surface within a certain depth could form a carburized layer of high hardness and wear resistance. The hearts area without carburizing could maintain sufficient strength and toughness. In this paper, the classification of caburized technology, the developments and improvements were reviewed.

1. Introduction
Carburization is that the parts placed in carburized atmosphere are heated and stay warm. Active carbon atoms proliferate from the surface to the interior. Then corresponding quenching and tempering processes are carried out. The surface with high-carbon martensite has high hardness and good wear resistance, while the interior with low-carbon martensite possesses enough toughness.

2. Classification of carburizing technology

2.1. Pack carburizing.
Pack carburizing is to put the work pieces into the carburized agents which are mainly composed by charcoal. Then parts are heated and carburized after being packed and sealed.

2.1.1. Carburized and braised steels. The mature results are carburized steels of block and stewed steels in early China[1]. The former is to forge carburized parts after adding catalyst. The latter is to put carburized parts into sealed jars and heat them. But there are many disadvantages in this process. The nonmetallic impurities are scattered and tiny. The gradient of carbon concentration is large in the carburized layer. The oxide skin on the surface is thick. The comprehensive mechanical properties of carburized steels are not high.

2.1.2. Rapid packing carburizing and the application of nonmetallic elements. Rapid packing carburizing uses different catalyzer to get carbon atoms’ key force of varying relaxation[2]. It could accelerate C and CO₂ to produce CO, improve the traditional time of packing carburizing, as well as add a variety of nonmetallic elements in steels to obtain the required carburized steels. For instance, adding nonmetallic element P is to increase the cold brittleness so as to make the explosion easy.

2.2. Gaseous carburizing.
The atmosphere of gaseous carburizing is composed of hydrocarbon or carbonous organic liquid. The active carbon atoms are adsorbed in the surfaces of metallic parts. The active carbon atoms will make the surfaces of the parts to establish a gradient of carbon concentration, and then the carbon atoms can be spread to the inside parts.

Hypothermal gaseous carburizing is that the C atoms are dissolved in the matrix of austenite, which forms a kind of expansive austenite, called S phase. S phase has very good mechanical properties and corrosion resistance. Supersaturated C atoms dissolved in austenite will make the original austenite...
face centered cubic lattice transformed into a face centered tetragonal lattice, which can improve the hardness and wear resistance greatly. But the expansion of austenite is an unstable organization. At a certain temperature, it is easily decomposed into the original face centered cubic structure and gives off black Cr carbide[3].

2.3. Vacuum carburizing
Because carburized atmosphere does not contain oxygen, the work pieces will not manifest internal oxidation and other defects. It can achieve hyperthermal carburization and significantly shorten the process[4].

2.3.1. Advantages of vacuum heating. Vacuum heating has three advantages.

(1) Vacuum protecting. If the work pieces are heated in an oxic atmosphere, then the oxide skin will arise on the surfaces of the work pieces. It is fatal to remove the oxide skin in the next process. Then the costs will increase. In order to achieve anaerobic heating, protective gas is used in the actual production. But the oxygen will inevitably exist in the heating room, which causes the work pieces to oxidate. In the vacuum state, the amount of oxide in the heating chamber is very low, which can achieve anaerobic calefaction. So the surfaces of work pieces maintain the original roughness, which is particularly important for accurate moulding.

(2) Vacuum degassing. The work pieces are heated in a vacuum state to make the gases(CO, H₂, N₂, etc.) which remain in the steels escaping from the surfaces of the work pieces. That is vacuum degassing, which improves the mechanical properties of the work pieces.

(3) Vacuum cleaning. The work pieces are often heated in a vacuum state, when the surface of the work pieces has oxides, hydrides, nitrides and mild rust. These compounds can be reduced, decomposed and evaporated out of the furnace in this condition. Surfaces of work pieces are purified. In particular, the role of purification can increase the exterior activity of the work pieces. Then the rate of vacuum carburizing is efficiently advanced.

2.3.2. Acetylene vacuum carburizing. Carburized gas is C₃H₈ which has lots of drawbacks. Some scholars have adopted C₂H₂ to overcome the “carbon black” problem and applied for patent in the world[5].

2.3.3. Technological conditions of vacuum carburizing. The process of vacuum carburizing mainly takes the strong infiltration-diffusion state, which is to adopt multiple strong infiltration-diffusion cycle. Though with a short period of strong osmosis, the carbon concentration in the surfaces of the work pieces reaches a saturated concentration in predetermined setting. Then the supply of the carburized gas stops and the diffusion stage begins. When the carbon concentration in the surfaces of the work pieces is reduced to the predetermined limited value, this stage ends. The supply of carburized gas is connected again and the circulation is not carried out until the carbon concentration meets requirements.

2.4. Ionic carburizing
Ionic carburizing gets carburized elements from the discharge of ionic gas. These ions penetrate into the surfaces of the work pieces under 950°C or 1050°C[6]. Although the carburized temperature is high, because of its high speed, the grains do not enlarge. On the other hand, according to the needs, the technical parameters can be adjusted. So the layer can achieve uniform permeation. The abrasive resistance and fatigue strength of work pieces can be effectively improved. Meanwhile, thermal stress of carburized parts as well as the deformation is small. However, the iconic carburized equipment is expensive. The interference of arc and the difficulty of operation exist.

3. Development tendency of carburizing technology

3.1. Carburizing of rare earth element.
Carburizing of rare earth element is to add a small amount of rare earth additives in the carburized process.
3.1.1. Effects of rare earth elements on decomposition of cementite. At carburized temperature, carbonaceous gases such as acetone and methanol are difficult to be decomposed. Because of rare earth elements’ unique electronic structure, their electronegativity is small but they possess active chemical reaction with strong affinity to oxygen, hydrogen, nitrogen, sulfur, which will be conducive to the decomposition of the hydrocarbons. Therefore, the number of active carbon atoms in the atmosphere increases. The carbon content is different from surfaces and the interior of work pieces, which accelerates carbons to spread.

3.1.2. Effect of rare earth elements on absorption of carbon atoms. The rare earth elements with large activity will be preferentially adsorbed into surfaces of work pieces. Their low negative potential values seize oxide of iron oxide to restore iron, which purifies and activates surfaces of metals, so that the active carbon atoms enter the surface easily. On the other hand, the atomic radius of rare earth is larger than that of iron, so the rare earth elements are more easily segregated in the grain boundary, secondary grain boundary and other crystal defects. Rare earth elements cause serious lattice distortion of ferrous atoms, so the energy increases, which results in carbon atoms easily absorbed by the work pieces.

3.1.3. Effect of rare earth elements on diffusion of carbon atoms. Rare earth elements promote the diffusion of carbon atoms, which is due to catalysis of rare earth caused by high carbon concentration of work pieces. The formation of gradient with high concentration is conducive to speed up the diffusion of carbon atoms. The rare earth elements cause a series of lattice distortions and these distortions provide a channel of diffusion, which accelerates the diffusion of carbon atoms.

3.1.4. Microalloying of rare earth elements. In the carburized process, rare earth atoms are firstly segregated in the grain boundary and diffused into internal crystal. Because rare earth atoms are much larger than iron atoms, the system energy is increased and the lattice is strongly distorted. Infiltrated carbon atoms are preferentially segregated in the distorted parts. If hypothermal carburization is used, the saturation of carbon atoms in austenite and the critical radius of the carbide are low. So it is easy to form the kernels of crystal and the carbides become fine grain. Due to the presence of a large number of dispersed and small carbides, the austenite has a low carbon content[7].

3.2. Hyperthermal carburization
Conventional carburized temperature is 930°C, the carburization above this temperature is called high temperature carburization. The carburized process mainly controls the diffusion process, which mainly relies on temperature. Therefore increasing the carburized temperature can shorten the carburized time and improve the productivity[8].

3.2.1. The control of grains’ growth. High temperature can improve the carburized speed, but it will make the grain thick and work pieces’ strength and plasticity declining. There are two solutions that have been developed:

3.2.2. The use of secondary quenching. The formation of a large number of small dispersed carbides in quenching obstructs the migration of the grain boundary in the process of heating homogenization. It can control the grain size. However, the secondary quenching process makes the industrial producing process become complicated and the cost increased.

3.2.3. Microalloying. Adding Nb, Ti, B and other elements into steels forms specialized hyperthermal carburized steels, which effectively solves the problem of grains’ enlarging. For example, hyperthermal carburized gear steels use Nb, which is considered to be the best element for grains’ refinement. Because not only the precipitating phase containing Nb has good stability under high temperature, but also the particle of the precipitating phase is small, spherical and ellipsoidal, which exerts a very good effect on grains’ refinement.

3.2.4. The control of organization. The gear steels at 1000°C need to use vacuum carburized furnace. The appropriate amount of residual austenite in the gear steel is beneficial to the properties of materials, especially the property of rotational bending fatigue. When the carburized temperature increases, the rate of carbons’ diffusing increases exponentially. The carbon content in the carburized layer decreases with phase lines of martensite declining. The amount of residual austenite in the
quenching process is higher than conventional carburization. In addition, hyperthermal carburization is easy to increase the carbon content of the layer and the trend of forming a large number of carbide increases. It is easy to form meshy and massy carbide, which makes grain boundary fragile and material fatigue life regressive. In summary, the concentration of carbon at hyperthermal carburization should not be too high.

4. Conclusion
From the history of long-term development of carburizing technology, the shortcomings of various of traditional carburized methods have been recognized and appreciated by the majority of users. The study of new carburizing technology will be a boom.

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