Research on Steel for Lock Washers and Bainite Transformation (Part 1)

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1. Introduction

Anti-loosening washers are required in threaded connections. These are mainly double-layer self-locking washers, tapered washers, spherical washers, spring washers, etc., as shown in **Figure 1** (hereinafter referred to as washers).

Figure 1. Washers

Washers are mostly made of spring steel and must be heat treated. The heat treatment process is similar to that of springs, but there are also differences due to the particularity of mechanical property requirements. Therefore, the finished product is required to have a higher elastic limit, yield-to-strength ratio and fatigue strength, as well as sufficient plastic toughness. The common materials for washers are carbon structural steel and low alloy spring steel, with approximately 0.50% to 0.75% carbon. **A large number of early washer failure analysis results show that more than 80% of failures are caused by scratched appearance, crushing, bending, oxide scale residue, rust spots, surface decarburization, surface corrosion, non-metallic substances in steel, uneven quenched structures, and hydrogen-induced delayed fracture, mainly due to high stress concentration at the defective locations.**

It is necessary to briefly discuss the research on steel for washers and bainite transformation, in order to look at ways to increase elasticity on the basis of improving strength, toughness and contact fatigue performance, select new steel types, strengthen heat treatment process or bainite austempering technology.

2. Spring Steel Grades for Producing Washers

The majority of washers are produced using structural steel (spring steel), and the chemical compositions of commonly used grades are shown in **Table 1**.

Table 1. Chemical compositions of commonly used spring steel grades for producing washers (quality grade, W%)

Grade	C	Si	Mn	P	S	Cr	V
S60C	0.55～0.61	0.15～0.35	0.60～0.90	≤ 0.030	≤ 0.035	≤ 0.20	/
65	0.62～0.70	0.17～0.37	0.50～0.80	≤ 0.035	≤ 0.035	≤ 0.25	/
70	0.67～0.75	0.17～0.37	0.50～0.80	≤ 0.035	≤ 0.035	≤ 0.25	/
SK5	0.8～0.9	≤ 0.35	≤ 0.50	≤ 0.030	≤ 0.030	≤ 0.30	/
SK7	0.6～0.7	≤ 0.35	≤ 0.50	≤ 0.030	≤ 0.030	≤ 0.20	/
65Mn	0.62～0.70	0.17～0.37	0.90～1.20	≤ 0.035	≤ 0.035	0.25	/
50CrV	0.47～0.55	≤ 0.40	0.70～1.00	≤ 0.025	≤ 0.025	0.90～1.20	0.10～0.20
51CrV4	0.47～0.55	0.17～0.37	0.70～1.00	≤ 0.020	≤ 0.015	0.90～1.20	0.10～0.20
60Si2Mn	0.57～0.65	1.60～2.00	0.70～1.00	≤ 0.025	≤ 0.025	0.20～0.45	/
27MnCrB5	0.24～0.30	≤ 0.40	1.10～1.40	≤ 0.025	≤ 0.035	0.30～0.60	B0.0008～0.0050

Spring steel has excellent strength, toughness and ductility, its processing is simple and its production cost is low. To obtain a bainite structure with enough hardenability during the continuous cooling process, it is usually necessary to add alloy elements to spring steel, such as B, Si, Mn, Cr, Nb and Mo. As an important part of washer production, heat treatment has been an important aspect in studying the theory of accelerated phase transformation of bainite in recent years. It has an important impact on the morphology, quantity and size of bainite. Research shows that austenitizing temperature affects phase transformation, and the original austenite phase with different grain sizes can be obtained through different quenching temperatures, thus affecting the transformation of bainite. **The transformation temperature of bainite is 550 °C ~ Ms, divided into upper bainite and lower bainite.** The hardness of upper bainite is lower and the toughness against impact is lower. Try to avoid the formation of upper bainite structure in the washer; the temperature to form lower bainite is 350 °C ~ Ms with grains smaller than upper bainite's, higher dislocation density, very small internal ferrite particles, and a large number of precipitated fine dispersed ε-carbides. The precipitation of this material plays a good dispersion strengthening effect on the lower bainite, so **lower bainite steel has high strength, good toughness, and excellent comprehensive mechanical properties.**

3. Mesh Belt Type Atmosphere Heating Furnace

3.1 Heating Furnace

Mesh belts continuously feed washers into the atmosphere heating furnace. There is a flame curtain at the front opening of the atmosphere heating furnace to isolate the outside air from the air inside (the air in the furnace is generally called "atmosphere"). The rear end of the heating furnace is sealed with a salt curtain and liquid salt. The first step in lower bainite austempering heat treatment is to heat the washer to about 860 °C. In order to dissolve all the spheroidized carbide in the washer, it needs to be kept at a temperature above 760 °C (Ac1) for at least 15 minutes. Atmosphere heating furnaces generally use electric or natural gas to heat up. Most heating furnaces are divided into 4 heating zones, which are controlled separately. The temperature in zone 1 is set at 830 °C, the temperature in zone 2 and zone 3 is set at 850 °C, and the temperature in zone 4 is set at 840 °C. The temperature in zone 1 is set at 830 °C to quickly heat washers to the set temperature. The temperature in zone 2 and zone 3 is set at 850 °C to dissolve all carbides. The temperature in zone 4 is set at about 840 °C to ensure that washers are are above 760 °C before entering the quenching salt solution; that is, in order to avoid the cooling C curve with no pearlite transformation, and thus ensuring that the washers are still austenite before entering the salt solution.

3.2 Controlled Atmosphere

Spring steel washers will oxidize and decarburize under high temperatures. Therefore, it is necessary to build up an atmosphere with a certain carbon potential in the furnace to avoid high-temperature oxidation and decarburization. The control of carbon potential is relatively complex. Problems such as water vapor mixed into the furnace, poor sealing, air leakage in the thermocouple mounting holes, cracks in the furnace body, blockage of gas pipelines, etc., may lead to out-of-control carbon potential. It is particularly difficult to solve the problem of water vapor mixed in the furnace. It can only be eliminated by stopping the furnace and reheating the oven at a low temperature.

The method of preparing a controlled atmosphere is to use nitrogen, methanol, and propane as enriched gases. Methanol will crack into hydrogen and carbon monoxide at high temperatures. Liquid methanol is directly dropped into the furnace, and a chemical reaction occurs: $CH_3OH \rightarrow 2H_2 + CO$. Nitrogen is directly introduced into the furnace, and the flow rate of methanol and nitrogen is adjusted, thereby adjusting the proportions of various components of the atmosphere.

At the working temperature of about 860 °C in a mesh belt furnace, the carbon potential of spring steel's basic atmosphere is set at 0.60% C. For example, 65Mn steel has a lower carbon content limit of 0.62%, and the carbon content of the washer material is slightly higher than the basic carbon potential of 0.60% C, so in addition to basic atmosphere nitrogen methanol cracking, a certain amount of enriched gas needs to be introduced into the furnace to increase the carbon potential of the atmosphere. Propane is selected as the enriched gas. Both endothermic atmosphere and nitrogen-methanol are feasible methods for controlled atmosphere technologies.

3.3 Isothermal Salt Bath Quenching

When washers are dropped from the high-temperature heating furnace into the salt bath, they must be instantly cooled from 860 °C in the heating furnace to the quenching temperature of 300 °C. When cooled in a salt bath and quickly passing through the "nose tip" of the C curve, supercooled austenite does not undergo structural transformation in advance. In this case, continuing to cool down in a salt bath or the air when the temperature drops below 350 °C, the supercooled austenite begins to undergo lower bainite transformation; any delay may lead to incomplete quenching; that is, the cooling does not avoid the C curve, but passes through the C curve, and the austenite re-transforms into a pearlescent body instead of resulting in a lower bainitic structure. After austenite transforms into proeutectoid ferrite + pearlite, it is similar to the spherical pearlite of the raw material, having low hardness and low mechanical properties, and must be avoided. Therefore, **the design going from the heating furnace to the hopper of salt bath quenching tank is the key to the entire lower bainite isothermal quenching heat treatment line. It is necessary to ensure that washers can quickly drop into the salt bath in the tank, while ensuring the air tightness of the atmosphere in the furnace.**

The salt bath's temperature in the salt bath quenching tank determines the hardness of washers after heat treatment. Since different sizes of washers have different hardness requirements, it is necessary to set the salt temperature according to the hardness value of different washers. Generally speaking, 1 °C will result in about 0.1HRC, which means that if the salt temperature is increased by 1 °C, the hardness will decrease by 0.1 HRC; lowering the salt temperature by 1 °C will increase the hardness by 0.1HRC. For washers made of 51CrV4 and 65Mn, the salt bath quenching isothermal treatment time is at least 60 minutes. ◘

Continuing from Part 1, Part 2 will appear in Jan. 2025 issue of Fastener World Magazine. Stay tuned!