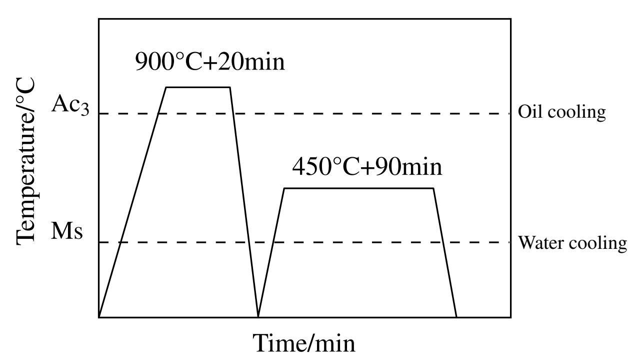
Research on Steel for Lock Washers and Bainite Transformation (Part 2)

Bainite Processes and Properties

It is well known that there are two ways to obtain bainite in structural steels. One is isothermal quenching; the other is alloying, where different alloying elements are added to enhance the properties of the steel in order to obtain a bainite structure. Isothermal quenching results in washers with less deformation and internal stress than single medium quenching. Isothermal quenching reduces the deformation and the surface notch sensitivity of washers, improving the plastic toughness of steel. The role of alloys in spring steels, when applied to washers, results in a strong and tough bainite structure. After the isothermal quenching process, the spring steel is tempered to further homogenize the structure and reduce the internal stresses; Differences in tempering temperatures also affect the strength, fatigue resistance and corrosion resistance of washers. Due to the addition of Cr and V, 51CrV4 steel has high strength and fatigue resistance. In the past 10 years, the research on the heat treatment technology of bainite isothermal quenching mainly focuses on the temperature and time in the quenching and isothermal process.

The difference between conventional quenching & tempering and isothermal quenching is that the conventional quenching & tempering process will cool to the room temperature during quenching and results in a quenched martensite, whereas in the isothermal quenching process there is no quenching to room temperature and the amount of martensite obtained is small. Because the small amount of martensite is mostly of large-angle grain boundaries, which is not conducive to the enhancement of steel strength, large angle grain boundaries can prevent crack expansion in the tensile impact process, improving the toughness and plasticity to a certain extent. In the traditional process, the bainite steel structure changes according to the tempering temperature, which usually results in the medium tempered troostite. It is the transformed product of martensite after medium temperature tempering at about 400°C. Tempered troostite has a higher elastic limit, yield strength and fatigue strength, and has a certain degree of toughness. The nature of its structure is composed of carbide and ferrite mechanical mixture. In order to distinguish it from the troostite transformed from overcooling austenite, it is called tempered troostite.

Figure 2. The Conventional Heat Treatment Process for 51CrV4 Steel



By comparing the structural properties with those of the conventional process, it provides a reference for the application of the lower bainitic in the heat treatment of washers. In order to better compare with the real process and exclude more interferences from external factors, the spring steel used was sampled in the finished washers. **Figure 2** shows a schematic diagram of the conventional heat treatment process for 51CrV4 steel.

Figure 3(a) shows the metallographic structure of 51CrV4 after quenching and tempering heat treatment, which is a single tempered troostite. From the tempered troostite we can see that, after tempering the structure is obviously refined, uniform and small, and the slat feature is also obvious. When martensite quenched at high temperatures is tempered at medium temperatures, its martensitic characteristics still cannot be eliminated. Tempered troostite, as a result of tempering, has a similar structure to slat martensite.

Figure 3(b) shows the metallographic structure of 51CrV4 after isothermal quenching heat treatment, which is mainly a complex phase structure composed of bainite, martensite and residual austenite. After the isothermal process maintains a warm temperature for a sufficiently long period of time in the bainite

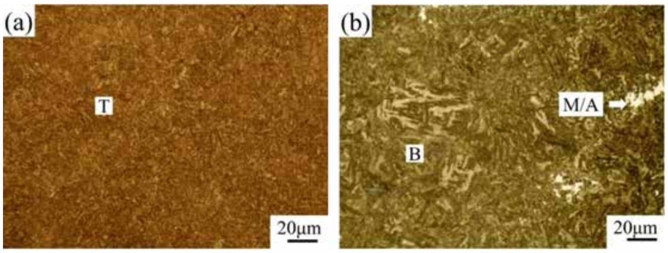


Fig. 3 Microstructure of 51CrV4 Steel by Heat Treatment：(a) Quenching and Tempering Process；(b) Isothermal Quenching Process

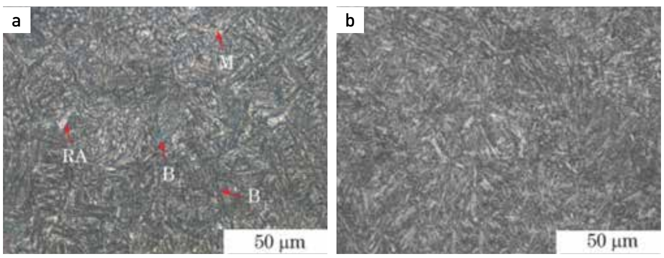


Fig. 4 shows the microstructures of the specimens: 4a shows it is mainly lower bainite + martensite + upper bainite + residual austenite, while 4b shows it is mainly lower bainite + tempered troostite + a small amount of tempered martensite.

transformation area, the bainite transformation is complete and the bainite structure appears. After etching, you will see obvious lower bainite features such as needle-like plates and stripes, and most of the area is the bainite structure; The picture shows the presence of areas that are not corroded and are recognized as martensite/austenite. Due to the high carbon content of the steel, the enrichment was retained until room temperature and a small amount of residual austenite appeared. A complex phase structure consisting of lower bainite, martensite, and residual austenite was finally obtained.

To see the tempered troostite from the SEM structure of 51CrV4 steel after quenching and tempering, the structure is mainly composed of ferrite and short rods or grains of cementite, and the needle-like form of ferrite has gradually disappeared. Most of the ferrite maintains the slate-like status, and the cementite structure is widely dispersed around the ferrite. The SEM structure of 51CrV4 steel after isothermal quenching treatment shows that the lower bainite in the microstructure is in the form of black bundles, and the bainite in the microstructure is in the form of black slats,

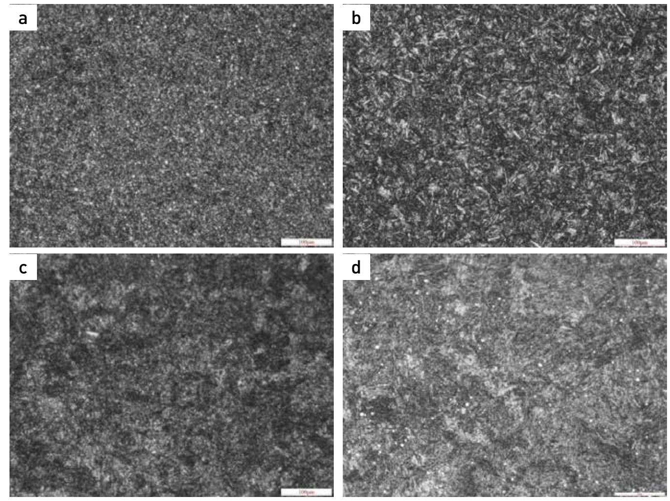


Fig. 5 Metallographic Structure Composed of Lower Bainite, Tempered Troostite, and a Small Amount of Tempered Martensite
a. 27MnCrB5 b. 65Mn c. S60C d. SK5

which is a mechanical mixture of ferrite and carbides with high strength and toughness. In the process of bainite transformation, the first transformation of the lower bainite can split and refine the overcooling austenite grains that have not yet been transformed. At the end of the isothermal air-cooling stage, a small amount of martensitic phase transformation occurs. The martensite structure is less abundant and fine needle-like, making it difficult to be distinguished from the bainite structure, because martensite is less susceptible to corrosion than bainite, and lighter in color in the microstructure, with uncorroded areas of martensite/austenite, and residual austenite dispersed as a thin film between the lower bainite and martensite.

During the isothermal quenching process, a portion of the overcooling austenite is retained by the compressive force formed by the volume expansion due to the structure change, and eventually lower bainite + martensite + residual austenite + particulate dispersed carbides are obtained, as shown in **Fig. 4a.** If we temper the small amount of martensite formed in the isothermal process at 300°C~350°C, the formation of tempered martensite will only account for a small portion because the tempering time is not long. The final isothermal quenched and tempered structure is the carbide composed of lower bainite, tempered troostite, and a small amount of tempered martensite in the form of particles, as shown in **Fig. 4b**.

Table 2. Washer Heat Treating Process

Type	Quenching/℃				Isothermal Temperature /℃	Tempering	
	Zone 1	Zone 2	Zone 3	Zone 4		℃	min
65Mn	820	830	830	820	310～330	320	60
S60C	840	850	850	840	310～330	320	60
35CrMo	840	850	850	840	290～310	300	60
51CrV4	850	860	860	850	330～350	340	90

According to the case study of early failure of washers, the hardness of washers should be controlled at 42 to 47 HRC, which can reduce the risk of hydrogen delayed fracture during use. For this purpose, the isothermal temperature should be 300°C~350°C. The isothermal time should be at least 60 ~ 70min. If the isothermal time is not enough, a larger number of austenite won't get enough time to change into lower bainite. When taken out for air cooling, it will turn into a certain amount of martensite and a small amount of residual austenite, and produce a certain amount of structural stress. For this reason, a proper extension of the isothermal time can fully transform austenite into lower bainite, which is an important measure to reduce martensite and internal stress. Because washers are subjected to axial reciprocating or alternating stresses, and are used under conditions of vibration and shock, the residual austenite content of the steel is required to be appropriate to ensure the required mechanical properties. More importantly, the percentage of residual austenite that will undergo transformation in practice should be as low as possible to avoid the generation of brittle martensite. Therefore, the final heat treatment technique was determined to be isothermal quenching with medium temperature tempering, as shown in Table 2.

The microstructure of bainite washers after isothermal quenching is a complex phase structure composed of lower bainite, tempered troostite, a small amount of tempered martensite, and granular dispersion of carbides, which features higher impact toughness and wear resistance.

Conclusion

The heat treatment of bainite as an important part of isothermal quenching has an important effect on the structure and mechanical properties of bainite. Temperature has a dominant effect on microstructure, which plays an important role in the properties of steel. Isothermal heat treatment is a common process for toughening steel. The quenching temperature determines to a certain extent the amount of primary martensite and unaltered austenite, which has great potential and room for development. ■

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