The Effect on Carburizing Process on Microstructure and Properties of 20MnCr5 Gear Steel

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Abstract: In this report, 20MnCr5 gear is characterized and analyzed under two carburizing heat treatment processes by optical microscope (OM) analysis, scanning electron microscope (SEM) analysis, X-ray diffraction (XRD) and Vickers hardness test. Results show that spherical and angular carbides can be obtained by a high concentration carburizing process for 20MnCr5 gear. Reheating and subsequent low-temperature tempering help refine the grains of the infiltration layer, reduce the residual austenite content in the permeable layer, and increase the thickness of the effective hardening layer.

1. Introduction
Automobile gears are mainly installed in the gearbox and the differential. Due to the sudden-changed impacting load and the periodic changed bending load bear by the tooth roots as the automobile gears always working under the high load, brittle fracture and bending fatigue failure may occur on the teeth of the gears. The working surface of the gear bears larger compressive stress and friction, which will result in pitting, contact fatigue damage, and deep delamination [1]. Therefore, automobile gears have high requirements in wear resistance, fatigue strength, core strength and impact toughness. It has been proved that automobile gears should be made of carburized steel and heat treated by carburization to ensure their service performance and service life [2][3]. In this report, the carburizing heat treatment is tested on the 20MnCr5 steel. The effects of carburization on tissue morphology, residual austenite content, and the hardness of the carburized layer are studied.

2. Materials and Methods
As a type of carburizing alloy steel in German DIN-17210 Standard, 20MnCr5 steel has a wider hardenability band. The sample is taken from the gear segment of the finished 20MnCr5 gear shaft product. The chemical compositions of the specimen are listed in table 1 below. The critical points of 20MnCr5 are Ac1=746℃, Ac3=813℃, Ar1=672℃, Ar3=754℃, and Ms=370℃ [4][5]. The CCT curves of 20MnCr5 are shown in figure 1.

| C   | Mn   | Cr   | Si   | S    | P    | Fe   |
|-----|------|------|------|------|------|------|
| 0.230 | 1.420 | 1.210 | 0.089 | 0.020 | 0.015 | Bal. |

Table 1 The chemical compositions of 20MnCr5 used in the experiment (wt.%)
The heat treatment curve used in Process A is shown in figure 2. Carburizing is carried out at 940°C in methanol and acetone. The strong carburizing is lasted for 210 minutes at the carbon potential of 0.9% and then diffuse for 480 minutes at the carbon potential of 0.75%. After the carburizing is completed, the gear needs to be kept at 880°C for 30 minutes at the carbon potential of 0.75% before quenching.

The heat treatment curve used in Process B is shown in figure 3. Carburizing is carried out at 940°C, while the carbon potentials of strong carburizing, diffusion and cooling are 1.25%, 0.80% and 0.80%, respectively. Then the sample is kept at 880°C for 30 minutes. To eliminate the net carbide on the infiltrated layer and refine the core structure, secondary heating, quenching and low-temperature tempering are processed.

The microstructure of the gear shaft samples is observed, and the Vickers hardness is measured after processed by the two different processes. After inlaying, grinding and polishing, the samples are
corroded with 4% nitric alcohol solution for 20s before being observed under the optical microscope and SEM. The content of residual austenite in the sample is measured by XRD.

3. Results & Discussion

![Figure 4 OM photos of the sample.](image)

(a). The surface layer treated by Process A. (b). 1mm from the surface treated by Process A. (c). 3mm from the core treated by Process A. (d). The surface layer treated by Process B. (e). 1mm from the surface treated by Process B. (f). 3mm from the core treated by Process B.

Compared to the microstructure obtained from the two carburizing processes in figure 4, the martensite grains in the carburized layer of Process B are refined after secondary heating and low-temperature tempering. As shown in figure 4.d,e,f, the residual austenite content decreases gradually from the surface to the core of the sample, and the martensite has transitioned to the mixed form of flakes and laths. In contrast, the core is predominantly made up of lath martensite.

![Figure 5 SEM photos of the surface of the sample by (a). Process A. (b). Process B.](image)

Figure 5. SEM photos of the surface of the sample by (a). Process A. (b). Process B.

As shown in figure 5.a, The near-surface microstructure of the sample processed by Process A (Figure 5.a) is composed of acicular martensite and M/A islands. The length and width of M/A islands are about 2.1μm and 0.9μm, respectively, and the content is about 36%. The M/A islands of the sample from Process B (Figure 5.b) are about 0.8μm in length and 0.4μm in width, of which the content is about 29%. Meanwhile, some spherical carbides and polygonal (angular) carbides are dispersely distributed in the matrix, of which the diameters are 0.1~0.5 μm and 0.8μm, respectively, most of which are large-grained
carbides. Spherical carbides can be obtained by a high concentration carburizing process. Fine and spherical carbides can not only improve the contact fatigue strength of bearings and gears but also improve their bending fatigue strength and wear resistance. Most spherical carbides are distributed on the carbon diffusion channels at the austenite grain boundaries, while the angular carbides are distributed on the M/A island.

![XRD pattern of the near-surface and the core of the samples under Process A and Process B.](image1)

![The comparison between the content of the residual austenite under Process A and Process B.](image2)

Four samples are compared and analyzed at a distance of 0.3mm from the near-surface and 1.8mm from the core in figure 6 and figure 7 to prevent the decarburizing of the tooth surface from affecting the XRD results. Results have found that due to the lack of secondary heating and low-temperature tempering, the content of undecomposed residual austenite is high, which is metastable organizations. The martensite will transform into high-carbon martensite during the grinding and service process. Since the lack of tempering transformation, the low strength and high brittleness of the secondary martensite is one reason for pitting and spalling on the tooth surface. Too much retained austenite will affect the wear resistance and contact fatigue strength of the gear as well. The content of retained austenite after direct cooling and quenching (Process A) is obviously higher than the process of secondary heating and low-temperature tempering (Process B).
The Vickers hardness of the carburized gear sample is measured at 1.8mm from the edge to the core in the transverse section direction with the 0.2mm distance between the measuring points. As shown in figure 8, the hardness of the carburized layer of the specimen is about 760-800HV, while the hardness of the core is about 410-450HV. The maximum hardness of the 20MnCr5 carburized sample at about 0.2mm from the surface is 797HV for Process A and 772HV for Process B. The thickness of the effective hardening layer is approximately 0.8-1.0mm. Results have shown that increasing the carbon potential, raising the carburizing temperature, shortening the carburizing time, and additional secondary heating, quenching and low-temperature tempering will not affect the surface hardness of the carburized sample.

4. Conclusion
The permeating layer structure of 20MnCr5 gear after primary carburizing is the mixture of lamellar martensite and retained austenite, while the structure is the mixture of lamellar martensite, retained austenite and carbides after primary carburizing, secondary heating, quenching and low-temperature tempering.

Most spherical carbides are distributed on the carbon diffusion channels at the austenite grain boundaries, while the angular carbides are distributed on the M/A island. Fine and spherical carbides can improve the contact fatigue strength, bending fatigue strength and wear resistance of the bearings and gears.

Increasing the carbon potential, raising the carburizing temperature, shortening the carburizing time, and additional secondary heating, quenching and low-temperature tempering can help refine the microstructure of the infiltration layer, improve the hardness distribution of the carburized gears, increase the thickness of the effective hardening layer, and reduce the residual austenite content in the permeable layer, which is expected to be helpful to increase the wear resistance and contact fatigue strength of the gears.

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